Computation of Scenic Routes in Street Networks
Hartwig H. HOCHMAIR and Gerhard NAVRATIL

Abstract
Shortest, fastest, simplest or most scenic route are common route selection criteria for navigating a street network. The computation of the most scenic route in electronic route planners is especially challenging. Firstly, scenery is a desirable route characteristics, i.e., a benefit criterion, so that the route with the highest number of scenic areas cannot be found with a shortest path algorithm. And secondly, the user is interested in a compromise route that finds a balance between attractive sections and route detour. This paper examines the usability of a standard shortest path computation for finding scenic routes in a street network. Hereby traverse costs of edges running within buffers around attractive places are reduced. The method is evaluated with a test street network in Fort Lauderdale, Florida.

1 Introduction
Electronic route planners provide the user with the optimal route between start and destination. Previous research found that route selection criteria for bicycle trip planning in urban street environments can be grouped into four general criteria, namely fast, safe, simple, attractive (Hochmair 2004; Hochmair 2007). A route search for the first three criteria can be solved with shortest path (SP) algorithms on a static network graph or its line graph, respectively (Winter 2002). More advanced approaches are necessary if truly dynamic network phenomena are to be included in route search. Shirabe (2005), for example, uses a time-expanded network to model arc travel time based on entering velocity, exiting velocity and acceleration rates in order to compute the fastest route. Leaving aside dynamic network phenomena, the computation of attractive routes is generally more complex than SP problems, as it involves also benefit criteria, such as maximization of park areas along the route. With a SP algorithm, it is not possible to find a route that maximizes a benefit criterion, as no efficient computational scheme presently exists for the general longest-path problem. The Bellman-Ford algorithm, for example, solves the single-source shortest-path problem, where weights may be negative. However, in case the graph contains negative cycles, it returns false. The problem of finding a route that maximizes one or several benefit criteria is of specific interest for the design of route planners, and therefore, focus of this paper.

The search for a compromise route that performs well on several criteria is a multi-objective decision problem. An example is the search for attractive routes, where the attractive route sections are to be maximized while minimizing route length at the same time. If both objectives involved are to be minimized, this constitutes a multi-criteria shortest path problems (MSPP), which is complex to solve. Historically many MSPP are reduced to a single-criterion shortest path problem by using a weighted linear combination of all criteria as the cost function, where optimal solutions may be overlooked (Mooney & Winstanley 2006). A related decision problem where one objective needs to be maximized...
and another minimized is the maximum population shortest path problem (MSPS) (Current et al. 1985) which aims to optimize path length and the number of delivery points visited along a path. This kind of problem is usually solved through integer programming methods or genetic algorithms (Pahlavani & Samadzadegan 2006).

This paper investigates the usefulness of single criterion SP computations for finding scenic routes. The approach is related to work by Muraleetharan & Hagiwara (2007) who use an SP approach to find the route with the highest Level of Service (LOS) for pedestrians. Hereby, the geometric length of a street link \( i \) is multiplied by the factor \( (C-\text{LOS}_i) \) where \( C \) is a constant. The LOS in this paper will be approximated through the proximity of scenic areas to the route segment.

2 Methodology: Search for Scenic Routes

The basic idea behind this paper is to reduce the traverse cost of network edges which run near attractive locations, i.e., within a certain buffer distance. This step of cost modification needs to be done before the SP algorithm is executed. A test network in Fort Lauderdale, Florida, which covers an area of approximately 189 square kilometers, and contains 11,418 nodes and 16,360 edges, will be used to test the effectiveness of this buffer based approach.

In this paper, the route selection criteria that characterize the attractiveness of a route refer to bicycle transportation mode, although the presented methodology could be applied to any other transportation modes as well. In previous work, sights, parks, lakes, and rivers were identified as the most relevant sub criteria of route attractiveness, followed by nice views, nice bridges, and city center (Hochmair 2004). The Fort Lauderdale test area is mostly residential, and no historical sights exist, but a large number of parks, lakes, and water channels. All other criteria do not apply. Therefore we name the route to be optimized scenic route, which maximizes exposure to parks and water bodies, and minimizes detour.

2.1 Buffering

A distinction is made between segment length \( (d) \) and perceived segment length \( (p) \). The first term denotes the geometric arc length. The second term denotes a measure also based on the geometric arc length, which, however, within a certain buffer distance around attractive areas, is reduced through a multiplication factor \( f \), so that \( p=d*f \), with \( 0 \leq f < 1 \). Undesirable locations, such as area in close proximity to waste disposal sites, can be modeled with \( f > 1 \) to find routes that avoid passing by such regions. The perceived route length is the parameter to be minimized within the shortest path computation. The difference between route length and perceived route length depends on the portion of a route running through buffers and the magnitude of \( f \).

