Generating Verbal Assistance for Tactile-Map Explorations[1]

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Abstract

Tactile maps are a means to communicate spatial knowledge providing access to spatial representations of knowledge for visually impaired people. However, compared to visual maps, tactile maps have some major drawbacks concerning the integration of information due to the need of sequential exploration. Verbal descriptions providing abstract propositional knowledge have an advantageous effect on tactile map reading. They can be used to communicate knowledge that on a visual map is usually realized in the form of textual labels. Further, verbal assistance can facilitate the acquisition of global spatial knowledge such as spatial relations of streets and support the tactile-map user by assisting exploration, for example, by giving information about landmarks next to a street. This paper presents an approach towards a verbally assisting *virtual-environment tactile map (VAVETaM)*, which provides a multimodal map, computing situated verbal assistance by categorizing the user's exploration movements in semantic categories called MEPs. Three types of verbal assistances are discussed. VAVETaM is realized using a computer system and the PHANToM® desktop haptic force-feedback device, which allows haptic exploration of 3D-graphics-like haptic scenarios.

Keywords: verbal assistance, tactile map, haptic, representation, propositional, analog, spatial-analog

1 INTRODUCTION

Tactile maps provide blind and visually impaired people with useful means to acquire knowledge of their environment. As such, they can be used as substitutes for visual maps (Ungar et al., 1993). As Espinosa et al. (1998) point out, tactile maps can potentially increase the independence and autonomy of blind and visually impaired people, in particular for navigation in complex urban environments without the assistance from a sighted guide. Although different types of tactile maps are in use, neither generally agreed principles for tactile-map design nor standards of tactile-map production exist today Perkins (2002); even if Perkins' progress-report covers the phase 1993 to 2001, with respect to design principles the situation has not changed. On the other hand, the technological development has led to additional options in map production and in haptic interfaces (see below.)

Compared to visual maps, the major problem in using tactile maps is due to the restriction of the haptic sense regarding the possibility of simultaneous perception of information, for an overview see Loomis et al. (1991). In haptic perception additional effort has to be assigned to integrate information perceived over time. This leads in the case of map exploration to specific limitations for building up cognitive maps, such as *sparse density of information* and *disadvantage of survey knowledge compared to route knowledge*. Due to the restriction of the haptic sense in simultaneous perception of information, additional information given in another modality, e.g., speech, can be very useful (Wang et al., 2009). The increasing availability of haptic interfaces for human-computer interaction (HCI) offers a large variety of prospects for training and assisting blind people. In particular, by the means of such devices (e.g., the PHANToM® desktop used for VAVETaM), it is possible to realize map-like representations of physical environments that are HCI counterparts to traditional tactile maps (Kostopoulos et al., 2007; Lahav & Mioduser, 2000). *Virtual-environment (VE) tactile maps* offer the option to generate situated verbal

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descriptions (compare figure 1 for a visualized virtual-environment tactile map in use). Thus, both representational modalities, maps and language, can be used to communicate spatial information. In particular, the sequential nature of verbal descriptions supports incremental construction and updating of spatial knowledge.

The multimodal combination of *virtual-environment haptic interaction* and *assistive auditory signals* has been proved to increase speed and accuracy in exploring tactilely depictions of different types, as well as the reliability of their interpretations: this holds, inter alia, for maps (Jacobson, 2002), graphs (Wall & Brewster, 2006) and tables (Kildal & Brewster, 2007). Several approaches to augmented tactile mapping systems exist, but they do not take the generation of natural language assistance in *interaction with the user's movements* into account (Wang et al., 2009; Jacobson, 1998; De Felice et al., 2007; Parente & Bishop, 2003; Moustakas et al., 2007). The approach presented in this paper combines both types of modalities for assistance, namely virtual-environment haptic interaction and natural language assistance, by focusing on the generation of natural language assistance based on computerized understanding of the *map-exploration procedures (MEPs)* (see section 4), i.e. by exploiting the movements the user does during exploring the virtual-environment tactile map to generate discourse that helps the user in building an internal mental map. With an abstract semantic categorization of the users' movements, knowledge about what they explore can be used to compute verbal assistance in scenarios where augmenting the haptic representation provides useful hints either for further exploration procedures or for the efficiency of building up survey knowledge of the environment represented in the map. Additionally, besides the description of labels in visual maps, users demand information about locations of auditory landmarks like audio-enabled traffic lights and further information about the relations of complex entities such as long streets (Wang et al., 2009). In our approach towards *verbally assisting virtual-environment tactile maps (VAVETaM)* presented in this paper, verbal descriptions are used to communicate three kinds of verbal assistances: (a) *labeling information* such as street names, (b) *complex global spatial relations* such as parallel roads or junctions in exploration direction, and (c) *comments to instruct exploration*, for example, if a landmark that is supposed to be important has been 'overlooked' (compare section 5 for an example).

