Augmented Maps with Route Sketches

Padraig Corcoran, Peter Mooney, Michela Bertolotto and Basel Magableh

Abstract This article proposes a novel representation for route descriptions called an Augmented Route Sketch Map (ARSM). In this representation a route is composed of a sketch map drawn over a detailed base-map. The base-map has the effect of augmenting ones knowledge and in turn reduces the complexity of accurately representing and interpreting a route. This is demonstrated through a set of user trials. The proposed ARSM representation also facilitates the automatic parsing of route descriptions and in turn the transformation to other representations such as a turn-by-turn instructions.

Keywords Route description · Sketch map

1 Introduction

Providing a route description to an individual with limited or no knowledge of the area in question is an activity most perform regularly in many different contexts. The oldest and most common of these is providing a route description which will take an individual to a desired destination. However, with the advent of social media this activity has gained significant popularity in many other contexts. For example, sites such as mapmyrun.com offer the facility for its members to share running routes. Route descriptions may contain many forms of information. Turn-by-turn

P. Corcoran (✉) · M. Bertolotto · B. Magableh
School of Computer Science and Informatics, University College Dublin, Dublin, Ireland
e-mail: padraig.corcoran@ucd.ie

P. Mooney
Department of Computer Science, National University of Ireland Maynooth, Maynooth, Ireland

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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". It is generally accepted that, although effective, such instructions do not coincide with the way humans intuitively describe routes (Ziegler et al. 2011). This is attributed to the fact that human route descriptions commonly contain landmark information where landmarks are defined as cognitively salient, prominent features in the environment (Duckham et al. 2010). 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 some environments, such as suburbs, landmarks may not be available or difficult to extract automatically (Westphal and Renz 2011). Destination descriptions do not provide information relating to the route explicitly but instead describe the route destination. They correspond to instructions such as "opposite the Stillorgan shopping centre". Destination descriptions have the potential to be of a shorter length than route descriptions based on 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.

There exists many means of representing a route description. These include text, linguistic, map, sketch, tactile and augmented-reality based representations (Rehrl et al. 2010). The most suitable representation used is in some cases context dependent. For example in the context of motorist navigation a linguistic representation is suitable because it does not distract the user's visual attention from the road. In this article we focus on sketch based representations of route descriptions. The most common form of sketch based representation is known as a Route Sketch Map (RSM) and involves drawing a sketch on a blank white background. We propose a novel type of sketch based representation, entitled an Augmented Route Sketch Map (ARSM), which overcomes a number of limitations associated with existing approaches to generating route descriptions. This approach is based on a fundamental concept of constraining a sketch by drawing it over a detailed base-map and in turn augmenting the knowledge of both the individuals who create and use it.

The layout of this article is as follows. In Sect. 2 we review existing sketch based representations of route descriptions. Section 3 describes the proposed ARSM representation. In Sect. 4 we present an evaluation of this approach through user trials. Section 5 describes results which demonstrate that the use of ARSMs reduces the complexity of transforming a route description to other representations. Finally in Sect. 6 we draw conclusion and present some possible future research directions.

2 Route Sketch Maps

A seminal study by Tversky and Lee (1999) of 29 RSMs demonstrated that each contained the information necessary to complete the navigation task in question. It was also found that linguistic and sketch representations exhibited the same

underlying structure and semantics and therefore a conversion between representation should be possible. Skubic et al. (2004) subsequently proposed a method for converting a sketch representation to a linguistic representation. Kopf et al. (2010) proposed a method for converting a map based representation to a sketch based representation. Igarashi et al. (1998) and Hagedorn and Dollner (2008) proposed methods for sketching paths in a virtual 3D environments. Sketch based representations of route descriptions have also been used many times in the context of robot navigation (Chronis and Skubic 2003; Shah et al. 2012).

The popularity of RSMs can be attributed to a number of factors. Tversky (2002) demonstrated that, when compared to a linguistic representation, sketch based representations generally contain a greater amount of the spatial information necessary to perform the navigation task at hand. Sketches are an external representation which complements human memory (Tversky 2002) . Therefore, unlike linguistic representations (Tom and Tversky 2012), they do not need to be remember. Sketches also complement information processing (Tversky 2002). They facilitate the user to perform processes such as spatial chunking which can be defined as the grouping of navigation instructions (Klippel et al. 2003).

