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Interactive Cartographic Route Descriptions

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Michela Bertolotto**

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Abstract Providing an adequate route description requires in-depth spatial knowledge of the route in question. In this article we demonstrate that despite having travelled a route recently and having much experience of the area in question, an individual may lack such a degree of knowledge. Previous research and experience informs us that a map is an effective tool for bridging gaps in one's spatial knowledge. In this article we propose an approach, known as an *Interactive Route Description*, for defining and interpreting route descriptions interactively with a map. This approach is based on the concept of annotating the map in question and allows the aforementioned gap in one's spatial knowledge to be bridged. An additional benefit of defining route descriptions in this way is that it facilitates automatic parsing and in turn offers many potential applications. One such application, illustrated in this paper, is the automatic transformation to other representations of the description such as turn-by-turn instructions.

Keywords Route description · Interactive cartography

1 Introduction

The tasks of providing and interpreting route descriptions are performed by most people on a regular basis. These tasks can occur in many different contexts the most common of which is the provision or interpretation of a route description with a specific destination. Other contexts include the provision or

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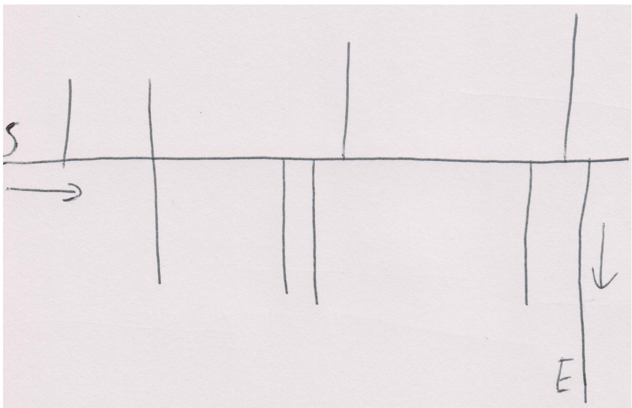
interpretation of a route description which passes by a number of scenic locations but without a specific destination. An important factor which must be considered when providing or interpreting a route description is both parties degree of spatial knowledge regarding the environment in question. A person's spatial knowledge of an environment is commonly referred to as their cognitive map [33] or environmental cognition [5]. There exists a relationship between one's ability to provide an adequate route description and their degree of spatial knowledge regarding the environment in question. In this context the term adequate route description describes a route description which can be easily interpreted and used to effectively navigate the route in question without difficulty. To illustrate the difficulties insufficient spatial knowledge can pose consider Fig. 1(a) and the situation where an individual wishes to describe the route from location S to E along the blue dashed line using a sketch map. In this case the most difficult and important part of the route to represent accurately is the right turn. A corresponding sketch map displayed in Fig. 1(b) represents this turn accurately in terms of the number of previous right turns. That is, the correct turn is the fifth turn on the right. Alternatively this turn could be represented accurately in terms of a landmark corresponding to the church located just prior to the turn in question. However if the individual creating the description does not know the correct number of previous right turns or the existence of the landmark they may not be able to create an adequate route description. Lovelace et al. [35] found that individuals with a greater degree of spatial knowledge provided route descriptions that were more complete, correct and greater in detail.

One's degree of spatial knowledge is in part a function of the complexity of the environment in question. This is because it is more difficult to build an accurate cognitive map of a complex environment [42,32]. Consequently the task of providing a route description is most difficult in complex environments. Furthermore, any knowledge one has of an environment will generally be distorted [50,34]. Therefore most route descriptions will contain some degree of inaccuracy, such as incorrect distances, or be lacking important details such as landmark information. However this does not imply that no route description can be adequate. Instead such deficiencies in the description may potentially be overcome by combining the route description with a wayfinding strategy [40] or if the individual interpreting the description has some prior knowledge of the environment this may be exploited [46]. Baskaya et al. [18] and Garling et al. [3] found that individuals with a greater degree of spatial knowledge can navigate routes quicker and make fewer mistakes. A recent study by Holscher et al. [23] demonstrated that in the face of insufficient spatial knowledge to adequately describe a particular route, people regularly describe a route of lesser complexity which in turn is easier to represent. However such an alternative route may not always be known and, even if it is, the route may be suboptimal in terms of other criteria (e.g. it may be longer).

In this article we pose three research questions. Firstly, in the context of runners providing and interpreting descriptions of running routes which are reasonable long and contained in urban environments, we ask the following

(a)



(b)

Fig. 1 A route shown on OpenStreetMap is displayed in (a). A corresponding sketch map is displayed in (b).

question. If an individual has travelled a route recently and has much previous experience of the area in question, will they generally have sufficient spatial knowledge to provide a corresponding adequate route description? As discussed above, route descriptions created with insufficient spatial knowledge may be inadequate. Previous research and experience informs us that a map is an effective tool for bridging gaps in one's spatial knowledge. In fact, Klippel et al. [28] states that maps are "the most common wayfinding support tools". This suggests that the difficulty associated with defining and interpreting route descriptions may be reduced by performing both tasks interactively with a map. In this article we propose an approach, known as an *Interactive Route Description*, for defining and interpreting route descriptions interactively with a map which is based on the concept of annotating the map in question. The second research question we ask in this article is the following. Does the Interactive Route Description reduce the difficulty associated with providing and interpreting route descriptions? Although the concept of annotating a map is not novel, the effectiveness of it as a tool for providing and interpreting route descriptions has yet to be evaluated. The final research question we ask in this article is the following. Does the Interactive Route Description facilitate the automatic transformation to other representations of the description such as turn-by-turn instructions?

The remainder of this article is structured as follows. Section 2 provides an overview of the types of information a route description may contain and how this information may be represented. Section 3 describes the proposed Interactive Route Description while section 4 describes its implementation. Sections 5 and 6 evaluate the effectiveness of the Interactive Route Description as a platform for providing and interpreting routing descriptions respectively. These sections provide answers to the first two research questions stated above. Section 7 demonstrates that an Interactive Route Description may be automatically transformed to a set of turn-by-turn linguistic instructions and in turn answers the final research question stated above. Finally in section 8 we draw conclusions and discuss possible future research directions.

