Computing the Fewest-turn Map Directions based on the Connectivity of Natural Roads

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1. Introduction and motivation

We introduce a topological representation that is based on the connectivity of individual natural roads; the topological representation is a graph consisting of nodes representing individual roads, and links if the corresponding roads are interconnected. Natural roads are joined road segments that perceptually constitute good continuity. The join process is self-organized in terms of the smallest deflection angle among adjacent segments (Thomson 2003), so they are also referred to as self-organized natural roads (Jiang, Zhao and Yin 2008). Based on the concept of natural roads, we developed an approach to computing fewest-turn map directions or routes. Experiments carried out indicate that the fewest-turns routes are superior to the simplest paths (Duckham and Kulik 2003, Mark 1985) and Google Maps routes in terms of the number of routes and distances involved.

To motivate the approach, let us start with a notational street network illustrated in Figure 1(a). It is a Manhattan like street network, which involves 8 streets intersected at 16 junctions. Ignoring the 16 street segments without a node in one end, it is a graph about the connectivity of 24 street segments via 16 nodes, or inversely, the connectivity of 16 nodes via 24 street segments. It is rather obvious that the shortest geometric distance between location (F) and location (T) is 6 blocks. There are many routes with the distance of 6, and the blue (dashed line) is one of the many. Out of the many shortest geometric distance routes, there are only two routes that have the fewest turns, and the red (dotted line) is one of the two. The shortest route with the most number of turns is the one along the diagonal direction between F and T. It involves in total 5 turns, forming a zigzag like path.

The very reason it leads to the routes with so many turns lies in the geometry oriented representation that lacks related topological information. The topological information or turn information (Jiang 2004) is higher order information, which is essential in personal navigation. For example, it is not difficult to note that the 1st avenue and the 8th street are directly intersected, so from F to T needs only one turn, or alternatively, one turn from the 5th street to the 4th avenue. The topological information can be intuitively reflected in a topology oriented representation as shown Figure 1b. The topological representation is embedded in the connectivity graph, in which each street is collapsed into one node and the corresponding street-street intersections are represented as links. Unlike the geometry oriented graph, the connectivity graph is a unit graph. We can note that the routes with the fewest turns are those with the shortest topological distances in the topological representation. This is the key for our algorithms.

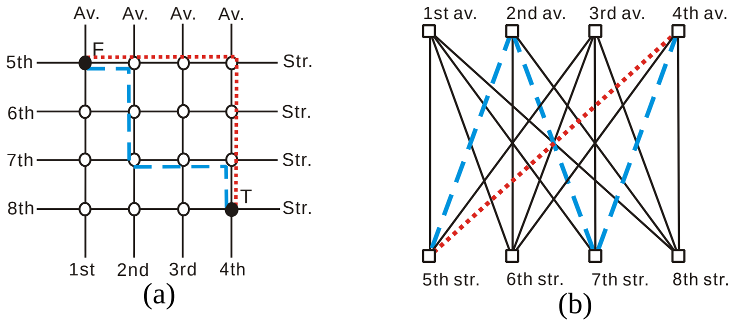

Figure 1: (Color online) Routes with shortest distance (dashed blue lines) and fewest turns (dotted red lines) shown in (a) geometry oriented representation, (b) topology oriented representation

2. Algorithms for computing map directions

We developed an algorithm that consists of three sequentially run functions for computing the fewest-turn route from extracted natural roads. First of all, the connectivity of natural roads in terms of what roads are connected to what other roads, or a connectivity graph, is used to compute the shortest topological distance (D_t) between the start and end road. We use the Breadth-First-Search strategy to traverse the connectivity graph from the start road till end road to get the shortest topological distances between the start road and all other roads including the end road. This is the major task of the first function. The resulting shortest topological distance (D_t) is then used as a variable for the second function to obtain all possible shortest topological paths. The process goes like this: Use the Depth-First-Search strategy to traverse the connectivity graph from the start road, and continuously compare whether or not the current topological distance equals the shortest topological distance (D_t). If true, and if the current node is the end node, then a fewest-turn path is formed. Continue the process till all fewest-turn paths are exhausted. Usually there exist multiple shortest topological paths. Finally, these shortest topological paths are further processed by the third function in order to select the only one with the shortest geometric distance. This path is supposed to be the fewest-turn (FT) route. Based on the FT routes algorithm, we developed another algorithm that further splits natural roads into straighter and shorter ones, so that we can compute fewest-turn-and-shortest (FTS) routes. More details about the algorithms can be found in Jiang and Liu (2010).

3. Experiments and results

We carried out some experiments applied to eight urban street networks from North America and Europe. The eight cities were deliberately and carefully chosen because of their different morphological structures. The experiments were done through comparisons between our solutions: fewest-turn (FT) and fewest-turn-and-shortest (FTS) routes and existing solutions: shortest (ST) paths, simplest (SP) paths, and Google Maps (GMP) routes.