Despite their popularity RSMs exhibit a number of limitations which we will now discuss. Generating an accurate RSM requires accurate knowledge of each part of the route in question where this knowledge can be represented in a number of different ways. Consider the map in Fig. 1a, which is an accurate representation of an urban area, where an individual wishes to draw a RSM representing the route from the green circle to the red circle along the blue dashed line. The most difficult and important part of the route to represent accurately in a RSM is the right turn. Next consider the corresponding RSM in Fig 1b where the start and end of the route are represented using the symbols *S* and *E* respectively. In this sketch the right turn is represented correctly in terms of the number of prior right turns (4 in this case). Therefore this sketch map contains accurate knowledge of the right turn in question represented in terms of the number of prior right turns. An alternative means of representing the right turn accurately, if the number of prior right turns is unknown, is in terms of distance along the road. Such a RSM would contain accurate knowledge of the right turn in question represented in terms of distance from a location. Accurate knowledge of the turn could also be represented accurately in terms of a landmark at the turn or the name of the street which is turned onto. It is evident from this discussion that representing the right turn correctly requires accurate knowledge of that part of the route. An individual with less than accurate knowledge would not know the correct number of prior right turns or distance along the road. They may also not know the name of individual street or know of a landmark at the turn if one actually exists. In the study of Tversky and Lee (1999) the authors asked individuals who "answered affirmatively" that they knew the route to a particular restaurant to draw a corresponding RSM. This suggests that all RSMs in the study were drawn by individuals who had accurate knowledge of the route in question.

Fig. 1 A route shown on OpenStreetMap is displayed in (**a**). A corresponding route sketch map is displayed in (**b**). Map data (c) OpenStreetMap contributors, CC-BY-SA

Other limitations of RSMs are that they are time consuming to draw and their quality is affected by individual drawing ability (Bell and Archibald 2011). Also the individual for which the route sketch map is intended may have prior knowledge of some parts of the route in question. In such a situation an optimal RSM will contain low levels of detail in areas for which users have prior knowledge and high levels of detail elsewhere (Ziegler et al. 2011; Richter et al. 2008). Finally in some situations it may be necessary to parse and convert the RSM to an alternative representation such as a linguistic description for use in car navigation. However the automatic parsing of an RMS is extremely challenging (Broelemann 2011; Chipofya et al. 2011).

To mitigate the above limitations the following strategies are generally employed. In most cases RSMs are only drawn for routes of short distance. For example in the study of Tversky and Lee (1999) the RSMs corresponded to a route from a university to a local restaurant for which the corresponding route was short and contained only three turns. Another strategy commonly used is to draw a RSM corresponding to a route which is not necessarily the best route, for example in terms of distance, but can be accurately represented by a sketch map due to its low complexity (Haque et al. 2007; Westphal and Renz 2011).

In the following section we propose a novel sketch based representation of route descriptions which is based on a fundamental concept of constraining a sketch by drawing it over a detailed base-map. de Silva and Aizawa (2010) proposed a method for drawing a route on a map although the purpose of this method was to retrieve a video along the path and not to specify a route description. Many web based routing services such as Google Maps and OpenRouteService provide a method for generating a route drawn over a map. However, these methods do not allow the user to draw the route and they may only specify the route to a limited degree through adding way-points.

3 Augmented Route Sketch Maps

To overcome a number of limitations associated with existing approaches to generating route descriptions we propose a novel type of sketch based representation entitled an Augmented Route Sketch Map (ARSM). An ARSM is created using the following steps which are performed by the individual whose task is to provide the route description. Firstly given a map of large geographical scale the individual selects the region in this map containing the route in question. We refer to the selected map region as the base-map. This map should contain a detailed road network along with addition information such as street names and local features. For example consider again the example from Sect. 1 where the goal is to represent the route from green to red circles along the blue dashed line represented in Fig. 1a. In this situation one would select a base-map such as that displayed in Fig. 2a. Given a suitable base-map the individual creates a corresponding sketch map, which is drawn over the base-map, as follows. The individual sketches a directed line or arrow over the base-map along the route path. For example in the context of specifying the route in Fig. 1a the individual would sketch a directed line over the base-map in Fig. 2a similar to that represented by the blue directed line in Fig. 2b. The user may also annotate the route in any way they please. For example in Fig. 2b 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 add it to the sketch map. Together the base-map and sketch map constitute the ARSM. The sketch map is drawn with a high degree of transparency to ensure it does not occlude important information in the base-map.

