Presenting Route Instructions on Mobile Devices

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ABSTRACT
In this paper, we evaluate several means of presenting route instructions to a mobile user. Starting from an abstract language-independent description of a route segment, we show how to generate various presentations for a mobile device ranging from spoken instructions to 3D visualizations. We then examine the relationship between the quality of positional information, available resources and the different types of presentations. The paper concludes with guidelines that help to determine, which presentation to choose for a given situation.

Keywords
Route instructions, mobile devices, positional information, multimodal presentations.

INTRODUCTION
Mobile devices such as portable digital assistants (PDAs) and mobile phones have become tools that we use on a daily basis. Currently, we can observe a convergence: cell phones incorporate more and more functionality, which was once the domain of PDAs and ultra-portable computers, while the later ones can be updated with communication abilities or have them out of the box. The proponents of this new class of devices often cite location-based services such as incremental guidance in a foreign city as a key benefit.

In this paper, we present an analysis of this specific service with a focus on how to present route instructions depending on various situational factors such as limited resources and varying quality of positional information. We first review some general considerations for presentations on mobile devices. After a brief definition of positional information, we discuss the process of generating route instructions. Based on this discussion and on empirical evidence, we then present guidelines on when to select which type of presentation.

PRESENTATIONS FOR MOBILE ASSISTANCE
In order to produce a coherent and cohesive presentation it is necessary to adapt a presentation to the available resources of the presentation environment. For the presentation of route instructions on mobile devices two types of resources are of special importance:

Technical resources include such factors as speed, bandwidth and screen resolution. The speed of the underlying hardware influences the speed of the presentation. The network bandwidth limits the streaming of data (e.g. movies). The screen resolution has an impact on the layout and the level of detail of a presentation. Consequently, limited technical resources are especially important for presentations on mobile devices.

The *cognitive resources* of the user also influence the way that information is presented to the user. An electronic tourist guide should for instance avoid to compute routes on which inexperienced users are likely to get lost [3]. Taking into account the cognitive resources of the user is crucial, because it can be observed that for many users a mobile device itself results in a higher cognitive load than other, more familiar electronic devices [6].

POSITIONAL INFORMATION
In addition to cognitive and technical resources, the user's current position is not only a key factor in determining what situation a mobile user is in but it is also a concept, which has to be defined precisely. As we see it, focusing solely on a person's location in space (e. g., X- and Y-coordinates) means to leave out some important facets: We subsume under the notion of *positional information* all spatial information that is necessary to uniquely align a human user in space.

Aside from the location the following aspects fall into that category: speed, acceleration, heading, and view direction. In many cases, a system has to know these factors as well in order to provide the user with services that are tailored to her current position. Route directions, for example, often include turning instructions, which are depend on a reference direction (i.e. view direction). The user's current speed and acceleration is equally important for timing and designing route instructions.