2 Route Descriptions - Information and Representation

A route description is generally categorized in terms of the type of information it contains and how this information is represented. We now discuss each of these features in turn. *Turn-by-turn instructions* provide very detailed information regarding the route in question and are commonly used in automotive navigation systems. They correspond to instructions such as "turn left at the next junction, go straight through the following junction, turn right at the following junction". Although effective, such instructions are very dissimilar to routes descriptions provided by most individuals [56]. This is attributed to the fact that human route descriptions commonly contain *landmark information* where landmarks are defined as environmental features that can function as a point of reference [2, 15]. An example of such a route description is the following "continue straight until you see a large church on your right, turn left at the following junction". However in featureless environments, such as suburban areas, landmarks may not always exist [54]. *Destination descriptions* do not provide information relating to the route explicitly but instead describe the route destination [48]. They correspond to instructions such as "opposite the Stillorgan shopping centre". Destination descriptions have the potential to be shorter than route descriptions containing turn-by-turn instructions or landmarks. However they assume the individual using the description has prior knowledge of the environment which may not always be the case.

Route description information may be represented in many ways. These include linguistic (text and verbal), map, sketch, tactile and augmented-reality representations [31,41]. Due to their ubiquity, linguistic representations are by far the most commonly studied. In fact, many models of linguistic route description production have been proposed [12,14,2]. For example the model of Allen [2] contains four stages of initiation, route description, securing and closure. The most suitable representation is a function of the information which requires representation. If one wishes to represent information regarding segments of the route which would be encountered during navigation, commonly referred to as a route perspective [24], a linguistic or augmented-reality representation is most suitable. On the other hand if one wishes to represent information regarding an overview of the environmental layout, commonly referred to as a survey perspective [24], a map or sketch representation is most suitable. In some cases the most suitable representation is context dependent. For example in the context of motorist navigation a verbal description is suitable because it does not distract visual attention from the road.

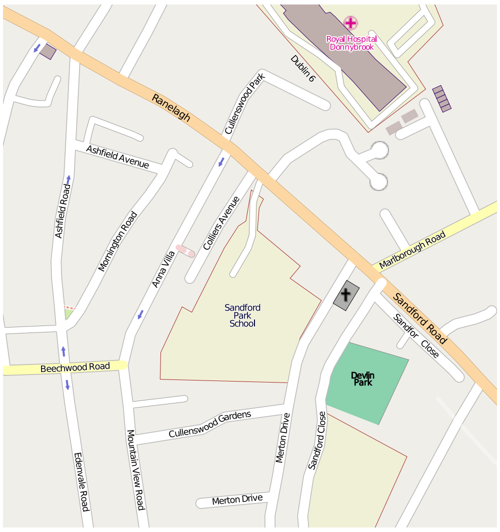
Empirical research [13] and personal experience demonstrates that the tasks of providing and interpreting route descriptions are complex cognitive processes which are not always successful [2]. Consequently many authors have attempted to evaluate the best strategies for performing these tasks. A number of authors have performed studies with the aim of determining which types of route information, for a given representation, are most effective [26,39]. Lovelace et al. [35] found that linguistic descriptions containing more landmark information were rated higher by individuals. Moreover, longer route descriptions, which contained more information, were also rated higher. Dennis et al. [14] found that linguistic descriptions which were clear, complete and containing an adequate number of landmarks, but without redundancy or uncertainty, were rated highly. Hund et al. [24] asked individuals to state their individual preferences regarding linguistic descriptions. Individuals responded positively to landmark and left-right information and negatively to cardinal directions. Allen [2] found that individuals following linguistic descriptions made fewer errors when landmark information was present at choice points. Furthermore the use of landmark information resulted in fewer errors compared to the use of cardinal directions and distances. In contrast the study of Hund and Minarik [25] found cardinal directions to be more effective than landmark information when navigating in a model town.

A number of studies have also been performed to determine the most suitable representation for a route description in a given context [21,17,44]. Ishikawa et al. [27] showed a map representation to be more effective than a turn-by-turn representation for pedestrian navigation. Meilinger and Knauff [37] found verbal descriptions and maps to be equally effective when navigating in an urban environment. Chittaro and Burigat [9] evaluated the integration of different pairs of representations for mobile tourist guides. Goodman et al. [21] found that landmark information is represented equally effectively using a text description, verbal description and photographs in the context of pedestrian navigation. Fickas [17] found a verbal description to outperform three other representations in the context of individuals with cognitive impairments performing pedestrian navigation. In the study of Wang and Li [52] it was demonstrated that a sketch representation is more effective than a verbal description in the context of pedestrian navigation.

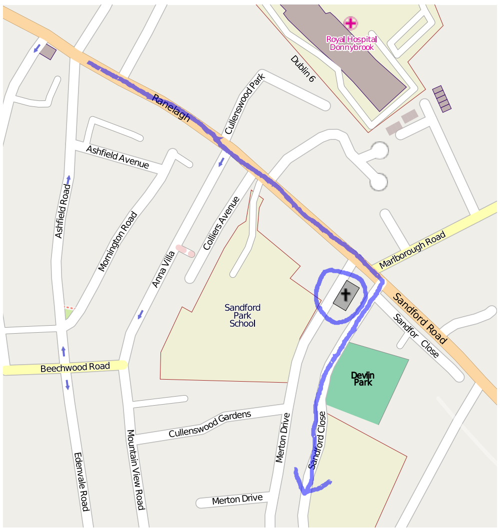
3 Interactive Route Description

As discussed in the introduction to this article, route descriptions created with insufficient spatial knowledge may be inadequate. The most commonly used strategy for bridging gaps in one's spatial knowledge is to examine a map of the corresponding environment. This suggests that the difficulty associated with defining and interpreting route descriptions may be reduced by performing both tasks interactively with a map. Specifying a route description interactively with a paper map is regularly performed by most people in their everyday lives. For example tourists holding a paper map will often approach someone to ask for directions. If a suitable route description is known it is generally specified interactively with the map and is accompanied by a linguistic description. The interaction in question usually involves pointing to features on the map such as landmarks and streets. Blades and Medlicott [5] assessed how children and adults specify route descriptions interactively with a paper map. The authors found that all adults gave accurate route descriptions. Ward et al. [53] found that when specifying route descriptions interactively with a paper map, males used more mileage estimates and cardinal directions than females and made fewer errors.