The proposed approach to the creation of sketch based representation offers many advantages over the traditional RSM. We now describe these in some detail.

Fig. 2 The selected base-map and corresponding sketch map are displayed in (**a**) and (**b**) receptively. Map data (c) OpenStreetMap contributors, CC-BY-SA

The proposed approach generally does not require the individual providing the route description to have accurate knowledge of every part of the route in question. If accurate knowledge regarding a particular part of the route is unknown it may possibly be inferred 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 to augment their less than complete route knowledge. Consider again the example in Fig. 2 where an individual wishes to accurately represent a right turn. If the correct number of right turns prior to the turn in question is unknown this information may be inferred in a number of ways. For example if the individual knows that the following part of the proposed route passes by the area known as *Devlin Park* (represented by a green polygon in Fig. 2a) 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 attempting to navigate with an ARSM the ability to augment the information contained in the sketch map where necessary. This in turn offers a number of benefits. Consider the situation where an individual is attempting to navigate using the ARSM in Fig. 2b. If they have taken a right turn but are unsure if it 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 ARSM may not have explicitly represented this feature in the sketch map. 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 (Richter et al. 2008; Ziegler et al. 2011). 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 (Eccles et al. 2002). Orienteering maps differ from ARSMs due to the fact that they only specify *controls* and not a route between them.

Another advantage offered by ARSMs over traditional sketch based representations is that they facilitate the transformation to other route description representations. This is achieved through performing matching between the proposed route in the sketch map and the street network in the base-map. This fact will be demonstrated in Sect. 5.

4 Evaluation

In this section we present an evaluation of the proposed ARSM representation relative to the traditional RSM representation. As discussed in the introduction to this paper the use of route descriptions can occur in many contexts. In this section

we evaluate the ARSM in the context of long distance runners providing and interpreting running route descriptions. Currently the most popular medium for runners to share routes is GPS traces using sites such as mapmyrun.com. A long distance runner can run anything between 10 and 30 km on a daily basis for training purposes. This offers the opportunity to evaluate the use of ARSMs for routes of such lengths. The evaluation consisted of a series of user trials where each trail contained two parts. The aim of the first and second parts of the trials were to evaluate the effectiveness of an ARSM as a medium for creating and interpreting a route description respectively.

In the first part of each trial an individual with knowledge of the area in question was asked to create a RSM of a route which they ran recently. Once completed the concept of an ARSM and their construction was explained to the individual. They were subsequently asked to create an ARSM corresponding to the route previously represented. In the second part of each trial the RSM and ARSM were used by two separate individuals with little knowledge of the area in an attempt to navigate the route in question. As is standard practice both forms of route maps were created in the presence of these individuals. This allowed the individual creating the route sketch map to explain the reasoning behind their actions.

To facilitate the above evaluation we created a software implementation for capturing an ARSM. When creating an ARSM the individual first pans and zooms the base-map in order to locate the region containing the route they wish to represent. Next they create the sketch map by sketching over the base-map. All results were printed on A4 white sheets of paper. These sheets were then used by the individuals who wished to navigate the route in question. The city of Dublin was used as the study area and the data used was taken from OpenStreetMap. The OpenStreetMap data for Dublin city is generally regarded as being of a high quality and rich in detail. RSMs were captured by sketching on an A4 white sheet of paper using a black pen.

In total seven trials were performed. All participants in the user trials were experienced male runners recruited from a local athletics club who regularly compete in long distance races including the marathon. All based maps used in the trials were taken from OpenStreetMap (www.openstreetmap.org). In the following two subsections we present results and analysis corresponding to both parts of the trials.