The impact of proximity to attractive sites can be kept constant within a threshold distance, or be varied through several distance bands. In the first case, a single ring buffer can be used, with \( f=1 \) for close segments, and \( f=\infty \) for all other segments. With ring buffers, one \( f \) value is assigned to each ring, where \( f \) values increase as buffer distance increases. Fig. 1
shows an example for a single ring and a multiple ring buffer with $f$ values printed in boldface. The hatched polygons denote attractive areas, i.e., parks or water bodies in the test area. The edges are split at buffer rings, and increments of 25 m are used between rings. The impact of $f$, buffer size, and buffer type on the characteristics of routes will be discussed in section 3.

![Fig. 1: Single ring buffer (a) and multiple ring buffer (b) with multiplication factors on split street segments.](image1)

![Fig. 2: Assignment of multiplication factors through the *intersect* method. Single ring buffer (a) and multiple ring buffer (b).](image2)

The approach taken in Fig. 1 will slow down the SP search, because network edges need to be split at buffer boundaries, and new nodes and edge are inserted into the network. For example, Dijkstra’s algorithm achieves in a network with $n$ nodes and $m$ edges a time bound
of $O(m+n \log n)$ when implemented with Fibonacci heaps (Mitchell 2000). A solution is to keep the network edges un-split, and to assign $f$ to the complete, un-split edge if it intersects a buffer within the threshold distance. Fig. 2 shows the same situation as in Fig. 1, now using the intersect method to assign $f$ values to complete edge segments.

### 2.2 Impact of multiplication factors on route detour

The buffering methods will only then yield an alternative route to the shortest path, if weight reduction along the scenic route makes up for the increased geometric distance. For demonstration purposes in the following examples we focus on situations where the shortest route does not pass by scenic sites, and where the alternative, scenic route is running partially (#1) or completely (#2) through scenic buffers. In Fig. 3 it is assumed that the navigator travels from A to D. The shortest path is along edge A-D with length $d$. Dotted lines indicate segments where $f < 1$. Fig. 3a-c refer to #1, and Fig. 3d and e to #2.

If for an alternative route $p < d$, the SP algorithm returns the alternative, i.e., a more scenic route, because $p_{SP} = d$. With $f = 0$ (Fig. 3a-c), the alternative route is chosen if the sum of connecting segments (A-B, C-D) to segments that intersect buffers (B-C) $\leq d$. With $f > 0$, the connecting segments need to be shorter than $d$ in order to yield $p \leq d$. Depending on the actual length of (B-C) and $f$, the acceptable detour varies. In Fig. 3a-c the acceptable detour increases from left to right (see also Tab. 1).

For fully overlapping route segments, as shown in Fig. 3d and e, if a single ring buffer is used, the maximum acceptable detour is found as $(1/f-1)\times100$. For Fig. 3d, this gives 400%. The equation also makes clear that with $f = 0$, the detour can be indefinitely long. Fig. 3e demonstrates that with appropriate $f$ values and buffer distances in a multi-ring buffer, it is possible for some situations to receive routes that run closer to the attractive site than with a
single buffer. The last two rows in Tab. 1 show that \( p \) of route ABB’C’CD is smaller than for the route with smaller detour (ABCD). With the same \( f \) for all segments besides A-D, which represents a single ring buffer case, the less scenic route ABCD would be chosen.

**Tab. 1:** Perceived route length \((p)\), geometric route length \((l)\), and detour \((a)\) of alternative routes

<table>
<thead>
<tr>
<th>Route</th>
<th>( p ) [d]</th>
<th>( l ) [d]</th>
<th>( a ) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>fig. a</td>
<td>ABCD 0.5+0+0.5 = 1</td>
<td>1.4</td>
<td>40</td>
</tr>
<tr>
<td>fig. b</td>
<td>ABCD 0.5+0+0.5 = 1</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>fig. c</td>
<td>ABCD 0.5+0+0.5 = 1</td>
<td>2.4</td>
<td>140</td>
</tr>
<tr>
<td>fig. d</td>
<td>ABCD 2<em>0.2+0.2+2</em>0.2 = 1</td>
<td>5</td>
<td>400</td>
</tr>
<tr>
<td>fig. e</td>
<td>ABCD 0.4<em>0.4+0.4</em>0.4+0.4 = 0.72</td>
<td>1.8</td>
<td>80</td>
</tr>
<tr>
<td>ABCD</td>
<td>0.4<em>0.4+0.4</em>0.4+0.4*0.4 = 0.68</td>
<td>2.6</td>
<td>160</td>
</tr>
</tbody>
</table>

### 2.3 Working Hypotheses

Following working hypotheses will be evaluated through a variety of shortest path computations on the test network. The trade-off rate describes the detour caused by an increase of scenic areas located within a 25 m buffer along a route.