In this article we propose an approach for specifying a route description interactively with a map which we refer to as an Interactive Route Description and is based on the concept of annotating the map in question. Although the concept of annotating a map is not novel, the effectiveness of it as a tool for providing and interpreting route descriptions has yet to be evaluated. An Interactive Route Description is created using the following steps. Firstly the region containing the route in question is selected from a larger map containing a detailed road network along with addition information such as street names and local features. We refer to this selected map region as the base-map. For example consider again the example from Section 1 where the goal is to represent the route from the letter S to the letter E along the blue dashed line represented in Fig. 1(a). In this situation one would select a base-map such as that displayed in Fig. 2(a). Given a suitable base-map the individual next annotates the base-map as follows. The individual draws a directed line or arrow over the base-map along the route path. For example in the context of specifying the route in Fig. 1(a) the individual would draw a directed line over the base-map in Fig. 2(a) similar to that represented by the blue directed line in Fig. 2(b). The individual may also annotate the route with landmark information. For example in Fig. 2(b) the individual has drawn a circle around a feature in the base-map corresponding to a church in order to indicate that this is a landmark. If a feature is not present in the base-map the individual may annotate the base-map with it.



(a)



(b)

Fig. 2 The selected base-map and corresponding sketch-map are displayed in (a) and (b) receptively.

If sufficient knowledge regarding a particular part of the route is not available it may be possible to infer this knowledge through spatial reasoning which is a function of the base-map and knowledge relating to other parts of the route. As such, the base-map allows the individual specifying the route to augment their spatial knowledge. To illustrate this concept consider again the example in Fig. 2 where an individual wishes to accurately represent a right turn. If the correct number of prior right turns is unknown this information may be inferred in a number of ways. For example if the individual knows that the following part of the route passes by the area known as Devlin Park (represented by a green polygon in Fig. 2(a)) they can infer the correct turn. Alternatively if they know that the turn in question is directly after the church represented in the scene, despite the fact that this feature may not be a suitable landmark, they again can infer the correct turn.

The base-map also allows an individual navigating with an Interactive Route Description to augment their spatial knowledge where necessary. This in turn offers a number of benefits. Consider the situation where an individual is attempting to navigate using the Interactive Route Description in Fig. 2(b). If they have taken a right turn but are unsure if this is in fact the correct turn they may reject the hypothesis that it is correct if a park does not appear on their left a short distance later. This is despite the fact that the individual who created the Interactive Route Description may not have explicitly represented this feature in the annotation. Other forms of information which may be drawn from the base-map to facilitate navigation are distances, compass directions and street names. The ability to augment route information where necessary allows one to obtain a route description of varying levels of detail [43, 56]. In locations where one has little prior knowledge, a detailed description is necessary and can be inferred. While in locations where one has significant prior knowledge there is no requirement to infer additional information. The above process of drawing additional information from a base-map is similar to the task orienteers perform when planning a route between locations (known as controls) on an orienteering map [16]. Orienteering maps differ from the Interactive Route Description due to the fact that they only specify controls and not a route between them.

The Interactive Route Description offers a number of advantages over how one would specify a route description interactively with a paper map. Firstly not everyone carries paper maps. On the other hand mobile devices, such as tablets, which support annotation and can access free map data from services, such as OpenStreetMap, are becoming ubiquitous. We qualify this statement with the fact that some remote areas may have no internet access and, as a consequence of the digital divide, some groups will have reduced access to, use of, or knowledge of information and communication technologies (ICT). Due to the fact that the Interactive Route Description is based on annotation it shares a number of benefits associated with sketch maps including the following. The Interactive Route Description is an external representation which complements human memory [51]. Therefore, unlike linguistic representations [47], it does not need to be remembered. The Interactive Route Description also complements information processing [51]. It facilitates the user to perform processes such as spatial chunking which can be defined as the grouping of navigation instructions [29]. However unlike a sketch map the Interactive Route Description is not affected so strongly by individual drawing ability [4]. Finally, as will be discussed in section 7 of this paper, the Interactive Route Description also facilitates the parsing of route descriptions. This has many potential applications such as the automated transformation to other representations.

Many route finding services exist for generating route descriptions which contain a start, end and set of way-points which are specified interactively with a map. One such service is OpenRouteService (www.openrouteservice.org) which is illustrated in Fig 3. The objective of such services is to find a route description for an unknown route, as opposed to communicate a route description for a known route which is the objective of the Interactive Route Description. It must be noted that, if enough way points were specified one could indirectly communicate a route description for a known route using a route finding service. However, fundamentally this is not the intended application of such services.

Fig. 3 A route generated by OpenRouteService which contains a start (green arrow), end (checkered arrow) and single way-point (yellow arrow) is displayed.

4 Implementation

The Interactive Route Description can be implemented in two ways. Firstly it can be implemented using a paper map and annotating this with a pencil or pen. However this approach requires that a suitable paper map is available which may not always be the case. Also after creating an Interactive Route Description it becomes difficult to reuse the paper map in question. Secondly the Interactive Route Description may be implemented as a software application. This approach offers a number of advantages. Desktop and mobile devices which have sketching functionality and in turn support the Interactive Route Description are ubiquitous in modern society. Such devices are generally internet enabled and can therefore access free and open map data from services such as OpenStreetMap (http://www.openstreetmap.org). Implementation as a software application allows the route description in question to be automatically parsed through map matching. This in turn offers many potential applications. In section 7 we illustrate this point by proposing an algorithm which automatically converts an Interactive Route Description to a linguistic representation of the route in question.

For these reasons, in this work, the Interactive Route Description was implemented as a web-application. The application functions as follows. When creating an Interactive Route Description the individual first pans and zooms the map in question until they locate the necessary base-map; that is the region containing the route they wish to represent. Next they annotates the base map with the route trajectory. Finally, if necessary, the user may annotate the map with other additional information. The OpenLayers Javascript Mapping Container (http://openlayers.org/) was used for the base-map display. OpenLayers is generally accepted as one of the best Javascript libraries for the development of web-based applications with high levels of interactivity. OpenLayers is a pure JavaScript library for displaying map data in most modern web browsers and has no server-side dependencies. It exposes its functionality using an extensive JavaScript API for building rich web-based geographic applications. The OpenLayers library allows very fine grained control over map interactions such as panning, zooming, and base-map feature identification and selection. Using additional Javascript we implemented some simple functionality to capture the mouse movements and events of the user as they traced out their sketch trajectory on the base-map display. As the trajectory was being traced the coordinates (transformed from screen display coordinates to latitude/longitude) were stored in a list data structure. When the user finished their sketch trajectory the coordinates in the list data structure were converted to a GeoJSON object representing the trajectory. Depending on the annotation that the user generates it may be necessary to generate a set of GeoJSON objects. As GeoJSON is a open specification text-based data format (and an extension of the very widely used JSON format) it is very easy to convert from a list of coordinates representing a geographic object to GeoJSON. OpenLayers can natively read and write GeoJSON files. The sketch trajectory is then overlayed onto a clean base-map by passing the GeoJSON objects to an OpenLayers Vector Layer object. This layer is displayed using a high degree of transparency to ensure it does not occlude important information in the base-map. OpenStreetMap data was used as the base-map. The resulting Interactive Route Description is printed on an A4 white sheet of paper.