4.1 Route Representation

Examining the corresponding pairs of RSM and ARSM route descriptions demonstrated a number of advantages offered by the ARSM which we will now discuss in turn. In all cases the time required to create a RSM was significantly greater than that required to create the corresponding ARSM. For example consider Figs. 3 and 4 which display a RSM and ARSM pair corresponding to an individual trail. The total length of the route represented in Fig. 4 is 10.1 km. The time

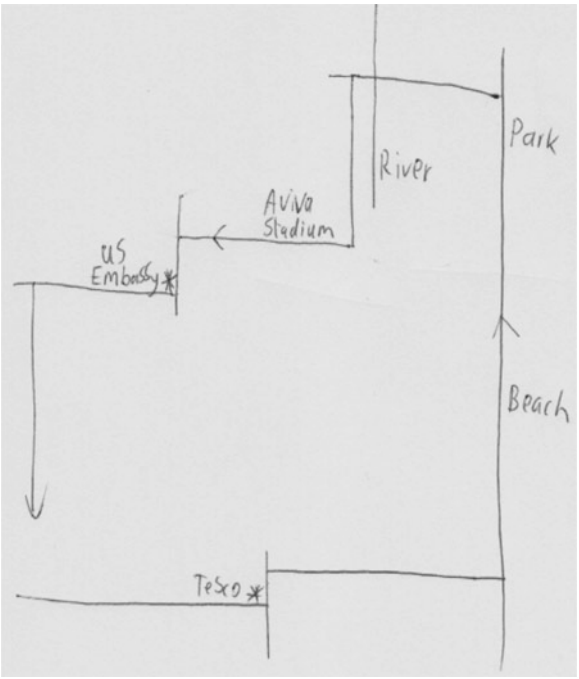

Fig. 3 The RSM for an individual user trial

required to create these route maps was 165 and 55 s respectively. Over all trials the average time required to create a RSM and ARSM was 162 and 70 s respectively. This saving in time offered by the ARSM can be attributed to a number of factors. Firstly in all cases creating the ARSM required a lesser amount of detail to be drawn. This included simply underlining or circling a feature in the base-map in order to represent a landmark in the ARSM. For example in top centre of Fig. 4 the text "Aviva Stadium" in the base-map is circled to indicate a landmark. While in the corresponding RSM the name of the landmark is written in full. This feature was exhibited in all trials. In some situations a landmark which required representation in the ARSM was not represented in the base-map. In all such cases the individual annotated the ARSM in order to include this information. For example in the left centre of Fig. 3 the ARSM is annotated to include a landmark corresponding to the Embassy of the United States. A number of individuals in the trials commented that creating the ARSM did not require them to attempt to recollect as much information regarding the route. This point is a direct consequence of the base-map augmenting the individuals knowledge.

Examining the set of RSMs generated indicated that in 5 of the 7 trials they were not sufficient. That is, each map contained some ambiguity with respect to the route in question. For example consider the top right of the RSM in Fig. 3 which contains a left turn. By examining the corresponding base-map in Fig. 4 we can see that there are a number of left turns in this area. Despite this fact the individual who created the map did not use a street name, landmark or any other strategy to distinguish the

Fig. 4 The ARSM for an individual user trial. Map data (c) OpenStreetMap contributors, CC-BY-SA

correct turn from others. By their nature of being drawn on an accurate base-map, the ARSMs did not contain any such ambiguities. The above point regarding the issue of route ambiguity will be discussed further in the next section.

Another point which was evident from comparing the set of corresponding RSM and ARSM representations was that a number depicted slightly different routes. For example consider again the RSM and ARSM of Figs. 3 and 4 respectively. The RSM contains only a single left turn after the Embassy of the United States landmark. On the hand the ARSM contains a number of left and right turns after this landmark. This property of representing a less complex route in the RSM was exhibited in 2 of the 7 trials. Upon questioning all the

corresponding individuals stated that they felt they could not represent the desired route using a RSM due to a lack of knowledge of the route and therefore represented a less complex route instead.

4.2 Route Interpretation

In 2 of the 7 trials performed using a RSM the individuals stated that they became lost and were forced to retract their path to the beginning. In a further 2 of these trials the individuals stated that they became lost for a short period but later rejoined the specified route. For example one individual became lost at the location corresponding to the top right of the RSM in Fig. 3 due to ambiguity regarding the correct left turn. However, this individual later rejoined the specified route at the Aviva stadium landmark.