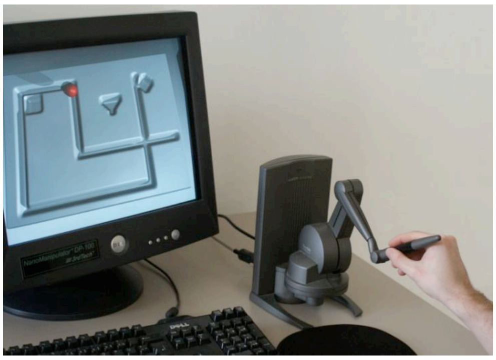
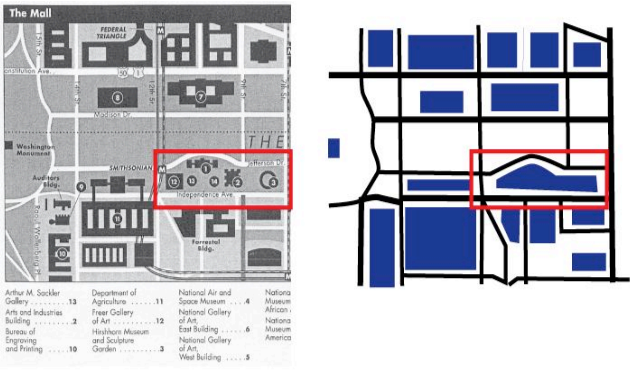


Fig 1: PHANToM® desktop and visualized VETM

A first example for the improvement of tactile maps with verbal descriptions is shown in figure 2, taken from a tourist guide of Washington[2]. This map provides a good example for the usefulness of augmenting tactile map exploration with verbal assistance, as it includes both, a large density of labeling information such as street and building names, and a lot of salient global spatial relations, such as streets being parallel.[3] Within the virtual-environment tactile map, written textual labels cannot be used. Even though the exemplifying visual map is a relatively straightforward one, exact information about the shape of the buildings is not (re-)presented within the tactile map modality, as shown in figure 2. Instead, verbal descriptions can be used to communicate further, more detailed knowledge about a given entity. This can be information about the name of a building, another landmark (e.g., *'This is*



(a) Visual Map (b) Abstraction for Tactile Map

Fig 2. Example of an abstraction for a tactile map of the National Mall of Washington

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[2] The depiction of the left map is derived from: Fodor's Washington, D.C. 2001, page 29. © Fodor's Travel Publications; Random House: New York.

[3] We have chosen *travel guides* as one domain of application. In particular we use 'published' map-text constellations to design tactile maps and to determine verbal comments to be adequate in assisting a haptically map-exploring user.

the Washington Monument'), or further information about a complex of buildings too intricate to be represented in the haptic modality like the one marked in figure 2. A useful output in this case could be: *'The landmark you are exploring consists of four large buildings. In the west is Freer Gallery of Art. In the east is Hishhorn Museum and Sculpture Garden. In between there is the Smithonian Institution Building and the Arts and Industries Building.'*

Another example is shown in figure 3. The red line indicates the exploratory movements along street segments of the map. At the point indicated with the arrowhead, several verbal assistances are possible. A useful assistance concerning labeling information would be to state the name of the street explored: *'You are exploring Independence Avenue'*. Further, information about the global spatial relations is useful for the integration of spatial knowledge: *'The street you are exploring is parallel to Constitution Avenue you explored before'* or *'You are heading towards a junction with 7th Street'*. A major drawback of tactile map exploration is the limited sensor field in exploring by finger movement; especially in virtual-environment haptics, it is complicated to find landmarks next to the track. Therefore, a verbal assistance such as: *'You are passing the church'* would be very useful. As exploration continues during the utterance, due to the time constraints resulting it is—in many scenarios—more efficient to say: *'You are passing three buildings'* than to mention each single building.