5 Evaluation - Providing Route Descriptions

This paper attempts to answer the following research questions in the context of runners providing and interpreting descriptions of running routes which are reasonable long and contained in urban environments. Firstly, if a runner has travelled a route recently and has much previous experience of the area in question, will they generally have sufficient spatial knowledge to provide a corresponding adequate route description? Secondly, does the Interactive Route Description reduce the difficulty associated with providing and interpreting route descriptions? In order to answer both these questions effectively we must consider both the perspective of those providing and interpreting route descriptions. These perspectives are considered in this section and section 6 respectively. Each of these sections contains three subsections which describe the evaluation methodology, the corresponding results, and a discussion.

5.1 Evaluation Methodology

The evaluation methodology implemented is based on that of Goodman et al. [20,21] and Fickas et al. [17]. As discussed in the introduction to this paper the use of route descriptions can occur in many contexts. In this study we chose to perform our evaluation in the context of long-distance runners providing and interpreting running route descriptions. A long distance runner can run between 5 and 30 kilometres on a daily basis for training purposes. Currently the most popular medium for runners to share routes is GPS traces through sites such as mapmyrun.com. Evaluating a navigation aid in the context of a specific user group is a common practice. For example, Fickas et al. [17] and Goodman et al. [21] evaluated navigation aids in the context of cognitively impaired and elderly groups respectively. In our evaluation, as is commonly done [49], we use sketch maps as a tool to measure one's degree of spatial knowledge regarding an environment. The materials chosen for creating the sketch maps were an A4 white sheet of paper and pencil.

5.1.1 Participants

Twelve participants (nine male, three female) were recruited for this study. Their ages ranged between 24 and 35 years (M=30.26, SD=3.15). All participants were active runners who regularly compete in long distance races. All were computer literate and eleven of them rated themselves as regular map users. All had previously used web mapping technologies such as Google Maps or OpenStreetMap. No participant was involved in the presented research. Participation in the study was on a voluntary basis without compensation.

5.1.2 Experimental Design

Dublin city and Longford town, which are both located in Ireland, were used as the study areas. These locations were chosen for the following reasons. Both urban areas facilitated sufficiently long routes. All participants had varying degrees of spatial knowledge of both areas. Finally OpenStreetMap for both of these areas is of a high quality and rich in detail.

5.1.3 Experimental Procedure

Each participant was given an initial briefing where the concepts of a sketch map and an Interactive Route Description and their creation was explained. They were then asked to consider a route they had run recently within an area which they do much of their training and in turn have significant spatial knowledge. They were subsequently asked to perform a repeated trial where they created a corresponding sketch map and Interactive Route Description for this route. The motivation for having each participant consider the same route in each trial was to ensure that the degree of spatial knowledge was constant. As a consequence of using the same route in each trial there existed the potential for the first trial to positively prime the second [19]. To minimize such priming each participant performed both trials on the same day but with a minimum of four hours between the end of the first trial and the start of the second. In order to ensure that the degree of spatial knowledge remained constant across trials each participant was asked not to travel the route or examine maps of the route between trials. It was felt that if the trials performed by a participant took place on different days this would be difficult to achieve. To counteract the possibility that a residual positive priming may bias the results in favour of the sketch map or the Interactive Route Description the order of trials was varied. That is, half the participants created the sketch map first while the remaining participants created the Interactive Route Description first.

Whether or not the sketch maps and Interactive Route Descriptions were created in the presence of the individuals who would later attempt to navigate the routes in question represented a major choice in the construction of the experimental procedure. Creating descriptions in the presence of these individuals would introduce the possibility that additional information would be communicated verbally. Such additional information would then need to be analysed jointly with the corresponding sketch map or Interactive Route Description. On the other hand, not creating descriptions in the presence of these individuals would not correspond to how route descriptions are generally provided and interpreted. Based on these considerations it was decided to create the descriptions in the presence of the individuals who would later attempt to navigate the routes in question. However the individuals creating the descriptions were informed before the trials that all route information should be represented explicitly in the sketch map or Interactive Route Description. And, that verbal communication should only be used to explain or clarify details contained in the sketch map or Interactive Route Description. If any additional information, which was not explicitly contained in the sketch map or Interactive Route Description, was communicated verbally this was noted by the researcher conducting the trial.

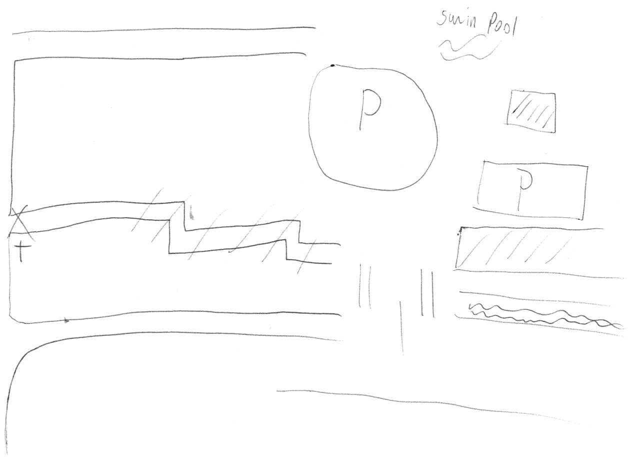
The time required by each participant to complete each trial was measured. In this case the amount of work or effort is the independent variable while the time required is the dependent variable. After completing each trial participants filled in the NASA Task Load Index (TLX) which measures perceived workload as an indication of how difficult participants found the task [22]. In this case the perceived workload is the independent variable while the TLX scores are the dependent variables. Each participant was also given the opportunity to provide feedback and comment on their experience after each trial. After completing both trials each participant was asked to indicate which representation they preferred. They were subsequently asked to comment on their choice.