In all trials performed using an ARSM the individuals stated that they followed the specified route correctly without becoming lost. They also stated that they drew significant information from the base-map and that this was necessary in order for them to follow the route correctly. Four individuals stated that this information included street names. Four individuals stated that it include distance and street angles. While two individual stated that it included the street class.

Tversky and Lee (1999) demonstrated a RSM to be effective when the route in question is of a short distance and the individual creating the map has intimate knowledge of it. However, it is evident from the results presented in this section and the previous that if both these criteria are not met the RSM representation is not effective. However, these results demonstrate that the ARSM representation overcomes these limitations.

5 Representation Conversion

As discussed in Sect. 2 the ability to convert between different representations of the same route description has many applications. However, the automatic converting of many representations, such as a RSM, is extremely challenging (Broelemann 2011; Chipofya et al. 2011). In this section we demonstrate that in the context of converting an ARSM to an alternative representation this challenge can be 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 (White et al. 2000). Due to the fact that an ARSM is created by drawing over a base-map containing a road network, the route in question may be registered to this road network by applying map matching. To demonstrate this we implemented a popular map matching technique know as the *weak Fréchet distance* (Brakatsoulas et al. 2005). Figure 5 displayed the result of applying this method to the route specified by the ARSM of Fig. 4. Visual

Fig. 5 The red line represents the result of applying map matching to the route in Fig. 4. Map data (c) OpenStreetMap contributors, CC-BY-SA

inspection verifies that this is an accurate registration to the street network. We evaluated the *weak Fréchet distance* using all ARSM routes generated in the user trials of Sect. 4. In all cases an accurate registration was achieved. In some cases is straight forward to convert a route which is registered to a street network to different a representation. This is the case when converting to a set of turn-by-turn instructions (Lou et al. 2009). In fact this type of conversion is performed by most commercial automotive navigation systems. This demonstrates that by being drawn over a base-map the proposed ARSM facilitates the transformation to other representations.

6 Conclusions

Sketch based representations are a popular medium for route descriptions. The seminal work of Tversky and Lee (1999) demonstrated traditional sketch representations drawn on a blank sheet of paper to be effective when the route in question is of a short distance and the individual creating the map has intimate knowledge of it. In this article we demonstrated that when these criteria are not met this representation is no longer effective. We have presented a new sketch based representation for route descriptions known as an *Augmented Route Sketch Map* (ARSM). A series of user trials were performed in order to evaluate this representation. They demonstrate that the use of a base-map in the ARSM augments ones knowledge and simplifies the tasks of route representation and interpretation. This facilitates the generation of suitable route descriptions even when the criteria above are not met.

In future work we plan to present a more in-depth and detailed evaluation of the proposed ARSM methodology. Due to the fact that an ARSM is a novel form of route representation it offers many other exciting opportunities of further research. These include the potential of applying map generalisation techniques to the map once the route in question has been determined through map matching (Agrawala and Stolte 2000). This would allow the reduction of information irrelevant to the individual attempting to navigate such as streets not travelled. 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 ARSM have been created using base maps taken from OpenStreetMap. Evaluating the impact of different base maps represents another possible research direction.

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References

Agrawala M, Stolte C (2000) A design and implementation for effective computer-generated route maps. In: AAAI symposium on smart graphics, Stanford University, CA, pp 61–65

Brakatsoulas S, Pfoser D, Salas R, Wenk C (2005) On map-matching vehicle tracking data. In: Proceedings of the 31st international conference on very large data bases, VLDB'05, VLDB Endowment, pp 853–864

Broelemann K (2011) A system for automatic localization and recognition of sketch map objects. In: Understanding and processing sketch maps, proceedings of the Cosit workshop, pp 11–20

Chipofya M, Wang J, Schwering A (2011) Towards cognitively plausible spatial representations for sketch map alignment. In: Egenhofer M, Giudice N, Moratz R, Worboys M (eds) Spatial information theory. Lecture notes in computer science, vol 6899. Springer, Heidelberg, pp 20–39

Chronis G, Skubic M (2003) Sketch-based navigation for mobile robots. In: Fuzzy systems, 2003. FUZZ'03. The 12th IEEE international conference on, vol 1. pp 284–289

De Silva GC, Aizawa K (2010) Interacting with location-based multimedia using sketches. In: Proceedings of the ACM international conference on image and video retrieval, NY, pp 189–196

