

Towards landmark-based instructions for pedestrian navigation systems using OpenStreetMap

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Abstract

Pedestrian navigation systems available today still use paradigms developed for car navigation. We present a novel landmark-based pedestrian navigation model using only OpenStreetMap data, which is open and available globally. This approach ensures that our landmark navigation model is widely applicable, rather than restricted to a certain area with exceptional data sources. Our contributions cover algorithms for extraction, weighing, and selection of landmarks based on their suitability, as well as the generation of landmark-based navigation instructions for pedestrian routes. Initial tests with pedestrians show promising results by confirming that our weighted landmark selection reduces the number of navigation errors and revealing future challenges for the generation of intuitive pedestrian navigation instructions.

Keywords: landmarks; navigation; wayfinding; pedestrians; OpenStreetMap

1 Introduction

Spatial cognition research has shown that humans need salient objects called landmarks for orientation and navigation. Landmarks help to structure space and support navigation by identifying points where navigational decisions have to be made (Millonig & Schechtner 2007). Including landmarks into navigational instructions has been shown to improve pedestrian navigation systems (Ross et al. 2004). For standard car navigation, it is sufficient to have access to street names and the geometry of the street network to generate turn-by-turn instructions such as “In 500 meters, turn right into Main Street”. In contrast, navigation by landmark objects requires extraction of more information such as points of interest (Elias 2003), and their subsequent connection in meaningful ways. Two common categories of landmarks are global and local landmarks. Local landmarks along a route can be categorized into landmarks at decision points, landmarks at potential decision points, and on-route landmarks along segments (Lovelace et al. 1999).

Since manual curation of landmark databases is time-consuming and thus expensive, it is necessary to develop techniques which can automatically extract suitable objects for pedestrian navigation instructions from available map data. Several approaches have been proposed, but the automatic extraction of these features from available geospatial datasets still remains problematic (Rousell et al. 2015). Many research projects and publications therefore use highly specific data, which is not available at a bigger scale, such as manually curated landmarks (Selvi et al. 2012), cadastral maps (Winter et al. 2008), city building databases (Elias & Sester 2002), building facade information (Raubal & Winter 2002), or digital surface model data (Brenner & Elias 2003).

One simple method to detect landmarks is to extract landmarks from a buildings database by intersecting named

buildings with the buffered route (Elias & Sester 2002). Improving on this approach, Elias (2003) and Winter et al. (2008) describe methods to compute landmarks uniqueness in the route environment using detailed geometry and attribute information about the specific landmark objects. While research into how to select and manage (Fang et al. 2012) landmarks from information-rich highly specific databases advanced significantly in previous years, landmark-based navigation outside dedicated research projects did not gain traction. As described by Duckham et al. (2010), in many cases the detailed information required by previously developed approaches “may be unavailable, proprietary, infrequently updated, or simply will not exist”. Dräger & Koller (2012) state that “updating the landmark database frequently when the real world changes (e.g., a shop closes down) remains an open issue.” Duckham et al. (2010) therefore present an algorithm to generate route instructions with references to landmarks from commonly available category-level information, such as Yellow Pages.

We currently observe two main research trends: The first trend is to devise ways for extracting additional landmark information from new sources, in particular social media (Quesnot & Roche 2014, Zhu & Karimi 2015). The second trend is to fill in the gaps to finally bring landmark-based navigation to the end user. Our research is mostly focused on using data from OpenStreetMap (OSM), because it is open and globally available and contains both information about the pedestrian network as well as potential landmarks. For example, Rousell et al. (2015) work on extracting landmarks from OSM and selecting the most suitable landmark based on distance and estimated visibility. In line with this trend, our goal is to develop a landmark-based pedestrian navigation system that leverages OSM data. Our contribution is twofold: (1) we propose a flexible approach for landmark extraction and weighing, which enables a landmark selection algorithm that goes beyond Rousell et al. (2015) and takes into account

different weights for different landmark categories; (2) we provide algorithms for generating navigation instructions.