5.2 Results

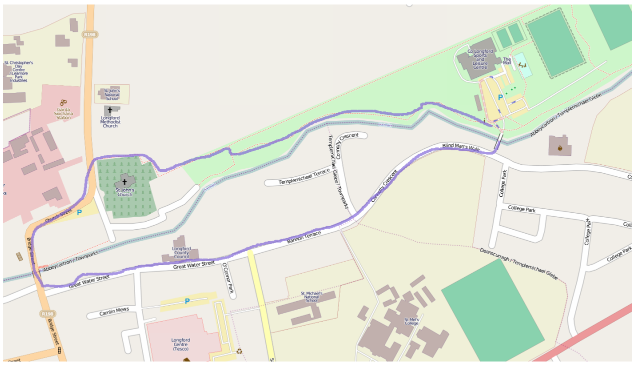
A total of 12 sketch maps and 12 Interactive Route Descriptions were created by the 12 participants. The mean time between the two trials performed by a single participant was 4.9 hours with a standard deviation of 0.7 hours. The lengths of the routes in question ranged from 3 to 12 kilometres with a mean of 9.4 kilometres where distance was measured using the street network representation in the Interactive Route Description base-map. Fig. 4, Fig. 5 and Fig. 6 display three sketch map and Interactive Route Description pairs captured during the evaluation.

In the case of all trials conducted no additional information was communicated verbally which was not explicitly represented in the corresponding sketch map or Interactive Route Description. The mean time required to create a sketch map was 233 seconds with a standard deviation of 52 seconds. On the other hand the mean time required to create an Interactive Route Description was 114 seconds with a standard deviation of 28 seconds. A within-subject analysis of variance (ANOVA) on these times shows that the difference in mean time is statistically significant ($p < 0.01$).

Completing the TLX required each participant to state the *Mental Demand*, *Physical Demand*, *Temporal Demand*, *Effort*, *Perceived Performance* and *Frustration Level* of the task. The mean of the scores for each individual component was calculated to give a Raw TLX (RTLX) which can be interpreted as a measure of overall workload [20,21]. Similar to Goodman et al. [20] we modified the TLX response scale to provide only 6 possible responses.



(a)

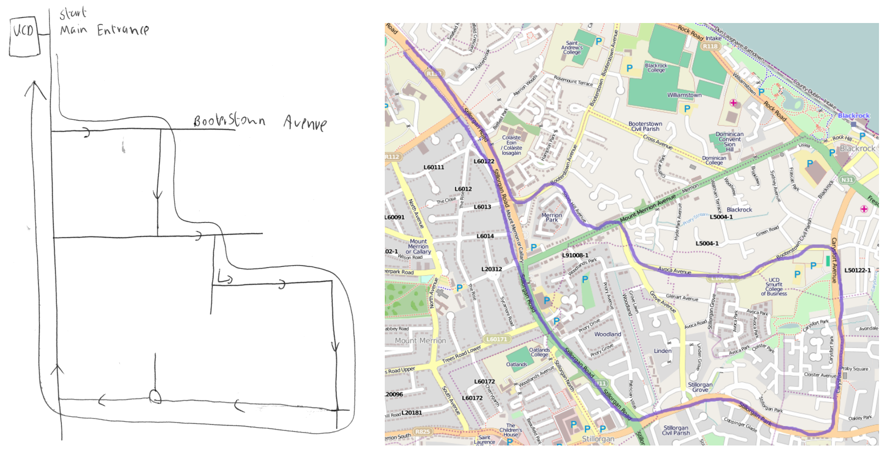


(b)

Fig. 4 The sketch map and corresponding Interactive Route Description are displayed in (a) and (b) receptively. In the Interactive Route Description annotation is represented by the colour purple.

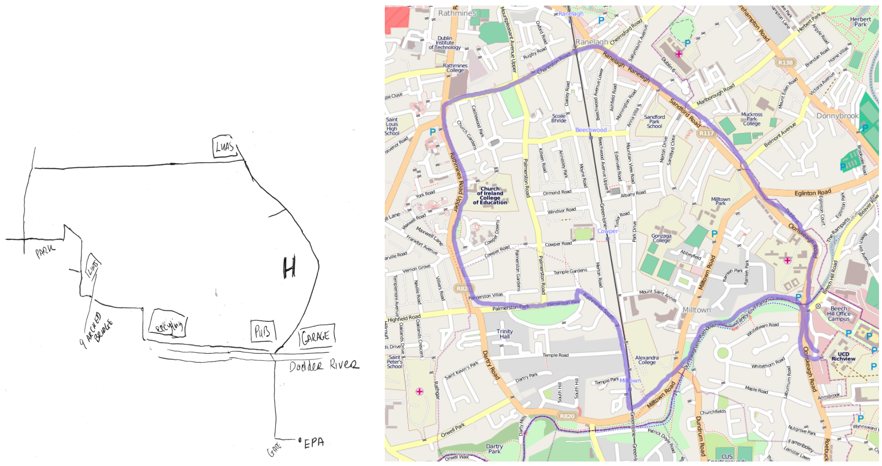
These responses are integers in the range 0 to 5 where higher values indicate higher workload and lower performance. The individual components of the TLX scores corresponding to the sketch maps and Interactive Route Descriptions are displayed in Fig. 7. The Interactive Route Description significantly outperformed the sketch map in terms of all components apart from *Physical Demand*. Within-subject ANOVA on each individual component shows that the differences in mean scores is statistically significant ($p < 0.01$) for all components apart from *Physical Demand*.

Each participants preferred method of providing a route description was measured using a 5-point scale. These results are shown in Fig. 8. All participants *preferred* or *strongly preferred* the Interactive Route Description.



(a) (b)

Fig. 5 The sketch map and corresponding Interactive Route Description are displayed in (a) and (b) receptively. In the Interactive Route Description annotation is represented by the colour purple..



(a) (b)

Fig. 6 The sketch map and corresponding Interactive Route Description are displayed in (a) and (b) receptively. In the Interactive Route Description annotation is represented by the colour purple.