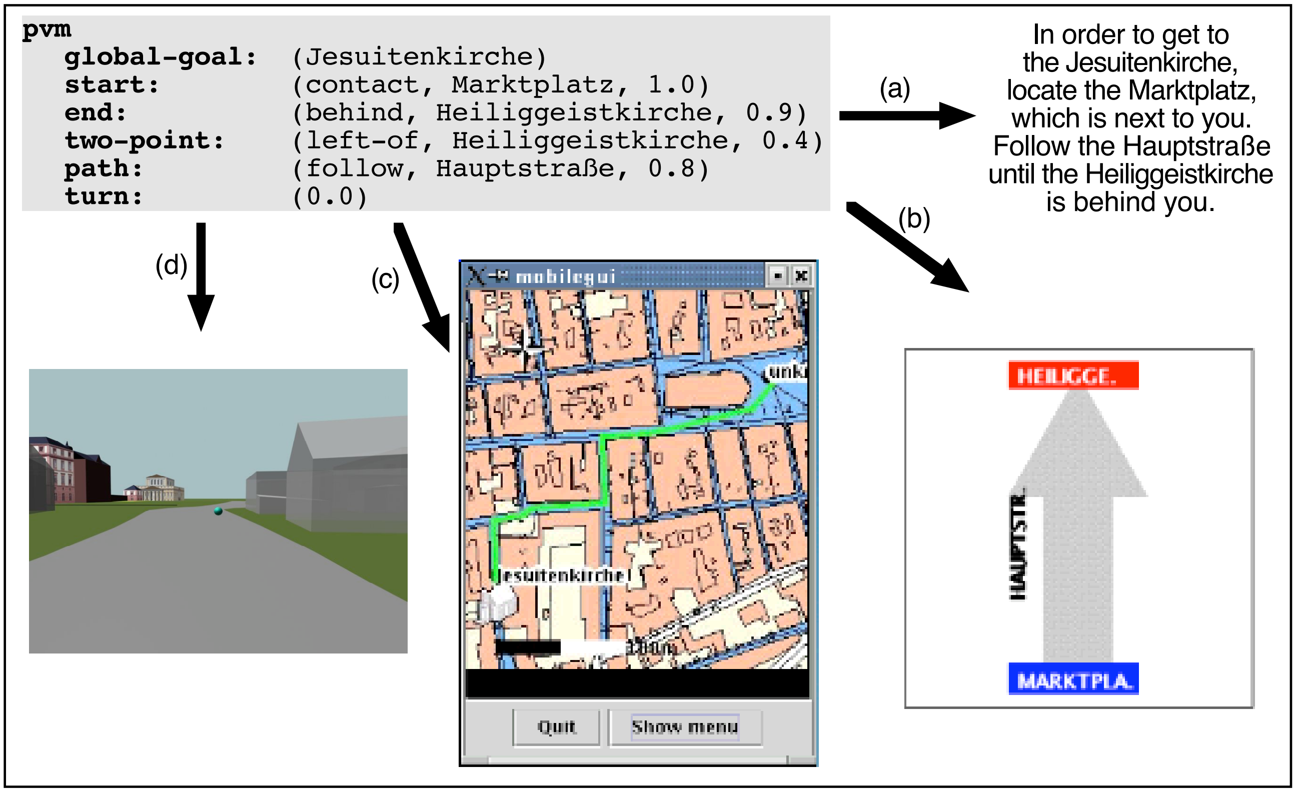

Figure 1: A preverbal message and four ways to present it to the user.

For all the different kinds of positional information there are several types of sensors that can measure it at varying precision and that are prone to various errors such as shielding, reflection, outage, or occlusion [2]. Since there is a limit of how much weight a user is willing to carry around, the number of sensors is also limited. Therefore, more often than not the user's current position cannot be determined precisely or entirely. Consequently, a robust system has to provide means to cope with missing or imprecise positional information, and should ideally be able to function in case of no sensor readings at all.

GENERATING ROUTE INSTRUCTIONS

Incremental guidance is a service that is frequently associated with the concept of a mobile assistant. It is one field, where the advantage of a mobile device compared to a stationary setting is directly apparent. In order to produce route instructions several processes have to be completed. In a first step, the origin and target location (and possibly intermediate locations) have to be determined. Depending on how the user relays this information to the system, this may include speech recognition, semantic parsing, gesture analysis, and frequently also the determination of the user's current position (i.e. when the origin of the route corresponds to the user's current position.)

The second step consists of the computation of a suitable route that does not only lead from origin to target but ideally takes into account situational factors such as the user's preferences or means of transportation. If the resulting route is to be described incrementally, it is also necessary to divide it into smaller segments.

Finally, the route has to be presented to the user, either as a whole or incrementally. In the later case, several presentations need to be generated that have to be timed according to the movement of the user, and the system has to present them at the right location. Additionally, it has to choose appropriate media and presentation modi. Consequently, there is a need for a high level representation of route instructions that allows for the generation of complete or incremental directions in various media and modi.

The format that we propose addresses theses requirements and has been successfully applied within a mobile tourist guide [11]. A *preverbal message (PVM)* comprises several relational localizations for key points on a route segment, a *path relation* [9] describing the trajectory, and a turning instruction. Relational localizations are generated for the start and the end point of the trajectory as well as for the trajectory as a whole. They consist of a qualitative spatial two-point relation [5] and a corresponding anchor object (or reference object). All relations are rated using a normalized degree of applicability. Figure 1 shows an example PVM as well as the different presentations that can be generated from it.

PRESENTING ROUTE INSTRUCTIONS

The following sections describe various ways to present route instructions on a mobile device as well as their respective properties.