The remainder of this paper is structured as follows: Section 2 discusses the data requirements and preprocessing steps. Section 3 describes the algorithms for generating landmark-based navigation instructions. Finally, Section 4 discusses the current status of the developments, including results from preliminary field tests and open research challenges.

2 Navigation Model Data Preprocessing

The data requirements for our landmark navigation model concern the pedestrian routing graph as well as the extraction of potential landmarks and the weighing of landmark categories according to their suitability. To enable turn-by-turn navigation instructions, a **routing graph** needs to contain certain information about the road network. In most basic applications, the necessary information is limited to street geometry and name. In order to provide more detailed information which is of particular relevance for pedestrians, we expand these basic graph information requirements. The following information which is available in OSM must be extracted for all edges in the routing graph: (1) Edge geometry is used to determine route length, location of turns, and direction of turns; (2) Street name is used to determine decision points based on changing road names, and describe the route in the navigation instructions; (3) Type of way is used to provide further context in navigation instructions. The relevant way types are sidewalks, crossings, squares, steps, and building passages.

The goal of the **landmark extraction** step is to create a list of potential landmarks for navigation. These potential landmarks are input for subsequent landmark selection steps. In line with Duckham et al. (2010) and Rousell et al. (2015), our approach uses information about the type or category of a geographic feature to identify potential landmarks. The geographic features available in OSM are filtered based on categories which are represented by corresponding tags in the OSM data structure. The complexity of the OSM data structure distinguishes it from other landmark data sources such as point of interest (POI) lists, yellow pages, and building databases, which tend to have a well-defined structure.

Our landmark extraction covers potential landmarks that are represented as either points or polygons. Figure 1 presents an excerpt of the SQL view definition to extract potential landmarks from the polygon table of our database, which is generated by importing OSM data into PostGIS using ogr2ogr. Besides filtering for certain categories, this view definition also takes care to exclude features which are not suitable as landmarks because they are located indoors or underground.

Figure 1: Extraction of polygon landmarks from the OSM database

```
SELECT ...
FROM osm20151021_vienna.multipolygons
WHERE (
multipolygons.amenity IN (
'restaurant', 'cafe', 'pub', 'bar', 'hospital', 'pharmacy', 'place_of_worship',
'bank', 'theatre', 'cinema', 'bicycle_rental', 'fuel', 'toilets', 'police',
'prison', 'fire_station', 'library', 'post_box', 'post_office', 'bus_station', 'embassy',
'telephone', 'fountain')
OR (multipolygons.amenity IN ('school', 'university') AND multipolygons.building = 'yes')
OR multipolygons.shop IN (
'supermarket', 'bakery', 'chemist', 'clothes', 'jewelry', 'kiosk', 'hairstylist')
OR multipolygons.building IN (
'church', 'mosque', 'synagogue', 'cathedral', 'school', 'university')
OR multipolygons.tourism IN (
'museum', 'attraction', 'hotel')
OR multipolygons.historic IN (
'memorial', 'archaeological_site')
OR multipolygons.leisure IN (
'park', 'playground')
OR multipolygons.other_tags -> 'railway' = 'subway_entrance'
OR multipolygons.other_tags -> 'public_transport' IN (
'platform', 'stop_position')
OR multipolygons.other_tags -> 'highway' IN (
'bus_stop', 'traffic_signals')
AND (place IS NULL OR place NOT IN ('neighbourhood'))
AND NOT (multipolygons.other_tags IS NOT NULL
AND ((exist(multipolygons.other_tags, 'layer')
AND multipolygons.other_tags -> 'layer' IN ('-1', '-2', '-3'))
OR (exist(multipolygons.other_tags, 'indoor')
AND multipolygons.other_tags -> 'indoor' = 'yes'))))
```

While available literature describes many approaches for assessing **landmark category suitability** for navigation (Duckham et al. 2010, Fang et al. 2012), only few publications provide insight into the results of these assessments. One of the available classifications is provided by Zhu & Karimi (2015). However, the proposed classification is rather coarse and does not cover all landmark categories which we consider relevant for pedestrian navigation. Figure 2 presents an excerpt of the SQL view definition assigning weights collected from expert feedback to potential landmark features. In combination with the query presented in Figure 1, this provides a weighted list of potential landmark features, which can be used as input for subsequent landmark selection algorithms discussed in Section 3.3.