5.3 Discussion

It is evident from examining the sketch maps in Fig. 4(a) and Fig. 5(a) that the type of information contained in the sketch maps varies considerably. Fig. 4(a) contains more landmark information while Fig. 5(a) contains more street infor-

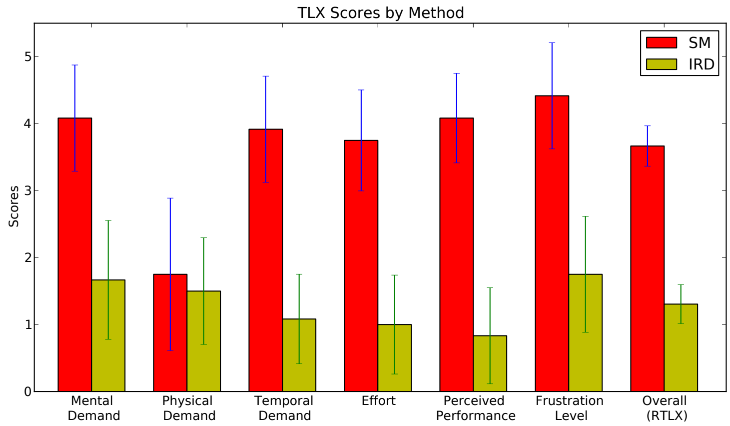


Fig. 7 Mean TLX scores for participants providing sketch maps (SM) and Interactive Route Descriptions (IRD). Higher values indicate higher workload and lower performance. Error bars show standard deviation.

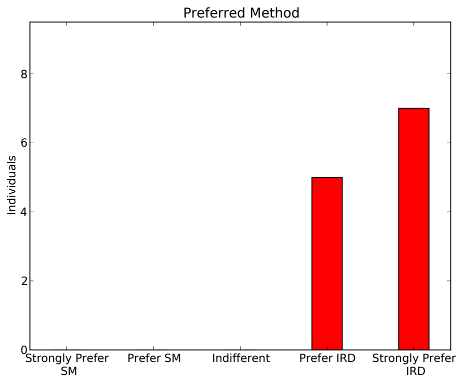


Fig. 8 Participants preferred method, sketch maps (SM) and Interactive Route Descriptions (IRD), for providing a route description.

mation. The use of a base-map breaks the link between environment knowledge and the type of information contained in route description. This is illustrated by the fact that Fig. 4(b) contains both landmark and street information despite the fact that both may not be known beforehand by the individual who created this Interactive Route Description. Seven of the twelve participants drew an undirected line as opposed to the directed line in the Interactive Route Description. However in all cases, due to the fact that the Interactive Route Description was created in the presence of the individual who would later attempt to navigate the route in question, the direction was implicit. Nine participants only annotated a directed/undirected line in the Interactive Route Description and did include additional details such as landmarks.

Most participants stated that a lack of environmental knowledge presented the greatest challenge to creating a suitable sketch map. Three participants stated that they were surprised by their inability to recall sufficient environment information given that they previously felt they were very familiar with the environment. Five participants referenced the ability to overcome a lack of environmental knowledge when justifying their preference for Interactive Route Description over sketch map. Seven participants stated that they found creating the sketch map mentally demanding and frustrating. This fact is reflected in the TLX scores. Four participants made mistakes when creating the sketch map and had to cross out details or start the sketch again. For example the sketch in Fig. 4(a) contains some details which have been crossed out. One participant commented that she would require “about three” attempts to draw the sketch map totally accurately. Despite this comment the participant only made a single attempt. A number of participants stated that the Interactive Route Description allowed them to “plan” their sketch effectively. We believe that the fact that no errors were reported when creating the Interactive Route Description can be attributed to this fact. The creator of the sketch map in Fig. 6(a) stated that they found it difficulty to create a sketch map that was accurate with respect to cardinal directions.

A number of participants stated that the most challenging aspect of creating an Interactive Route Description was locating the correct base-map. Another point which was evident from comparing the set of corresponding sketch maps and Interactive Route Descriptions was that a number depicted slightly different routes. Upon questioning all the corresponding individuals stated that they felt they could not represent the desired route using a sketch map due to a lack of knowledge of the route and therefore represented a less complex route instead. As discussed earlier this strategy of representing a less complex route was shown by Holscher et al. [23] to be common. The ability to represent more complex routes using the Interactive Route Description illustrates the expressive power of the method.

6 Evaluation - Interpreting Route Descriptions

Towards answering the first two research questions in this paper, in this section we consider the perspective of those interpreting route descriptions.

6.1 Evaluation Methodology

The evaluation methodology is based on that of Goodman et al. [20, 21] and Fickas et al. [17] using the same context as before of long-distance runners providing and interpreting running route descriptions.

6.1.1 Participants

The same set of participants described in section 5.1.1 were used in this evaluation.

6.1.2 Experimental Design

The representations used were the 12 pairs of sketch maps and Interactive Route Descriptions, corresponding to 12 unique routes, created during the evaluation described in section 5.1. These representations were distributed among the individuals so that each route was navigated using both representations. As discussed in section 5.1.3 all representations were created in the presence of the individuals attempting to navigate the route in question. A lightweight belt designed for running with a pocket for carrying the sketch maps and Interactive Route Descriptions was provided to each participant.

6.1.3 Experimental Procedure

Each participant was given an initial briefing where the concepts of a sketch map and Interactive Route Description and their usage was explained. They were then asked to navigate two distinct routes, one using the sketch map and the other using the Interactive Route Description. The routes in question were contained in regions for which the participants had little prior knowledge and in turn poor spatial knowledge. The order of the two navigation tasks performed by each individual was random. The participants were informed that the navigation tasks in question would not be timed and that no risks should be taken when crossing streets. During each navigation task one of the researchers in the study ran with the participant in order to make observations on navigation behaviour as well as providing help when participants become lost. The researcher ran a few meters behind the participant to avoid influencing navigation. In all cases the researcher was an experienced runner and therefore maintaining close proximity to the participant did not present a challenge.

The number of times a participant became lost during each navigation task was noted by the researcher. A participant was defined as lost if the researcher had to intervene and provide navigation assistance. This occurred when the participant travelled roughly 25 or more meters in an incorrect direction or the participant asked for navigation assistance. After completing each navigation task participants filled in the NASA TLX and were given the opportunity to provide feedback and comment on their experience. Task completion time is a measure commonly used to indicate the effectiveness of a navigation aid [20, 21]. However given the variability in running speed ability of our participants and researchers it was an unsuitable measure in this study. After completing both navigation tasks each participant was asked to indicate whether they preferred the sketch map or Interactive Route Description. They were subsequently asked to comment on their choice.

6.2 Results

As a result of this study 12 routes were navigated using a sketch map and 12 routes were navigated using an Interactive Route Description. The mean number of times a participant became lost using a sketch map was 4.08 with a standard deviation of 1.72. Only a single participant using a sketch map managed to navigate successfully without becoming lost at some stage. On the other hand the mean number of times a participant became lost using an Interactive Route Description was 0.43 with a standard deviation of 0.67. Eight participants using a Interactive Route Description managed to navigate successfully without becoming lost at some stage. A within-subject analysis of variance (ANOVA) shows that the difference in the mean number of times participants became lost is statistically significant ($p < 0.01$).