Textual and spoken instructions

Figure 1 (a) shows an example of route instruction in natural language. Depending on the situation (e. g., availability of rendering resources) the system can either chose to output it textually, using speech synthesis, or a combination of both. When generating a natural language utterance, there are several degrees of freedom that result from the information contained within the PVM. First of all, not all information needs to be verbalized. For example, the overall goal of the route should probably only be mentioned at the very beginning of a route (to make sure that is the right one), or when the route is resumed after an interruption.

Depending on the user's knowledge of the environment, the system may chose to leave out most information (if she is familiar with it) or to always include all (if she is on a sightseeing tour in a city, which is unfamiliar to her). If speed is an issue, only a turning instruction may be given at exactly the right moment. In case of high cognitive load, a combination of a turning instructions paired with the path relation may be advantageous as it would result in a short instructions ("Turn right into Main street.") and require little memorizing effort.

However, as the length of the segment/route increases the user needs to remember spoken instruction longer, which may require constant rehearsal in case of an elaborate sentence such as shown in Figure 1(a). Textual instructions may also require re-reading in such a case, and may take longer to decode compared to other graphical means (such as 2D route sketches or 2D maps).

2D route sketches

Another way to present route instructions is familiar to users of car navigation systems. It consists of a (mostly qualitative) 2D route sketch such as the one shown in Figure 1(b). In its most abstract form, only an arrow pointing in the intended direction of motion is shown. The PVM can be used to annotate this with additional information. Since key points of a segment are localized using qualitative spatial relations, it is a straightforward task to add the corresponding annotations to the basic arrow. Using the path relation included in the PVM, a label for the arrow may be generated. As for most other presentation means, the selection of which components of a PVM should be realized can be guided by the degree of applicability of the corresponding relation as well as by situational factors.

The main advantage of route sketches can also be a key disadvantage: While the high level of abstraction takes away all unnecessary information and may help to focus on the relevant aspects, it may also leave out things that would help a user to find her way.

2D maps

The most common way to present route instructions graphically is a geographic 2D map that is annotated with route information. A 2D map provides a reasonable overview of the surroundings and is well suited to present a general overview of a tour. Contrary to dynamic 3D walkthroughs (see below) a 2D map is a more abstract rendering of the user's location. It is also usually rendered as a static picture, so that the user does not need to focus on the map all the time thereby preserving the user's cognitive resources.

The information contained in the PVM can be used to generate maps that are a graphical rendering of a route instruction: The names of the relevant locations of the route instruction (contained in `(start)`, `(global-goal)` etc.) are included in the map and the path of the user is highlighted on the map.

One challenge in generating maps is to produce geographical information that can be properly decoded by the user. Therefore it is important to annotate a 2D map with additional information that makes it possible for the user to match it with her actual surroundings.

First it is necessary to find a proper zoom factor for the map, which provides sufficient details, but does not overload the user with information. If contextual information about the user's orientation is provided it may be useful to rotate the map into her current viewing/walking direction. This is a convenient way to preserve the user's cognitive resources, as she does not need to turn the map into her walking direction.

If no information about the user's orientation is available it is crucial to include information about landmarks (e.g. churches) into the map that can be viewed from a distance and serve as orientation points. Finally it is also necessary to find a proper level of detail for the annotations of the map, e.g. street names or the highlighting of certain buildings or areas.

Pseudo realistic instructions

A more natural way to present route instructions is to use pseudo realistic instructions, i.e. three-dimensional maps. There has been some evidence that people recognize landmarks and find route in the cities easier using a 3D model than using a symbolic 2D map and that search and visualization of location-based information of a city becomes more intuitive with life-like 3D [12].

For the preparation of three-dimensional maps similar principles apply as for the design of conventional maps. The three-dimensional visualization has a model character, i.e. the shown objects of the real world shall be represented in a geometrically correct way and in the right position. Furthermore, the visualization as a means of communication demands an adequate degree of readability.

A preverbal message contains the most relevant information for route instructions. It defines the thematic focus of the resulting 3D map. In order to prepare a graphic abstraction according to a given thematic focus the contribution of the different features within this focus must be specified. For each feature, it has to be decided how important it is for achieving this output goal. For the given route, start, end and the global goal of the PVM are of special importance as well as the anchor objects of the two-point relations. Eye-catching buildings are also very helpful as visual landmarks, and should be accentuated in the representation. Additional buildings can deliver a helpful context, but can also confuse and distract from the original aim of the navigation support. Figure 2 shows an example sequence of a 3D-route map. Landmarks are visualized in detail with textured models to attract the user's attention. Less relevant buildings are rendered in gray and in a semi-transparent way.