Figure 2: Assignment of weights based on landmark categories in the OSM database

```
SELECT
multipolygons.osm_id,
multipolygons.name,
...
CASE
WHEN multipolygons.amenity IN ('place_of_worship')
OR multipolygons.building IN ('church', 'mosque', 'synagogue', 'cathedral') THEN 94
WHEN multipolygons.historic IN ('memorial', 'attraction') THEN 91
WHEN multipolygons.amenity IN ('fountain') THEN 91
WHEN multipolygons.amenity IN ('police', 'fire_station') THEN 90
WHEN multipolygons.amenity = 'cinema' THEN 86
WHEN multipolygons.amenity = 'theatre' THEN 85
WHEN multipolygons.tourism = 'hotel' THEN 84
WHEN multipolygons.tourism IN ('restaurant', 'cafe', 'pub', 'bar') THEN 84
WHEN multipolygons.amenity = 'post_office' THEN 83
WHEN multipolygons.other_tags -> 'railway' = 'subway_entrance' THEN 83
WHEN multipolygons.shop = 'supermarket' THEN 81
WHEN multipolygons.amenity = 'pharmacy' THEN 79
WHEN multipolygons.tourism = 'museum' THEN 79
WHEN (multipolygons.amenity IN ('school', 'university') AND multipolygons.building = 'yes')
OR multipolygons.building IN ('school', 'university') THEN 75
WHEN multipolygons.leisure IN ('park', 'playground') THEN 75
WHEN multipolygons.amenity = 'hospital' THEN 75
WHEN multipolygons.amenity = 'fuel' THEN 75
WHEN multipolygons.amenity = 'library' THEN 71
WHEN multipolygons.shop IN ('bakery', 'chemist', 'clothes', 'jewelry', 'kiosk') THEN 50
WHEN multipolygons.amenity = 'embassy' THEN 45
WHEN multipolygons.shop = 'hairstylist' THEN 42
WHEN multipolygons.amenity = 'bank' THEN 38
WHEN multipolygons.other_tags -> 'public_transport' IN ('platform', 'stop_position')
OR multipolygons.other_tags -> 'amenity' IN ('bicycle_rental', 'bus_station') THEN 30
WHEN multipolygons.amenity IN ('post_box', 'toilets', 'telephone') THEN 20
ELSE 50
END AS nav_priority
FROM osm20151021_vienna.multipolygons
```

3 Generating Landmark-based Pedestrian Navigation Instructions

The algorithm for generating landmark navigation instructions for pedestrian routes can be broken down into the five main steps, which are described in detail in the subsequent sections.

3.1 Splitting Routes into Episodes

The first step analyses the route and segments it into episodes between decision points. A decision point is characterized by at least one of the following: a change in the route direction, street name, or type of way. To detect changes, we perform a pairwise comparison of successive route edges. Checking for direction changes needs to account for a certain tolerance to allow minor changes, which would not be characterized as turns.

While this approach often provides a reasonable segmentation into route episodes, the results are highly dependent on modelling details of the routing graph, in particular when it comes to detecting relevant direction changes. Figure 3 illustrates this issue: A pedestrian following Fichtegasse only needs to cross Hegelgasse and continue straight on. From a pedestrian’s perspective, there is no need for a decision point and associated navigation instructions. From the algorithm’s point of view, this simple route section contains two potential decision points due to the layout of the routing graph at this intersection, which results in a zig-zag route and thus introduces two direction changes (“slightly left” followed by “slightly right”) within six meters.

Figure 3: Detecting relevant direction changes in zig-zag routes



Zig-zags occur frequently in pedestrian routing graphs, which contain sidewalk edges, pedestrian crossings, and other short features. Therefore, we recommend a preprocessing step, which merges zig-zag sections, that are below a certain length limit and not essential to the route description, like pedestrian crossings or steps, as outlined in Figure 4.