1. The splitting of street segments at buffer boundaries (Fig. 1) does not provide significantly better trade-off rates than with non-split street segments (Fig. 2).
2. Multiple buffer rings provide a better trade-off rate than single ring buffers.
3. The use of buffer zones around scenic sites in combination with a shortest path algorithm on perceived segment lengths provides a useful trade-off rate.

### 2.4 Design of the Study

Two networks were derived from the original street set, i.e., one for the split method (compare Fig. 1) and one for the intersect method (compare Fig. 2). Both networks were expanded with new attributes that stored perceived segment distances. These were derived from segment lengths and multiplication factors assigned to the various buffer distances. To test hypothesis 1, six buffer types were implemented using both intersect and split mode. For hypothesis 2 and 3, a total of 14 buffer designs were tested for the intersect method only. On the modified networks, the SP was computed between 50 selected start-destination pairs for each type of perceived segment distance. The retrieved routes were intersected with a 25m buffer to compute route statistics, such as detour.

### 3 Results

#### 3.1 Split vs. Intersect Selection Method

In the Fort Lauderdale test area, the view from the street to water bodies (lakes and channels) is often blocked through buildings. The distance between the street center line and the water boundary in this area is typically about 40 m (i.e., the depths of a water front property). To classify a route segment as scenic in the analysis, we use a maximum buffer distance around a scenic area of 25 m to make sure to exclude streets with a blocked view. For parks, similar rules apply. Fig. 4 compares the impact of intersect vs. split mode. Four
single ring buffers of 25 m buffer distance and \( f = 0.01, f = 0.1, f = 0.5, \) and \( f = 0.8 \) were tested besides two 4 ring buffers with \( f_1 = 0.1, f_2 = 0.2, f_3 = 0.4, \) and \( f = 0.1, f = 0.2, f = 0.4, f = 0.8, \) and the shortest geometric path. Fig. 4 shows that single ring buffers perform better with the intersect than with the split method regarding the route portion (in %) running within the 25m buffers. For multiple ring buffers, both intersect and split method yield similar results. As expected, both approaches perform better than the shortest path.

Except for the large detour value associated with \( f = 0.01 \) and the intersect method, routes with the intersect method are only slightly longer or even shorter than those found with the split method (Fig. 4b). These results suggest that the intersect method generally tends to provide a better trade-off rate than the split method, which confirms hypothesis 1. Based on these findings and the fact that the intersect method does not require adding new nodes and edges to the network, further analysis in this paper will focus on the intersect method only. In some extreme cases, where segments are very long, and scenic spots are only sparsely found along these segments, the intersect method may yield unsatisfactory results. This is because the intersect method produces low traverse cost for the complete segment.

![Fig. 4: Impact of intersect vs. split method on route portion within 25m from scenic spots (a). Detour rates compared to the shortest path (b).](image)

### 3.2 Scenic Sections vs. Route Distance

An \( f \) value for buffers close to 1 will hardly cause a deviation from the shortest path, whereas a small \( f \) will generally yield a more meandering and longer route that runs along more scenic areas. As an example, Fig. 5a visualizes three routes found with the shortest path algorithm based on the \( p \) values for one of the 50 start-destination pairs tested. \( f = 0.01, f = 0.1, \) and \( f = 0.5 \) are used in this example. Besides this, the shortest path is visualized as continuous black line. The detailed map in Fig. 5b demonstrates how a small \( f \) increases sinuosity (i.e., the curving), and in consequence, detour of a route. The route found with \( f = 0.1 \) (shown as dotted line) deviates from the more direct route found with \( f = 0.5 \) (shown as continuous line), whereby it runs along more scenic locations. The route with \( f = 0.01 \) has a more extreme detour and is probably unacceptable for most users.
Fig. 5: Impact of multiplication factor $f$ on route shape, route length, and portion of scenic sections along route. Complete overview (a) and detail in circle (b).

Tab. 2 summarizes the values for the routes in Fig. 5. Starting with the shortest path ($f=1$ in the buffer areas), a decreasing $f$ value causes the path length within the 25 m buffer, the total path length, and the detour to increase. The selection method causes the relative scenic section not to increase monotonically with a smaller $f$.