In order to specify the abstraction level we relate a dominance value to each feature, similar to the approach of [7], reflecting the ranking of this feature in the communication of the reply to the original request. For a better handling, these dominance values can be classified, according to [10], into four representation classes: *identifiable, classifiable, discriminable* and *visible.* A dominance function relates a dominance value to each feature according to the PVM:

dom: F □ PVM □

One factor that influences the dominance function is the relevance of a feature concerning a user specific query. In the case of route instructions this is a spatial query searching all buildings along the route. This query assigns a relevance factor to each feature in the underlying 3D city model. This relevance factor is calculated based on the approach of [8]. First, the distance between an attribute and the corresponding query values is determined for each feature. The distance functions used in this step depend on data-type and application.

However, not only the relevance factor influences the dominance dom_f of a feature. Other factors are the use of *f* as a reference object in the specific query and its general function as a landmark in the environment. The dominance of a feature is composed by three components, the relevance factor *R(PVM)*, the use of a feature as a anchor object *O(PVM)* in a two-point relation, and the general use of this feature as a landmark *L(User)*. These three influence factors can be weighted using the parameters a_0, a_1, and a_2:

$$dom = a_0 * R(PVM) + a_1 * O(PVM) + a_2 * L(User)$$

For route visualization the dominance value of a feature is mapped to a level-of-detail function. Simply speaking, the higher the dominance of a feature the more detailed a model will be that is used to visualize it.

Assigning a_0 a low value results in fewer buildings along the route that are neither landmark nor anchor object. This will lead to a very abstract presentation where only anchor objects and landmarks are shown in detail. Other buildings along the route will appear as simple gray boxes. A higher value of a_0 will lead to more realistic models. However, the visualization will not immediately draw the user's attention to the landmarks and anchor objects.

Multimodal instructions

There are several possibilities how to combine the above-mentioned presentations. However, not each combination produces meaningful results. It is a basic problem of presentation planning to compose multimodal presentations that are coherent and can be properly decoded by the user [15]. This is especially true in case of presentations, in which modalities include coreferences to world objects (e.g. buildings in route instructions) [1].

Since 2D cartographic route instructions provide a rather abstract rendering by means of a geographic map it is useful to combine it with a linguistic output modality, which can add the details of the route instructions (e.g. exactly when to turn on the route) by means of speech or graphic text.

This exploits the property of linguistic modalities to be able to represent nearly any given content on a certain level of detail [4]. A common problem of presentations involving speech is that many users prefer to explore presentations rather than being a passive consumer (e.g. users might want to stop and repeat a certain part of the presentation if they did not understand it properly). Therefore it is useful to additionally employ graphic text so that users are able to re-read it [6].

Moreover the voice of the speech synthesis is also crucial for the acceptance of the whole presentation since a user is easily annoyed by a voice that she dislikes. Many implementations of multimodal dialog systems suffer from rather long processing times. Here acoustic speech output also serves to signal that an answer to the user's request has been calculated.

For the presentation of a route that usually consists of several route elements it makes also sense to employ dynamic presentations. Dynamic presentations benefit from the fact, that a user can be guided step by step through the presentation so that in each step the presentation can focus only on those elements that are necessary for this step (e.g. a certain location on the route or the direction to choose at a crossing). Therefore it is possible to avoid including too many details into a static map. However, contrary to static maps dynamic presentations demand the user's attention all the time and therefore increase the cognitive load of the user. Therefore dynamic presentations on mobile devices have to be chosen with care.

We explored two kinds of dynamic presentations: The first one included a sequence of map-text presentations, in which each step described a route element of the tour that was highlighted on the map. We also examined an alternative with a scrolling 2D map that followed the path of the tour. Text was displayed dynamically below the map whenever a new route element was reached. In both cases the user should be able to stop, continue or reset the presentation.