Now let us take a detailed look at the experimental results. Taking the second row in Table 1 as an example, we found that FT paths are on average 6.3% shorter than the corresponding SP paths, and the number of turns is 1 less (5.0 for SP and 3.9 for FT). This is a very encouraging result. Even more encouraging is the comparison between FTS and SP. FTS are 10.8% shorter than the corresponding SP, while the number of turns is almost at the same level (5.0 for FTS and 4.9 for SP). In comparison with ST, FT and FTS are respectively 18% and 12.7% longer, but the number of turns is dramatically reduced (only half). In the mean time, SP paths are 26% longer than ST, rather than 16% as previously reported by Duckham and Kulik (2003). Unsurprising to us, Manhattan has even more encouraging results, but the results for the European cites are less encouraging. However, in all cases, FTS are always shorter than SP, while the number of turns is 1 less.

Table 1: Comparison results with SP and ST in terms of distances (D) and the number of turns (T)

	FT/SP			FT/ST			FTS/SP			FTS/ST			SP/ST		
	D(%)	T(/)		D(%)	T(/)		D(%)	T(/)		D(%)	T(/)		D(%)	T(/)	
Bloomington*	2.4	3.9	5.0	21.4	3.9	8.2	-5.0	5.0	4.9	12.6	5.0	8.2	23.5	5.0	8.2
Bloomington	-6.3	3.9	5.0	18.0	3.9	8.2	-10.8	5.0	4.9	12.7	5.0	8.2	26.0	5.0	8.2
Manhattan	-14.0	2.4	6.9	17.1	2.4	7.3	-20.1	2.9	6.7	8.2	2.9	7.3	34.9	6.7	7.3
San Francisco	1.3	3.6	5.6	30.8	3.6	13.5	-5.6	4.6	5.7	21.5	4.6	13.6	28.7	5.7	13.6
Toronto	7.8	3.6	5.1	21.9	3.6	12.9	-1.3	4.0	5.2	10.6	4.0	12.9	12.1	5.2	12.9
Gävle	4.9	4.9	5.6	22.8	4.9	8.7	-2.7	6.4	5.8	13.6	6.4	9.0	16.5	5.6	8.7
Copenhagen	5.1	3.6	5.1	31.9	3.6	9.0	-4.1	4.8	5.2	20.0	4.8	9.1	25.2	5.2	9.1
London	17.1	4.7	6.4	48.3	4.7	10.6	-7.0	5.9	6.5	17.0	5.9	10.7	25.8	6.5	10.7
Paris	2.6	4.6	7.4	53.1	4.6	12.0	-16.9	5.8	7.4	23.3	5.8	12.1	48.4	7.4	12.1
MEAN	2.3	3.9	5.9	30.5	3.9	10.3	-8.6	4.9	5.9	15.9	4.9	10.4	27.2	5.9	10.3

Table 2: Comparison results with GMP in terms of distances (D) and the number of turns (T)

	FT/GMP			FTS/GMP			GMP/ST (FTS)			GMP/ST (FT)		
	D(%)	T(/)		D(%)	T(/)		D(%)	T(/)		D(%)	T(/)	
Bloomington	-18.2	3.9	7.9	-26.1	5.0	7.9	55.6	7.9	8.2	55.5	7.8	8.2
Manhattan	-22.3	2.4	5.9	-28.9	2.9	6.1	52.3	6.1	7.3	52.4	5.9	7.3
San Francisco	-19.7	3.6	9.7	-19.8	4.9	0.7	29.1	5.6	13.5	63.4	9.7	13.5
Toronto	-15.8	3.6	6.6	-24.0	4.0	6.6	45.7	6.6	12.9	46.3	13.3	12.9
Gävle	4.2	4.9	8.5	-17.9	6.4	8.2	40.7	8.2	9.0	20.7	8.5	8.7
Copenhagen	16.9	3.6	11.8	6.2	4.8	11.8	12.4	11.8	9.1	13.2	11.8	9.0
London	20.4	4.7	11.4	-5.5	5.9	11.2	23.7	11.2	10.7	24.5	11.4	10.6
Paris	16.1	4.6	17.6	-6.5	5.8	17.7	31.1	17.7	12.1	32.2	17.6	12.0
MEAN	-2.3	3.9	9.9	-15.3	5.0	8.8	36.3	9.4	10.4	38.5	10.8	10.3

In comparison with GMP (Table 2), FT is on average 2.3% shorter, while the number of turns is half as much. It is important to note that the -2.3% average makes little sense since percentages deviate substantially from case to case. For example, the Manhattan FT paths are 22.3% shorter than GMP, while for London, FT paths are 20.4% longer than GMP. FTS paths are 15.3% shorter than GMP, while the number of turns is 3.8 less. In the mean time, we also made comparison between GMP and ST, and found that GMP are over 30% longer, and the number of turns is very similar. FT and FTS appear to over perform European cities compared to US cities.

In summary, the average distance of FT is almost at the same level as SP, but the number of turns is much less. On the other hand, the average distance of FTS is much shorter than that of SP, while the number of turns is almost the same. It implies that both FT and FTS are superior to SP either for the distance or the turns. This superiority is even more obvious when compared to GMP for both FT and FTS.

Acknowledgements

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