The individual components of the TLX scores corresponding to the sketch maps and Interactive Route Descriptions are displayed in Fig. 9. The Interactive Route Description significantly outperformed the sketch map in terms of all components apart from *Physical Demand*. Within-subject ANOVA on each individual component shows that the differences in mean scores is statistically significant ($p < 0.01$) for all components apart from *Physical Demand*.

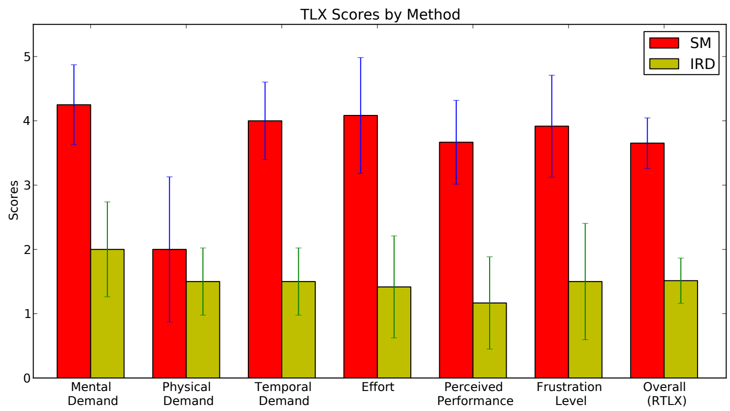


Fig. 9 Mean TLX scores for participants interpreting sketch maps (SM) and Interactive Route Descriptions (IRD). Higher values indicate higher workload and lower performance. Error bars show standard deviation.

Each participants preferred method for interpreting a route description was measured using a 5-point scale. These results are shown in Fig. 10. All participants *preferred* or *strongly preferred* the Interactive Route Description.

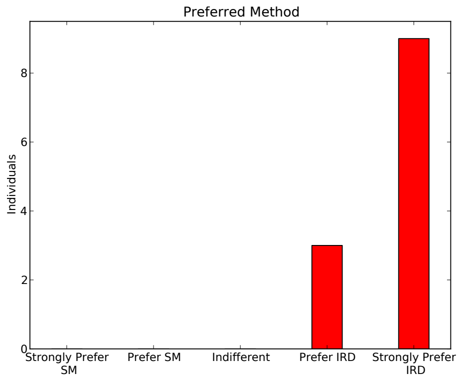


Fig. 10 Participants preferred method, sketch maps (SM) and Interactive Route Descriptions (IRD), for interpreting a route description.

6.3 Discussion

Most participant stated that they found interpreting the sketch map to be more mentally demanding and frustrating than interpreting the Interactive Route Description. Two participants stated that they found the symbology contained in the sketch map to be confusing. For example the sketch map in Fig. 5(a) contains additional arrows representing directions which a participant found difficult to distinguish from the street network. These facts are reflected in the TLX scores and the number of times participant became lost.

Participants stated that they drew significant information from the Interactive Route Description base-map and that this was necessary for successful navigation. Four individuals stated that this information included street names. Four individuals stated that it included distance and street angles. While two individual stated that it included the street class. Runners are very distance orientated and consequently a number of participants stated that the ability to draw distance information from the base-map was particularly important to them. A number of participants commented that they drew additional information from the base-map on a number of occasions in order to reassure themselves that they were correctly navigating the route in question.

Let us consider the first research question this paper poses. That is, if an individual has travelled a route in an urban area recently and has much previous experience of that area, will they generally have sufficient spatial knowledge to provide a corresponding adequate route description? The analysis presented in this section and section 5 demonstrates that participants in our study experienced great difficulty providing and interpreting route descriptions using sketch maps. This difficulty appears to be a consequence of a lack of spatial knowledge on the part of the individual creating the sketch map. This is despite the fact that in all cases the individual had travelled the route in question recently and this route was contained in an area which they do much of their training. This implies the answer to the above question is no.

Next let us consider the second research question this paper poses. That is, does the Interactive Route Description reduce the above difficulty associated with providing and interpreting route descriptions? The analysis presented in this section and section 5 demonstrates that participants experienced little or no difficulty providing and interpreting route descriptions using the Interactive Route Descriptions. This implies the answer to the above question is yes. In the following section we attempt to answer the final research question posed in this paper.

7 Conversion of Interactive Route Description

Using map matching an Interactive Route Description may be automatically parsed and this offers many potential applications. In this section we illustrate this point by proposing an algorithm which automatically converts an Interactive Route Description to a corresponding linguistic representation.

As discussed in section 2 the most suitable representation for a given route description is context dependent. Consequently the ability to convert between representations offers many potential applications. For example a motorist may wish to convert a sketch representation to a verbal linguistic representation. Many authors have developed algorithms for converting between representations. Skubic et al. [45] proposed a method for converting a sketch representation to a linguistic representation. Kopf et al. [30] proposed a method for converting a map representation to a sketch representation. However the automatic conversion of many representations, such converting a sketch to a linguistic representation, is extremely challenging [7,8]. In this section we demonstrate that in the context of converting an Interactive Route Description to an alternative representation this challenge is simplified through the application of existing map matching techniques. Map matching is a process by which an inaccurate route, typically a GPS trace, is registered with a street network [55]. Due to the fact that an Interactive Route Description is created by annotating a base-map containing a road network, the annotation in question may be registered to this road network through map matching. To demonstrate this we implemented a popular map matching technique know as the weak Fréchet distance [6].

Consider Fig. 11(a) which displays an Interactive Route Description and Fig. 11(b) which displays the result of applying the weak Fréchet distance to the annotation. Visual inspection verifies this to be an accurate registration to the street network. We evaluated the weak Fréchet distance using all Interactive Route Descriptions generated in the analysis of section 5. In all cases an accurate registration was achieved. Registering a route to a street network can simplify the problem of converting to an alternative representation. To demonstrate this we propose a simple algorithm which converts a route registered to a street network to a set of turn-by-turn instructions; specifically, the set of turn-by-turn instructions generated are *path relations* [31].