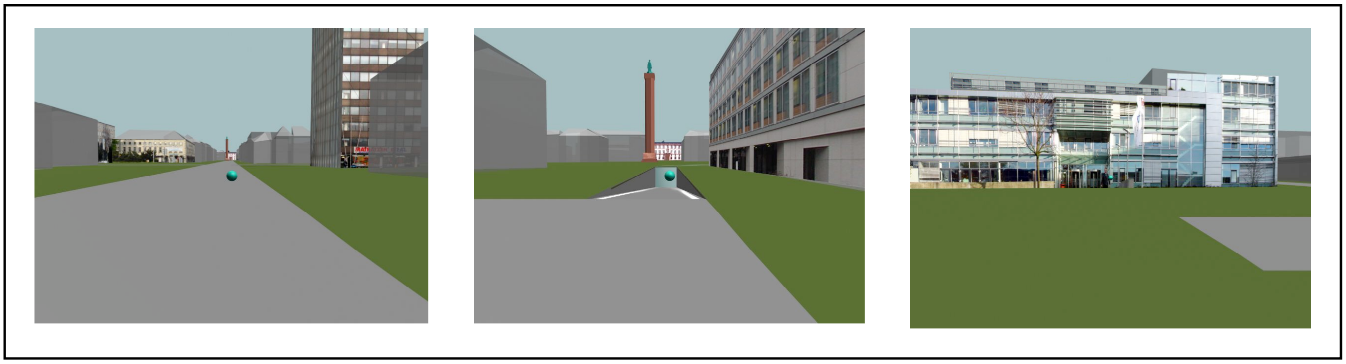

Figure 2: Some sequences of a 3D-route map to the Fraunhofer Institute of Computer Graphics. Navigational landmarks are visualized in detail with textured models to attract the user's focus while buildings with less dominance are shows in grey-scale and semi-transparent rendering style.

Like dynamic 2D instructions dynamic 3D instructions demand the full attention of the user. Therefore we suggest that those presentations should not be augmented with graphic text and speech, but rather by only one of these at most.

Concerning sketched 2D route instructions it is possible to add a complete 2D geographic map. Then, the user can focus on the main information of the route instruction as displayed by the sketch as well as explore the surroundings on the map. In this presentation it is important that the user can identify his position on the sketch with his position in the map. Therefore the user's location should be pinpointed in both and the orientation of the sketch and the map should be the same. This is crucial as evaluation results (see section below) suggest that the cognitive demands of matching two maps (in this case 2D and 3D) are high. However, [12] also shows that users prefer a combination of a 2D and a 3D map, which are properly aligned over a presentation with a single map.

EVALUATION OF 3D MAPS

Empirical results for the presentation of route instructions in connection with combinations of 2D and 3D maps were collected during the evaluation of the first prototype of a 3D-map application for the Nokia Communicator. This evaluation took place in August 2002 in Tønsberg, Norway with a group of ten boat tourists (see Figure 3).

The main purpose of this pilot study was to collect feedback about using mobile 3D maps in city environments. We plan to follow this up with evaluations of later prototypes.

Participants

There was a total of ten users and one pilot user participating in the tests. All users were selected at Tønsberg harbor without strict criteria. Nine of the actual users were males and one was female. The ages of the actual users varied from 33 to 63 years, the average age was 51.6 years. All participants got a voucher worth a free night in Tønsberg harbor (approx. 17,- €) for their participation.

All users had visited Tønsberg before, but most of them had not seen or used the map of Tønsberg before the tests. The users were also quite experienced with maps in general and almost all of them claimed they used maps often, especially sea maps. Most participants rated themselves as being professional or skillful map users.

Apparatus

The tests were performed with an IBM ThinkPad 240 laptop running a mobile phone emulator at a screen resolution of 800x600 pixels (see Figure 3).

Figure 3: Evaluating 3D maps: The white house in the middle was found easy to recognize.

Procedure

Each test session consisted of three parts: introduction, test tasks and interview. In the first part the project and the application were introduced to the user. The user filled out a questionnaire, in which some basic data about age, sex, education and prior knowledge about maps and the area was asked. In the end of the introduction phase a rough course of the test was explained to the user.

The test part included six similar tasks. In all of them the user was asked to go from one place to another. In the first four tasks the participants were asked to use the application and its 3D map. In the two last ones they were asked to use a normal paper map. Starting and target locations were marked in the maps, but no GPS was available to highlight the user's current position on the map.