Tab. 2: Characteristics of four routes shown in Fig. 5

<table>
<thead>
<tr>
<th></th>
<th>$f=0.01$</th>
<th>$f=0.1$</th>
<th>$f=0.5$</th>
<th>SP ($f=1$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenic section [m]</td>
<td>13,083</td>
<td>7,687</td>
<td>3,769</td>
<td>1,369</td>
</tr>
<tr>
<td>Path length [m]</td>
<td>37,413</td>
<td>21,172</td>
<td>17,886</td>
<td>16,743</td>
</tr>
<tr>
<td>Scenic section [%]</td>
<td>35.0</td>
<td>36.3</td>
<td>21.1</td>
<td>8.2</td>
</tr>
<tr>
<td>Detour [%]</td>
<td>123.5</td>
<td>26.4</td>
<td>6.8</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Depending on the route planning situation, either the absolute route portion (in length units) or the relative route portion (in percentage values) within the 25m buffer is of relevance. Fig. 6a charts the absolute route portion for 14 buffer types analyzed and the shortest route. With small $f$ values, the average absolute route portion within the 25m buffer is a multiple of the corresponding value for the SP. For example, $f=0.01$ yields a value of 5,747 m in contrast to 1,319 m for the SP. A comparison between single ring buffers with 25 m, 50 m, and 100 m buffer radius ($f=0.2$) reveal that the 25 m buffer performs best. This might be caused by the fact that the analyzed buffer distance for scenic features amounts to 25 m as well. The three multiple ring buffers perform about as well as ring buffers with $f=0.01$. 
For the relative route portion within a 25 m buffer, small $f$ values tend to provide higher results for single ring buffers (Fig. 6b). Multiple ring buffers provide somewhat lower values than single ring buffers. The value differences between buffered routes and the shortest path lie between 2.1% (100 m buffer, $f=0.8$) and 17.3% (25 m buffer, $f=0.01$).

**Fig. 6:** Mean absolute (a) and relative (b) route portions within 25 m from scenic areas. Error bars show the 95% confidence interval of the means.

**Fig. 7** charts the detour of scenic routes. The three peak values associated with $f=0.01$ indicate that routes found with this method cause high detours of 60 percent or more to reach an increase of scenic route section from 12.5% (SP) to 29.8% (25 m buffer), 25.1% (50 m buffer), or 19.8% (100 m buffer), respectively (compare Fig. 6b). Detours for corresponding multiple ring buffers are more moderate. Single ring buffers with a range of around $f=0.1$ or $f=0.2$ provide small detours of about 25% or less, yet causing an increase of the scenic route portion from 12.5% to about 20%.

**Fig. 7:** Detour (in %) compared to shortest path.
3.3 Coefficient of Elasticity

To evaluate the “effectiveness” of a detour, the coefficient of elasticity $c$ is used. It describes how the scenic route portion (in %) is impacted by a change in detour (in %). A higher $c$ indicates a higher (and more desirable) ratio, although it does not mean that more scenic sites are trespassed for such route. $c = (d_{25_i} - d_{25SP})/d_{25SP}/(d_i - d_{SP})/d_{SP}$, where $d_{25_i}$ denotes the portion of route $i$ within 25 m from scenic areas, and $d_i$ denotes total route length. Fig. 8 reveals that a higher portion of scenic route must be paid with an increase out of proportion in detour. For $f=0.1$ and $f=0.2$, detours are most effective on the 25 m buffer.

![Elasticity coefficients.](image)

3.4 Conclusions

Multiple ring buffers receive low coefficients of elasticity (Fig. 8), and detours are longer than for single ring buffers with $f=0.1$ and $f=0.2$ (compare Fig. 7), whereas the relative route portion within 25 m buffers is in the same range. We conclude that multiple ring buffers do not provide a better trade-off rate than single ring buffers, and that hypothesis 2 needs to be rejected. With single ring buffers, an increase from an average attractive portion from 12.5 % (SP) to about 28% can be reached with a detour of less than 20%. This seems like a reasonable trade-off rate for practical route planning, which confirms hypothesis 3.

4 Summary and Outlook

This paper used a shortest path algorithm on perceived route lengths to find attractive routes. Single ring buffers in combination with the intersect method were found to provide useful results, where the practical value of the presented method lies in the straight forward implementation in route planning tools. Whereas for the Fort Lauderdale test area only two attributes, i.e., parks and water bodies, were considered, other urban regions may require additional criteria of attractiveness, such as cultural landmarks or city centers. The availability of such data sets varies for different geographical locations. Whereas automated extraction of relevant feature attributes, such as attractiveness, or obstruction through buildings, works for some existing GIS databases (Elias & Brenner 2004), the accessibility
to this information is generally difficult. However, the emerging Web 2.0 technologies may lead to vast amounts of data to be used in route planning applications (Goodchild 2007). In future work, it needs to be assessed through human subjects testing which trade-off rates for attractive routes are preferred from a user point of view. A related study by Thompson et al. (2007), for example, showed that cyclists are willing to travel an average of 51% additional distance to include off-street paths as part of their routes.

Bibliography