This algorithm first converts the street network to a graph representation where vertices are the street intersections and the extremes of dead end streets, and the edges the street fragments connecting these vertices. Details regarding how to convert an OSM street network to a graph representation can be found in [10,11]. For each edge in the graph we assign attributes which contain the name and length (in meters) of the street it represents. Two additional vertices are added to the graph to represent the start and end points of the route specified by the Interactive Route Description. Subsequently the route specified by the Interactive Route Description corresponds to a path in the graph and turn-by-turn instructions are generated by describing this path. Let $\{e_1, e_2, \ldots, e_n\}$ be the sequence of edges corresponding to such a path. Algorithm 1 presents pseudocode for converting this path to a sequence of turn-by-turn instructions. In this algorithm $e_i.name$ and $e_{i+1}.length$ correspond to the name and length (in meters) respectively of the street represented by the edge e_i. The function leftRight on line 7 examines the angle between two consecutive edges and returns "left" or "right" to indicate the direction of the turn in question.

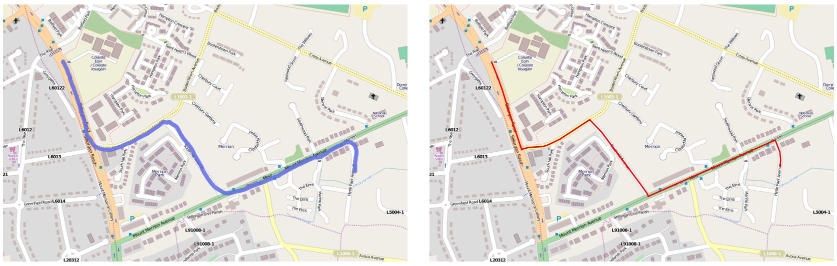
Algorithm 1 Algorithm for converting the graph path $\{e_1, e_2, \ldots, e_n\}$ to turn-by-turn instructions.

```
 1: d = 0
 2: for i = 1 → (n − 1) do
 3:     if e_i.name == e_{i+1}.name then
 4:         d = d + e_{i+1}.length
 5:     else
 6:         print "Continue along " + e_i.name + " for " + d + " meters and then turn "
 7:                 + leftRight(e_i, e_{i+1}) + " onto " + e_{i+1}.name
 8:         d = e_{i+1}.length
 9:     end if
10: end for
11: print "Continue along " + e_n.name + " for " e_n.length + " meters"
```

The result of applying Algorithm 1 to the Interactive Route Description of Fig. 11(a) is as follows:

1. *Continue along Stillorgan Road for 350 Meters and then turn left onto Booterstown Avenue.*
2. *Continue along Booterstown Avenue for 250 Meters and then turn right onto South Hill Avenue.*
3. *Continue along South Hill Avenue for 300 Meters and then turn left onto Mount Merrion Avenue.*
4. *Continue along Mount Merrion Avenue for 300 Meters and then turn right onto Hyde Park Avenue.*
5. *Continue along Hyde Park Avenue for 75 Meters.*

It is evident from the above results that the Interactive Route Description facilitates the transformation to other representations of the description such as turn-by-turn instructions. However, these turn-by-turn instructions are not optimal in the sense that they do not contain any landmark information or specify the number of turns prior to a given turn. As discussed in section 2, such additional information would reduce the difficulty of interpreting the route description.



(a) (b)

Fig. 11 An Interactive Route Description and the corresponding result of applying map matching are displayed in (a) and (b) respectively. The routes resulting from annotating and map-matching are represented by the colours purple and red respectively.

8 Conclusions

Klippel et al. [28] state that “We are living in times where spatial information is available in a much wider array of formats, currency, and fidelity. Hence, it is time to rethink how to provide spatial information for orientation and wayfinding from the perspective of creating spatial awareness”. In this paper we have shown that, even if an individual has travelled a route in an urban area recently and has much previous experience of that area, they may not have sufficient spatial knowledge to provide a corresponding adequate route description. This supports the thinking of Klippel et al. that current approaches for providing spatial information for navigation are not optimal and that new approaches which exploit the high availability of spatial information need to be considered. Towards achieving this goal we have shown that the difficulty associated with providing and interpreting route descriptions can be reduced by performing both tasks interactively with a map. In this paper we have also demonstrated that such interaction facilitates the automatic parsing of route descriptions and this in turn offers many potential applications such as the transformation to other representations. The authors hope that the research presented in this paper encourages others to work towards achieving the above goal set out by Klippel et al.

All analysis in this paper took place in a specific context. As such, one must be careful not to generalise the corresponding results. As discussed in section 5.1.1 all participants in our study were computer literate and had experience of web mapping technologies. Due to the fact that using an Interactive Route Description requires such skills, this most likely positively effected their ability to exploit the benefits of this approach. Without such skills, the authors suspect, this ability would have been reduced. However we qualify this statement with the fact that there exists a high degree of computer literacy in developed countries and the ability to use web mapping has become a fundamental element of such literacy. All the analysis in this study was performed in complex urban environments. For less complex environments, such as the countryside, it is easier for one to build an accurate cognitive map and in turn provide adequate route descriptions (see section 1). Furthermore all routes considered were reasonably long with a mean length of 9.4 kilometres. Clearly providing and interpreting adequate route descriptions for shorter routes of lesser complexity requires a lesser degree of spatial knowledge. Consequently, when providing and interpreting route descriptions for such routes it is more likely that a sketch map and an Interactive Route Description would be equally effective. It must also be noted that the geographical regions within which this study was performed have corresponding freely available spatial data of high quality. However the quality of such data generally exhibits spatial heterogeneity [38]. In the presence of poor quality spatial data, the Interactive Route Description would be ineffective.

The proposed Interactive Route Description offers many exciting opportunities of further research. These include the potential for applying map generalisation techniques to the map once the route in question has been determined through map matching [1]. This would allow the reduction of information irrelevant to the individual attempting to navigate such as streets not travelled [36]. On the other hand it would also allow the enhancement of relevant route information such as street names. Another possibility for future research would be the introduction of route consistency checks. This would include checks such as ensuring the route does not travel the incorrect direction along a one-way street. In this paper all Interactive Route Descriptions were created using base-maps taken from Openstreetmap. Evaluating the impact of different base-maps represents another possible research direction. Although an algorithm for converting an Interactive Route Description to a set of turn-by-turn instructions was presented, as discussed in section 7, these instruction are not optimal. In future work we hope to improve this algorithm by including landmark information in the turn-by-turn instructions. This presents a significant challenge due to the fact that, as discussed in section 2, some environments will lack suitable landmarks.

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