Each test session ended with an interview, in which the user's opinions about the application, 2D and 3D maps in general and the test session was asked. The users were also asked to fill out another short questionnaire.

Results

Users' attitudes towards the prototype were very positive and three fourths of them would like to use this kind of service rather than 2D paper maps and guidebooks. The 3D map itself was found to be a good idea, although many experienced map users thought that an electronic 2D map would be sufficient for them.

There were two major problems in the tests: the laptop screen was hard to see in the sunlight and the users had to navigate in the model themselves because no GPS was available. Both of these issues influenced the users' satisfaction ratings.

Most of the users tried to use the 3D model as a navigational aid in the tasks. All of them used it to recognize buildings, and mostly successfully. Some users claimed that non-textured buildings were hard to distinguish from each other, but textured buildings, especially one white house (see Figure 3), were considered easy to recognize. Some users complained that comparison between the 2D and 3D maps was difficult, because there was no clear correspondence between them.

Apart from matching buildings the most common navigation strategy of a user was to follow the direction arrow in the 3D view, and the target location and current location being displayed in the 2D map. The users also had the possibility to choose the viewing height in the 3D view to switch between walking level (pedestrian view, 1.8m altitude) and flying level (bird's-eye-view, 25m altitude). Interestingly, the flying mode was found to be much easier for navigational purposes.

3D maps were found to be slower to use both in initial orientation and route finding compared to 2D maps. We defined the orientation interval to begin at the moment the user was shown the target location and to end when she starts to walk towards it. Then the route finding interval began which lasted until the user reached the target.

An average orientation interval lasted 42 seconds when the users used the 3D map, and 10 seconds when the 2D paper map was in use. Route finding interval times also depend on the lengths of the routes, so a proper measurement is needed. Therefore, we rely on the average speed of the user (optimal route length divided by the average time), which was about 1 m/s for the 3D map and 1,5 m/s for the 2D paper map. A t-test returned a p-value of 0.023 for the orientation times and 0.001 for the route speeds. This suggests that both results are relevant.

When the users were asked how they would like to improve the application four things were mentioned frequently. According to the users the 3D model should be more detailed and realistic and the target should be highlighted in it. Street names should be visible and a zoom function should be included in the 2D map.

Discussion

The purpose of this pilot study was to collect experience on how to improve future prototypes of our navigation system. The small amount of test users and the fact that the choice of participants was not random, suggest that the results of this study cannot be generalized. However, all users performed the same tasks in different order using four times a 3D map and two times a 2D map. Therefore we collected 40 samples for 3D maps and 20 samples for 2D maps, which makes us confident that the results are relevant for our prototype in spite of the small number of participants. It should also be noted that the majority of the users were males and all of them were experienced with 2D paper maps. It has been shown that males and females use different strategies in navigation (e.g. [14]).

Despite the observation that experienced male users preferred the familiar 2D maps to the new 3D maps the results were promising. Users were able to recognize real world objects from the 3D model and use these landmarks as navigational aids. Many users also said that even though a 3D map would not give them much additional value, it was more fun to use.

Another interesting result was that users generally preferred the flying mode to the walking mode. The flying mode gave them a better overview of the surroundings and helped them in building recognition.

The results also indicate that the contrast of the 3D model (especially the 3D arrow) has to be improved in order to make the application usable in sunlight. There should also be a better correspondence between the 3D and the 2D map in order to assist users in switching between both systems of reference.

SELECTING A PRESENTATION

Previous sections have shown that we can generate a broad range of different presentations from a single preverbal message. However, it is still unclear, which presentation to choose for a given situation. The field test described in the precedent section certainly shows that there are differences that are not only related to performance but also to perception of the users: Even though most candidates were much faster using 2D maps, they all noted 3D visualizations were 'more fun'.

Table 1 lists the different presentation types that we reviewed in this paper, and highlights their relationship to positional information and cognitive and technical resources. Obviously, the more sophisticated a presentation is, the more technical resources it requires. However, the same does not necessarily apply in the case of cognitive resources. While textual and spoken instructions in general do not require much to be understood by a human user, they include little context. Furthermore, to include additional context (such as information about the surrounding area) means to add more text, which quickly increases the cognitive load, or to generate a multimodal presentation.