Duckham M, Winter S, Robinson M (2010) Including landmarks in routing instructions. J Location Based Serv 4(1):28–52

Eccles DW, Walsh SE, Ingledew DK (2002) The use of heuristics during route planning by expert and novice orienteers. J Sports Sci 20(4):327–337

Hagedorn B, Dollner J (2008) Sketch-based navigation in 3D virtual environments. In: Butz A, Fisher B, Kruger A, Olivier P, Christie M (eds) Smart Graphics. Lecture Notes in Computer Science, vol 5166. Springer, Heidelberg, pp 239–246

Haque S, Kulik L, Klippel A (2007) Algorithms for reliable navigation and wayfinding. In: Barkowsky T, Knauff M, Ligozat G, Montello D (eds) Spatial cognition V reasoning, action, interaction, Lecture notes in computer science, vol 4387. Springer, Heidelberg, pp 308–326

Igarashi T, Kadobayashi R, Mase K, Tanaka H (1998) Path drawing for 3D walkthrough. In: Proceedings of the 11th annual ACM symposium on user interface software and technology, NY, pp 173–174

Klippel A, Tappe H, Habel C (2003) Pictorial representations of routes: chunking route segments during comprehension. In: Freksa C, Brauer W, Habel C, Wender K (eds) Spatial cognition III, Lecture notes in computer science, vol 2685. Springer, Heidelberg, p 1034

Kopf J, Agrawala M, Bargeron D, Salesin D, Cohen M (2010) Automatic generation of destination maps. ACM Trans Graph 29(6:158):1–158:12

Lou Y, Zhang C, Zheng Y, Xie Y, Wang W, Huang Y (2009) Map-matching for low-sampling-rate gps trajectories. In: Proceedings of the 17th ACM SIGSPATIAL international conference on advances in geographic information systems, GIS'09, NY, pp 352–361

Rehrl K, Hausler E, Leitinger S (2010) Comparing the effectiveness of GPS-enhanced voice guidance for pedestrians with metric—and landmark-based instruction sets. In: Fabrikant S, Reichenbacher T, van Kreveld M, Schlieder C (eds) Geographic information science, Springer, Heidelberg, vol 6292. pp 189–203

Richter KF, Tomko M, Winter S (2008) A dialog-driven process of generating route directions. Comput Environ Urban Syst 32(3):233–245

Bell S and Archibald J (2011) Sketch mapping and geographic knowledge: what role for drawing ability? In: J Wang, K Broelemann, M Chipofya, A Schwering, Wallgrn JO (eds) An interdisciplinary approach to understanding and processing sketch maps, pp 5–14

Shah D, Schneider J, Campbell M (2012) A sketch interface for robust and natural robot control. Proc IEEE 100(3):604–622

Skubic M, Blisard S, Bailey C, Adams J, Matsakis P (2004) Qualitative analysis of sketched route maps: translating a sketch into linguistic descriptions. IEEE Trans Syst Man Cybern B Cybern 34(2):1275–1282

Tom AC, Tversky B (2012) Remembering routes: streets and landmarks. Appl Cogn Psychol 26(2):182–193

Tversky B (2002) What do Sketches say about Thinking? In: Stahovic T, Landay J, Davis R (eds) Proceedings of AAAI spring symposium on sketch understanding, AMI press, CA

Tversky B, Lee P (1999) Pictorial and verbal tools for conveying routes. In: Freksa C, Mark D (eds) Spatial information theory. Cognitive and computational foundations of geographic information science, Lecture notes in computer science, vol 1661. Springer, Heidelberg, p 752

Westphal M, Renz J (2011) Evaluating and minimizing ambiguities in qualitative route instructions. In: Proceedings of the 19th ACM SIGSPATIAL international conference on advances in geographic information systems, NY, pp 171–180

White C, Bernstein D, Kornhauser A (2000) Some map matching algorithms for personal navigation assistants. Transp Res Part C Emerg Technol 8(1–6):91–108

Ziegler J, Hussein T, Munter D, Hofmann J, Linder T (2011) Generating route instructions with varying levels of detail. In: International conference on automotive user interfaces and interactive vehicular applications, Salzburg, Austria