Figure 4: Algorithm to merge short zig-zag sections

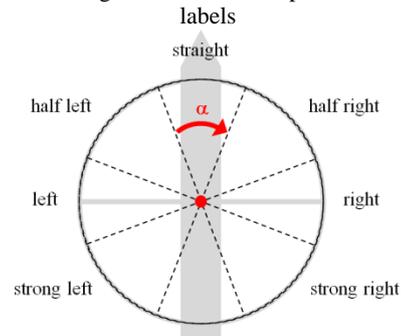
```

while the route contains an edge  $e$  shorter than the length limit, which is not
of type pedestrian crossing or steps do
    Replace  $e$  by a node at its center point  $c$ ;
    Connect  $c$  to the second to last node of the previous edge and the second
    node of the following edge;
end
    
```

3.2 Computing Turn Instructions

Turn directions along routes are discussed by Klippel & Montello (2007). The seven distinguishable directions they use are half left, left, sharp left, straight, half right, right, and sharp right. They argue that in case of decision points and associated changes in travel direction, the labels left and right describe sectors centred on the orthogonal axes of 90 and 270. We adopt this approach and also add a sector for the straight label, as illustrated by Figure 5, to allow for some deviation (α) from the completely straight line.

Figure 5: Turn angles at the decision point and associated labels



3.3 Selecting Landmarks at Decision Points

Once decision points are identified, landmark selection is performed to pick the most suitable landmark at a given decision point. Particularly in busy urban settings, there can be numerous potential landmarks in close vicinity of a decision point. Therefore, it is necessary to find the most suitable landmark. Approaches to determine this suitability from databases which contain information about the object type but lack details needed to determine the object’s salience are described, for example, by Duckham et al. (2010) and Rousell et al. (2015). We suggest the following algorithm to determine landmark suitability from the database of weighted potential landmarks, which combines and expands previously published approaches into one landmark suitability measure

$$S = ((d_{max} - d) * w_d - (c_{max} - c) * \frac{d_{max}}{c_{max}} * w_c + s * w_s + l * w_l) * v$$

where

- d is the distance between decision point and landmark,
- d_{max} is the maximum distance for a candidate to be considered,
- c is the landmark category weight,
- c_{max} is the maximum landmark category weight,
- s is the side of the landmark relative to the next turn: same side (1) or other side (0),
- l is the location of the landmark relative to the route: before (1) or after (0) the decision point,
- v is the visibility of the landmark: visible (1) or hidden (0), and
- w_d, w_c, w_s, w_l are the weights for the terms for distance, category suitability, side, and location.

Distances between landmarks and decision points are computed as follows: for point landmarks it equals the Euclidean distance between point and decision point; for

polygon landmarks it equals the distance between decision point and polygon outline.

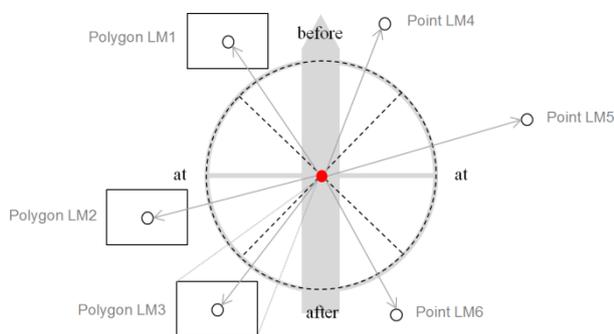
Landmark visibility estimates can be computed using different approaches. The visibility method introduced by Rousell et al. (2015) estimates a landmark’s visibility on the approach to the decision point using line of sight computations, which is computationally expensive and unreliable for point landmarks inside building polygons. To avoid expensive calculations on questionable point landmark locations, our visibility method estimates visibility using distance. Any landmark that is within a certain distance is assumed to be visible. The downside of this approach is that it ignores potentially available information about visibility and occlusion by buildings.

Salience considerations, such as landmark size, height, shape, colour, or architectural style are not included in this suitability measure since – for the vast majority of potential landmarks – OSM does not provide the necessary data.