	Location	Orientation	Cognitive resources	Technical resources
Text	req.	req. for turns	medium	low
Speech	req.	req. for turns	low	low-medium
2D sketch	req.	not req.	medium	low-medium
2D map	not req.	not req.	medium-high (context)	medium-high
3D vis.	not req.	not req.	medium-high (context)	high

Table 1: Relationship among presentation type, positional information, and resources – an overview.

Due to the lack of context, the current location of the user has to be known rather precisely in order to generate verbal instructions. Turning instructions, for example, do rely on the precise knowledge about the user's current orientation. The same is true for directional information. While it is possible to compensate varying quality of positional information using *induced frames of reference* [2], the resulting utterance will be more demanding in terms of cognitive resources as the listener has to perform one or more mental (or physical) rotations/translations.

2D sketches are similar to verbal presentations as they are easily understood since they leave out the 'unnecessary' and focus on information that is immediately relevant to the current task. They also require only limited technical resources, as only simple geometrical forms have to be drawn. If the presentation is constantly aligned to the user's current view direction, the continuous redrawing entails a higher consumption of technical resources.

Generating 2D maps is a process that consumes significantly more resources than verbal output or 2D sketches. Depending on the implementation, a map has to be generated from a large dataset (or to be clipped from a larger image), which may include the selection of an appropriate zoom factor, of a level of detail, and of which objects to depict. Placing labels on the corresponding map is also a computationally demanding task. And if the map is aligned to the user current view direction, it has to be rotated continuously.

However, a map does provide much more context than verbal instructions as it naturally includes nearby objects. Consequently, maps can easily compensate imprecise or missing positional information. If the view direction of the user is unknown, the map can be rendered using canonical directions. If her location is imprecise, the depicted area can be enlarged. The same is true in case of missing positional information, where the map allows the user to compensate, albeit at the price of a higher cognitive load (as anyone knows who has tried to navigate in a foreign city with nothing but a paper map).

3D visualization can be even more demanding in terms of technical resources than 2D maps. While the results from our field test indicate that they may not necessarily lead to better performance, 3D visualization can strongly support the recognition of landmarks if they are sufficiently detailed. Additionally, there may be an esthetical factor that should not be underestimated.

From the above discussion, we can draw several guidelines concerning the selection of presentation for route instructions. Spoken instructions have the unique advantage of not requiring visual attention, but rely on precise positional information. Written instructions are the least demanding as far as technical resources are concerned, and can be combined with all other presentation types. Both written and spoken instructions are not well suited to provide context. Due to the sequential nature of audio output, this is especially true for the later case.

Route sketches are a good compromise in terms of resource consumption and dependency on positional information. Since only a few very simple forms have to be drawn, they are well adapted to the small display size of a mobile device. They are easily understood but do offer little context, and providing additional context comes at the cost of increased complexity.

2D maps on the other hand naturally incorporate contextual information, and are therefore a good means to address situations, where only imprecise positional information is available. Additionally, they are a well-known tool for navigation, and may help an untrained user to familiarize her with the system. However, due to high demands on technical resources, 2D maps are not well suited for situations, where a fast response is required.

The same applies even more in the case of 3D visualizations. The more realistic the visualization, the more demanding it is in terms of technical resources. But the resulting realism also enables the user to recognize objects from the rendering in the real world, which is a distinct advantage over all other means of presentation. This makes 3D visualizations well suited for situations, where time and technical resources are not an issue, and where the available positional information is somewhat imprecise: The realistic presentations allows the user to search her environment visually for specific objects, and then to align herself accordingly, thereby compensating the imprecision. Additionally, our field test hints at another good application for 3D-visualizations: entertainment. On a leisurely sightseeing tour, it may add to the enjoyment of a tourist, and it may be beneficial when planning such a tour (e.g., over the internet).

CONCLUSIONS

Route instructions can take various forms, and we reviewed several of them for a mobile user. We introduced an abstract format that allows for the generation of many different presentations. Based on a field test and a thorough analysis of the relationship among presentation type, positional information, and technical and cognitive resources, we presented several guidelines for the selection of a presentation in a given situation. In the future, we intend to apply this knowledge within the design-evaluation circles of the different prototype systems mentioned in this paper.

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