Applying Traditional Speed-up Techniques into Switch-Point-based Multimodal Shortest Paths Algorithms

Lu Liu[1], Liqiu Meng[2]

[1]Department of Cartography, Technische Universität München, Arcisstr. 21, D-80333 Munich, Germany
Email: liu.lu@bv.tum.de

[2]Department of Cartography, Technische Universität München, Arcisstr. 21, D-80333 Munich, Germany
Email: meng@bv.tum.de

1. Introduction and State of the Art

Multimodal route planning in the transportation field provides the user with an optimal route between the source and the target of a trip which may involve several different transportation modes. (Hochmair 2008). Rehrl et al. (2007) described the requirements of a multimodal transportation routing system in more detail.

A multimodal route planning system is essentially rooted on the multimodal shortest paths algorithms (MMSPA). The problem of finding the shortest paths in a multimodal network has been investigated for years (Lozano and Storchi 2002, Boussedjra et al. 2004, Bielli et al. 2006, Zografos and Androutsopoulos 2008, Kheirikharzar 2010). Frank (2008) proposed a novel approach applying the traditional shortest paths algorithms (SPA) in the product of the navigation and business graphs. Bousquet et al. (2009) investigated the two-way viable multimodal shortest paths problem. Additionally, the researchers from Karlsruhe Institute of Technology proposed a multimodal path finding method based on (regular-) language-constrained SPA (Barrett et al. 2008). Unfortunately, as remarked in (Delling et al. 2009), using a fast routing algorithm in such a label-constrained scenario is very complicated and challenging task.

As mentioned in our previous work (Liu and Meng 2009), we keep our focus on a general-purpose multimodal shortest paths problem which comes from, but is not restricted in transportation field. The data model based on *Switch Point* allows us to develop MMSPAs which can make good use of the traditional label-setting and label-correcting algorithms. In this paper, we further abstracted the two proposed MMSPAs, clarified a generic algorithmic framework, applied three fast monomodal SPAs into the framework and got considerable performance improvement practically.

2. Applying Faster SPAs in the General MMSPA Framework

2.1 A General Algorithmic Framework of Multimodal Shortest Paths Finding

For the concept of *Switch Point* in multimodal route planning and the *Switch Point Matrix* (SPM), we strongly recommend the readers to refer to (Liu and Meng 2009) where two MMSPAs were proposed as well. Both of the algorithms are rooted in the traditional SPAs. In fact, not only the two classical SPAs are eligible to be generalized into the multimodal situation, but also the other numerous improved SPAs. They can be depicted within a general algorithmic framework.

Formally, we are given a mode set $M = \{m_i \mid i \in [1, N], N \geq 2\}$, a vertex attribute set Λ and a vertex-labeled, non-negative weighted, directed graph set

$G_M = \{G_i = \{V_i, E_i\}\}$ denoting MMGS. $\lambda\colon V \to \Lambda, V = \bigcup_{i \in M} V_i$ is the vertex attribute function, and $C_M = \{c_i\colon E_i \to R^+\}$ is the set of cost functions. For each calculation of multimodal shortest paths, a sequential list $M_{input} = \langle m_1^i, m_2^i, \ldots, m_q^i \rangle$, $q \geq 1, m_k^i \in M, m_k^i \neq m_{k+1}^i, k \in [1, q-1]$ indicating the modes to be involved in the path calculation is given. $S, S \in V_{m_1^i}$ is the source vertex. The switch point value $\lambda_{SP}^{k(k+1)} = \mathrm{SPM}(m_k^i, m_{k+1}^i)$, $k \in [1, q-1]$ can be retrieved in the SPM. With M_{input}, G_M, C_M and *S* as the input, MMSPA can be generally described as following:

MULTIMODALSHORTESTPATH(M_{input}, G_M, C_M, S)

for $k \leftarrow 1$ **to** q
    do if $k = 1$
        then MULTIMODALINITIALIZE$(G_M, k, \mathrm{NIL}, S)$
        else MULTIMODALINITIALIZE$(G_M, k, \lambda_{SP}^{(k-1)k}, S)$
      SHORTESTPATHSEARCH(G_M, k, C_M)

where the routine MULTIMODALINITIALIZE works as following:

MULTIMODALINITIALIZE$(G_M, k, \lambda_{SP}, S)$

if $\lambda_{SP} = \mathrm{NIL}$
  then for each vertex $v \in V_{m_k^i}$
      do $distance[k][v] \leftarrow \infty$
        $predecessor[k][v] \leftarrow \mathrm{NIL}$
    $distance[k][S] \leftarrow 0$
    $predecessor[k][S] \leftarrow S$
  else for each vertex $v \in V_{m_k^i}$
      do if $\lambda(v) \neq \lambda_{SP}$
        then $distance[k][v] \leftarrow \infty$
          $predecessor[k][v] \leftarrow \mathrm{NIL}$
        else $distance[k][v] \leftarrow distance[k-1][v]$
          $predecessor[k][v] \leftarrow v$

The SHORTESTPATHSEARCH routine can be substituted by any existing SPA based on labeling method without the initialization phase. Consequently, we applied three more efficient single-source SPAs and got substantially improved results.