3.4 Computing Prepositions

To determine the relative position of the selected landmark with respect to the decision point, we distinguish between three different **prepositions**: “before” if the landmark is in front of the decision point, “at” if the landmark is at approximately the same location along the route as the decision point, and “after” if the landmark lies behind the decision point. Similar to the turning instructions, prepositions are determined based on the angle between the movement direction and the location of the landmark. In case of polygon landmarks, the angle is computed using the polygon centroid rather than its outline since points on the outline can fall into different preposition sectors and would thus lead to ambiguous results as depicted in the example for polygon landmark LM3 in Figure 6.

Figure 6: Landmark locations relative to the decision point and associated preposition sectors



One particular challenge for generating intuitive navigation instructions worth noting are big polygon landmarks, since they might be selected for multiple successive decision points. This can lead to confusing and ambiguous navigation instructions. If the same landmark-preposition combination is selected for multiple decision points, it is therefore recommended to repeat the landmark selection and preposition computation steps and exclude the problematic landmark.

3.5 Generating instructions

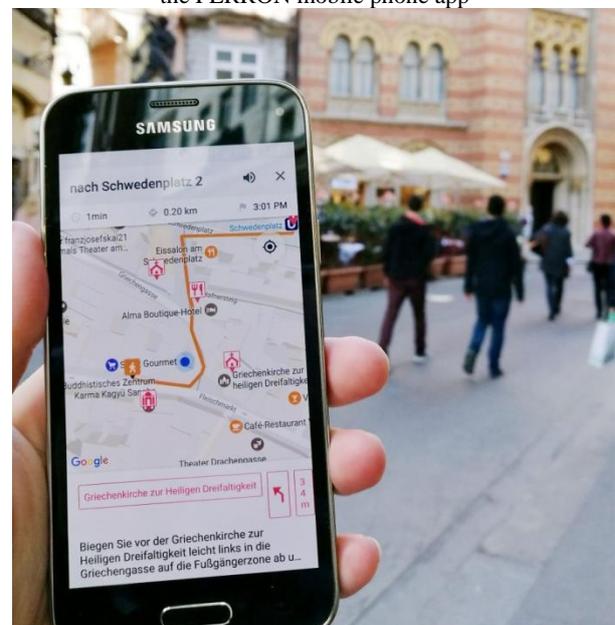
To generate the final route description, we combine the results of the previous steps and information associated with the episode edges. The route description contains turn instructions, landmark information (landmark with preposition), and information about the travelled edges. The instructions distinguish between different edges, such as, sidewalks, crossing of streets or open spaces (such as squares and plazas), building passages, and steps. Instructions can be tested using a publicly available interactive web application at <http://bit.do/perron-project>, as shown in Figure 7.

Figure 7: Pedestrian route with landmark-based instructions in the PERRON web viewer. Route from A to B. Black circles mark decision points and stars mark selected landmarks.



Furthermore, the route instructions are provided via an API and presented to pedestrians using apps on smart phones or watches. Figure 8 shows a preliminary test version of the smart phone app. The app consists of a map view which shows route and landmarks, as well as a navigation instruction section. Instructions are provided in both textual as well as audio form.

Figure 8: Pedestrian route with landmark-based instructions in the PERRON mobile phone app



4 Discussion and Conclusion

The landmark-based navigation instructions have been tested for two 10 minute long routes with 9 and 17 instructions. Results showed that our landmark selection algorithm with weighed landmarks clearly outperformed the baseline approach of selecting the nearest landmarks: Both a reduction in navigation errors, as well as a higher reported quality of landmark-based instructions were observed for the weighed landmark selection. The test also revealed challenges: The real-world visibility and salience of an individual landmark are unknown. For example, while a building might be very salient when approached from the front, it can be nondescript if approached from a different side. Algorithms that can derive information about which side of an OSM polygon feature represents the salient building side therefore have the potential to further improve the selection process. Furthermore, it is important to detect and remove unnecessary instructions to avoid confusion.

Future work will focus both on algorithmic improvements as well as more user tests. Algorithmically, we plan to further reduce the number of unnecessary navigation instructions. Future tests will be performed using the recently developed app rather than paper printouts, which will provide us with the opportunity to be more flexible in the test setup and execution.

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