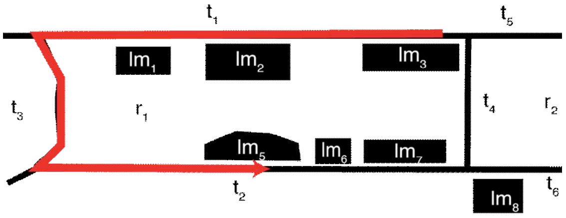

Fig 3. Example exploration of streets in a tactile map

2 An outline of VAVETaM

The system we propose has two major interaction modalities: On the one hand, a virtual-environment tactile map accessible by the haptic device, and, on the other hand, verbal descriptions providing additional assistance. The virtual-environment (VE) tactile map is based on a virtual three-dimensional haptic space, which can be explored by moving a *virtual interface point (IP)* with the handle of the device (Salisbury et al., 1995). The virtual tactile map is realized by using 3D-graphics-like shapes. A VE-tactile map can, for example, be a simulated plane area with depressed lines representing streets and depressed or raised areas representing landmarks (see figure 1, which shows a simple map for training people in the usage of our VE-tactile maps). During exploration, the user moves the device and information about these movements is accessible to the system.

The structure of VAVETaM is illustrated in figure 4: A component called *Virtual-Environment Tactile Map* component (VETM) provides a model of the tactile map including spatial-geometric specification and propositional information (such as qualitative relations between map entities and labeling information). As maps can be seen as hybrid representation systems for knowledge about the physical environment (see section 3 for more detailed discussion), the VETM consists of two representational layers, a spatial-geometric layer and a propositional layer. The spatial-geometric layer enables the generation of *spatial-analog map presentations*, in particular for tactile exploration.

While this VE-tactile map presentation is explored, the *Haptic Device* provides position and, hence, movement information. This information is processed by the so called *MEP Observer*, a component essential for the interaction between the modalities, which is discussed in more detail in section 4. The MEP Observer is the system internal counterpart to human assistants who observe a tactile-map exploring user. Based on their observation of the hand movements and their interpretation of the map, the assistants are able to give verbal comments. The stream of movement data has to be represented abstract and interpreted semantically, therefore, the movements are categorized in *map-exploration procedures (MEPs)* in the *MEP Observer*, which consists of two subcomponents, the *Haptic-Movement Observer (HMO)* and the *MEP Categorization (MEPC)*. Furthermore, the MEP Observer has access to the *MEP Specification* component providing information about the MEPs in use during the exploration movements.