2.2 Three Fast Multimodal Shortest Path Algorithms

According to the comprehensive evaluation results (Zhan and Noon 1998), TWOQ, DIKBA and DIKBD are suggested using in the practical transportation routing systems. That means that the methods based on both label-setting and label-correcting algorithms are applicable in the route planning task in transportation field. In this paper, however, we select *Bellman-Ford with FIFO queue and parent-checking* (BFP) (Cherkassky et al. 1996), *Dijkstra's algorithm with Fibonacci heap* (DIKF) (Fredman and Tarjan 1987) and TWOQ (Pallottino 1984) because: 1) In our previous work, we studied and developed MMBF based on the most basic Bellman-Ford with high complexity. Logically, we adopt the improved version BFP so as to conduct the evaluation on the improved MMBF. 2) Theoretically, DIKF has a lower computing complexity than the plain implementation of Dijkstra's algorithm. So the performance of MMSPA generalized from monomodal DIKF is interesting to us. 3) TWOQ has been experimentally proved to be one of the fastest SPAs, and is suggested to be the best choice especially in transportation network. Since our multimodal route planning problem considers firstly the transportation field, TWOQ makes sense.

These three SPAs are fast since different speed-up techniques were applied. And our practical work proved that the MMSPAs can also benefit from these speed-up techniques. By substituting BFP, DIKF and TwoQ apart from their initialization phases into the general MMSPA framework, we got MMBFP, MMDIKF and MMTQ for experimental studies.

3. Experimental Results

We implemented the three proposed algorithms as well as the previous two in C and developed a MMSPA library. The spatial datasets of a portion of Munich provided by United Maps Co., Ltd were taken as our test bed. Figure 1 illustrates the corresponding transportation networks in this test area in which the lines in green, red and solid black indicate motorized ways, pedestrian-only ways and underground lines respectively. The basic information of the test bed is listed in Table 1.

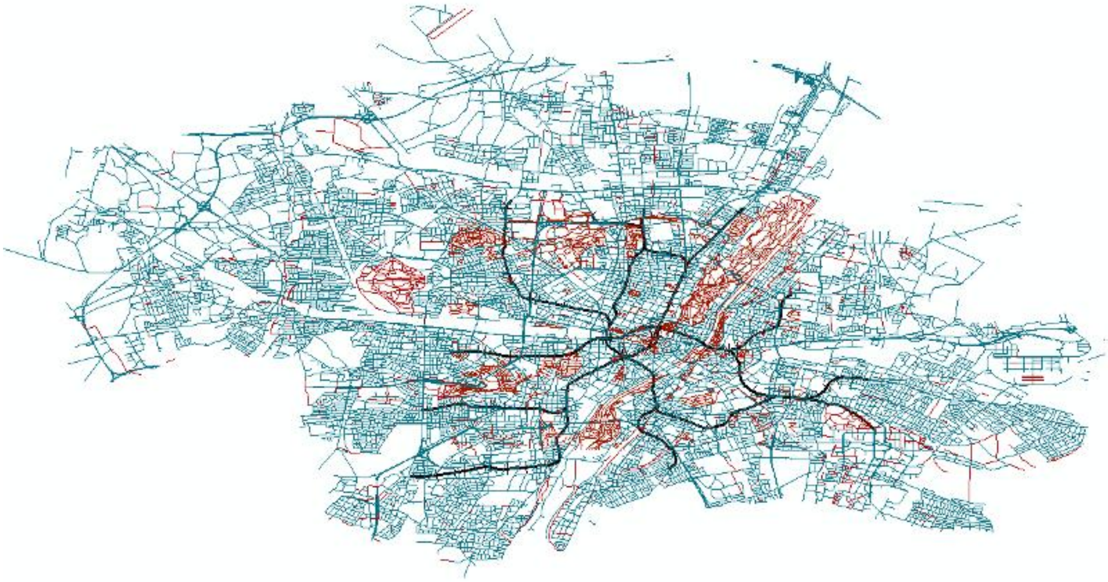

Figure 1. A portion of Munich's transportation network for the experimental study.

