The Landmark Spider:
Weaving the Landmark Web

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Landmarks play an important role when humans navigate through foreign environments (Lynch, 1960; May, Ross, Bayer, and Tarkiainen, 2003). For example, trying to find the way is much easier if the navigator can rely on a description of the route based on well-recognizable objects in the environment, instead of navigating solely on the basis of street names and metric directions (Tom, and Denis, 2003). Therefore, collecting and incorporating landmarks along a route is a crucial task of pedestrian navigation systems that aim at providing efficient and reliable route instructions. Several proposals have been made on how to automatically extract landmarks from data sets and how such landmarks could be used to enhance wayfinding instructions for pedestrians (Elias, 2003; Nothegger, 2003; Raubal, and Winter, 2002). So far, however, the questions what landmarks to consider and how to integrate them in the route generation process is only poorly understood. We propose a *landmark spider* that assesses the relevance of landmarks along a route, includes these landmarks in the route generation process, and weaves a web of landmarks along that route.

Cognitive research has indicated that the complexity of route instructions may be as important in pedestrian navigation as the overall length of the route. Streeter and co-authors found that human navigators were prepared to take suboptimal routes in terms of travel time, if these routes were potentially easier to describe and to follow (Streeter, and Vitello, 1986; Streeter, Vitello, and Wonsiewicz, 1985). Landmarks are important elements in route instructions as they ensure efficient and reliable navigation (Denis, Pazzaglia, Cornoldi, and Bertolo, 1999). So far, the typical approach to incorporate landmarks in route descriptions has been to enrich navigation instructions with information about landmarks (Nothegger, 2003; Raubal *et al.*, 2002; Redish, and Touretzky, 1995). Our approach is different in that it uses a subset of the available landmarks, which are most prominent and easy to find, to determine the optimal route. The introduction of landmarks in the route generation process is advantageous, since it enables us to avoid areas of low landmark density and ensures consistent access to landmark information along the complete route.

The landmark spider consists of a route network and a set of landmarks, including their spatial attributes and non-spatial properties (salience, visibility, etc.). The network is represented as a connected, simple, directed graph. The landmark spider uses a revised version of Dijkstra's shortest weighted path algorithm to find the optimal path between two nodes. The weighting function reflects the presence of landmarks at each point along the route, where navigators might need assistance. The model framing the weighting function is based on findings by Michon and Denis (Michon, and Denis, 2001). According to them, the three most important reasons why landmarks are required during navigation are: 1) signaling where an action should be executed, 2) creating the link to the next section of the route in terms of assisting in locating the next landmark, and 3) reassuring navigators that they are still on track. These reasons are applied at specific locations along the way, and hence, can be mapped onto any network graph representing routes pedestrians may take.

Signaling where an action should be taken occurs at places where three or more edges meet, typically at nodes, with the exception of turning around, which may happen along any given edge. However, for the purpose of this study we neglect this case and assume that any decision taken by the navigator is correct and no turning around is required. Hence, each node needs to have at least one landmark associated with it. The ideal case would be a set of landmarks that are visible from the nodes and which are prominent enough as to provide guidance from one decision point to the next. As the distance between nodes grows, however, one landmark eventually gets out of sight and the need arises to find the next reference point. Hence, landmarks along edges may be required. In this case, we consider the vertices of the route network, which aid in assisting to find the next landmark, as well as affirming that navigators are still on track.

Now that we know where landmarks are required along the way, we can define the weighting function. Basically, the weight is the sum of the factors that define the binary relation between points on the route and potential landmarks. These factors are 1) the distance between a point and the landmark, 2) the orientation of the user with respect to the landmark, and 3) the salience of the landmark itself. The distance is important since close landmarks make better reference points than distant landmarks. Orientation is included due to the fact that following route instructions is a directed process. Hence, the orientation of a landmark with respect to the navigator is important when referring to landmarks. For instance, landmarks located in the line of view are more likely to serve as navigational references than objects located at the navigator's back. Finally, the saliency of the landmark indicates its quality, which is in essence a measure of the 'visibility' of the landmark. As a result, the salience is an essential part of the relation between points on the route and the landmark. This configuration ensures that each node and each vertex along the route is associated with a weight indicating the relevance of potential landmarks. Introducing these weights in the weighted shortest path algorithms and summing them up results in the optimal route in terms of landmark coverage.

In the best-case scenario, the optimal route computed by the landmark spider is identical to the shortest path between starting point and destination. The worst-case scenario occurs if the density of available landmarks is too low, in which case parameters of the weighting function may have to be adjusted appropriately. Questions on results analysis and comparison, as well as computational issues and performance are subject of ongoing research. Nevertheless, the landmark spider provides a valid approach to integrating landmarks in the route generation process, in contrast to linking landmarks and route description after route generation.

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