Table 1. The size of test networks.

Data source	Area of coverage (width, length)*	Mode**	|V|	|E|	|E|/|V|
United Maps	(20.34, 26.18)	*D*	19471	44979	2.31
		W	20516	57694	2.81
	(9.829, 11.00)	*U*	64	132	2.06

* The unit of width and length is km

** *D*: motorized ways; *W*: pedestrian ways; *U*: underground lines

The experimental results (Table 2) show that the three improved MMSPAs are considerably faster than the two old algorithms. This means the speed-up techniques used in monomodal SPAs can lead to acceleration of the corresponding MMSPAs. The MMTQ is the fastest, which is identical with the evaluation results of the corresponding monomodal SPA.

Table 2. Computing speed of the MMSPA.

Mode list		MMBF (s)	MMD (s)	MMBFP (s)	MMDIKF (s)	MMTQ (s)
1-modal	*D*	36.90	3.765	0.02812	0.03267	0.02469
	W	56.32	4.783	0.03220	0.03062	0.02405
2-modal	<*D*,*W*>	92.14	9.570	0.05501	0.07047	0.05031
	<*W*,*U*>	49.21	4.516	0.04328	0.04021	0.03455
	<*U*,*W*>	48.95	4.924	0.02872	0.03092	0.02692
3-modal	<*D*,*W*,*U*>	85.27	9.486	0.06032	0.07078	0.05398
	<*W*,*U*,*W*>	103.2	9.643	0.06438	0.06907	0.05484
4-modal	<*D*,*W*,*U*,*W*>	134.5	13.75	0.09299	0.1042	0.08189

The MMSPA library is applied in one of our prototype systems – Multimodal Route Planner online (Figure 2). It uses MMTQ as the underlying routing algorithm.

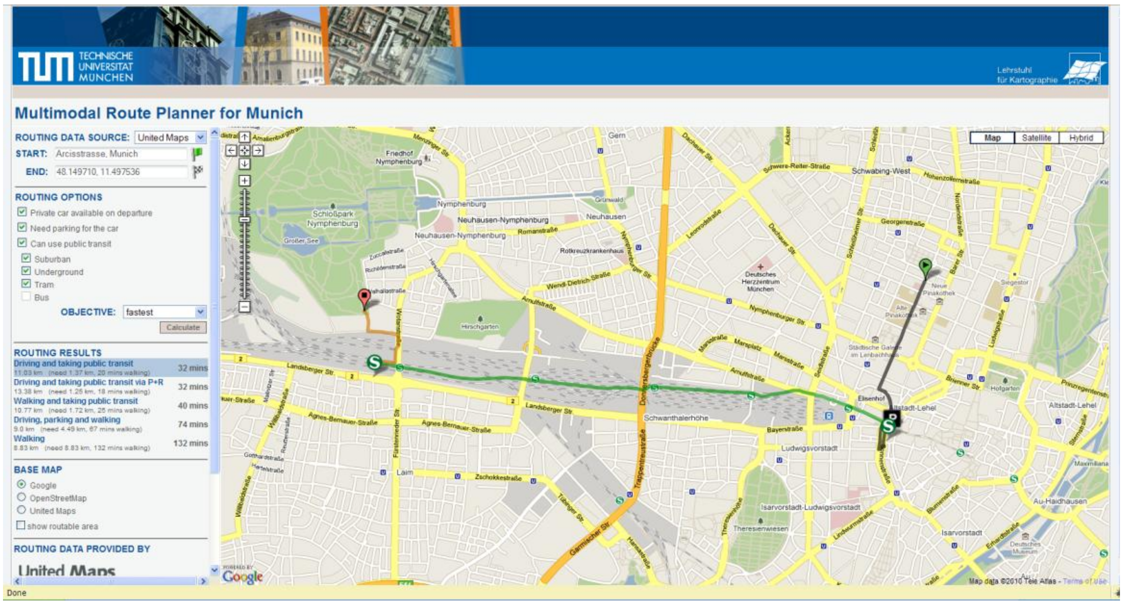

Figure 2. A screen shot of the Multimodal Route Planner online prototype system.

Now, we are trying to apply the heuristic speed-up techniques including goal-directed search, bidirectional search, hierarchical network organization and graph partitioning into the proposed algorithmic framework. The latest result will be introduced in detail in the next paper.

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