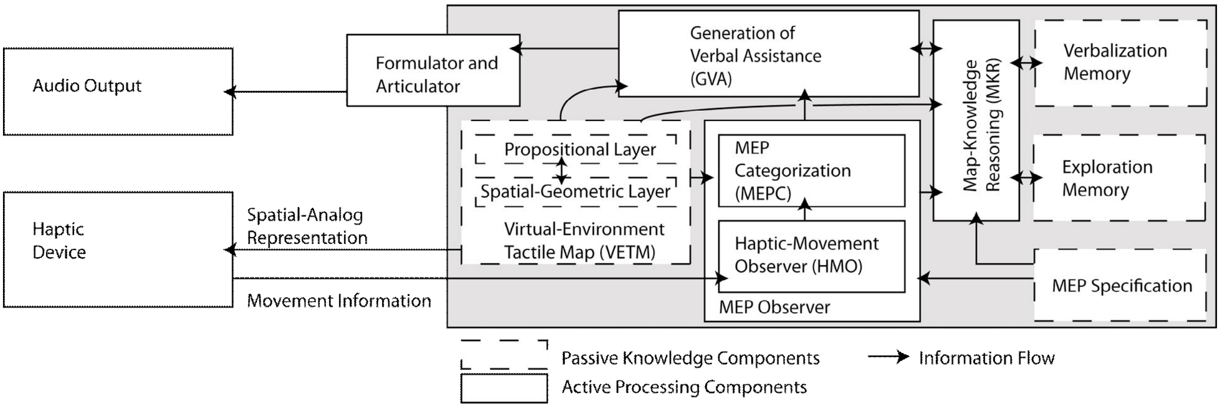

Fig 4. Structural model of VAVETaM

For the generation of non-redundant and efficient verbal assistance, it is essential to analyze the user's exploration, in particular, to build assumptions about what parts of the maps are known and what parts are still unexplored. This information is stored by the *Map-Knowledge Reasoning (MKR)*. This component accesses two memories: The *Verbalization Memory* and the *Exploration Memory*. The MEP Observer's output and the assumptions about the knowledge the user has gained from exploration and verbal assistance are used within the *Generation of Verbal Assistance (GVA)* component generating propositional, pre-verbal messages (Levelt, 1989) in order to fill *informational needs* of the user (Pirolli & Card, 1999). Once such a pre-verbal description is generated, it is stored in the *Verbalization Memory* and is sent to the *Formulator and Articulator* component to generate a speech.

3 HYBRID REPRESENTATION WITHIN MAPS – VIRTUAL-ENVIRONMENT TACTILE MAPS

In the previous section the need for a model of spatial representations within the VETM was described. In order to construct such a model, the formats for representing knowledge in maps are discussed in this section.[4] We focus here on maps as *external* representations, in contrast to *internal* spatial representations usually called mental maps (see, e.g., Lobben, 2004).

Generally, the investigation of representation in cognitive science has led to the discussion of two representational setups: *propositional* and *analog* (Palmer, 1978). A propositional representation is, in contrast to the analog, discontinuous. This means, a propositional representation has relational entities that correspond to entities represented. Paradigm cases for propositional representations are written and spoken language, operator-operand structures or table-like representations as the mileage chart shown in figure 5(a). Typical definitions of analog representations include that the representation is organized continuously rather than discrete. Further, analog representations preserve spatial information about what they present (Palmer, 1978). As the notion 'analog representation' is deceptive in respect to VAVETaM being realized on a digital basis, this kind of representation will for the sake of a clear terminology in this paper be referred to as *spatial-analog*. A prototypical example for a spatial-analog representation is a depiction of distances as shown in figure 5(c): The spatial relations between the cities are spatially represented in this depiction. Maps represent spatial relations in a spatial-analog way. In addition, visual maps usually rely on labeling. Furthermore, we know about domain-specific concepts that are included in a representation of a map, e.g., streets are depicted as lines or water is depicted as a blue area. This conceptual knowledge is knowledge about *map concepts (MCs)* (Habel 2003). Map concepts consist of conventional knowledge about the components occurring on a map and the conventional knowledge about the usual

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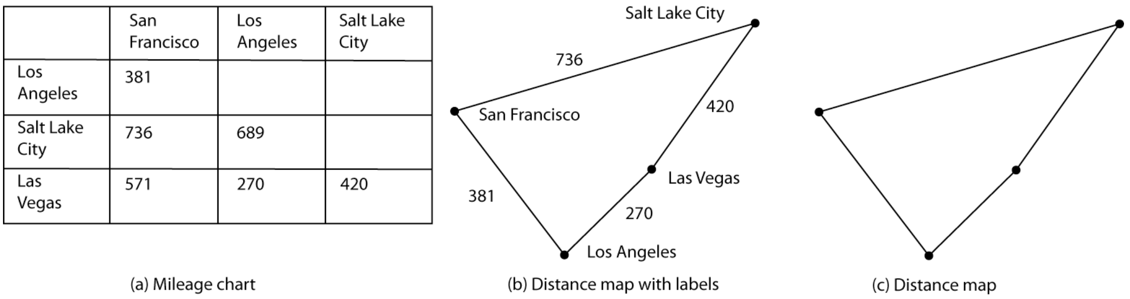
[4] Our use of the notion 'format' is committed to Kosslyn's discussion of propositional and depictive formats (see, e.g., Kosslyn, Thompson and Ganis, 2006, pp. 8-14.)

spatial-analog depiction of those. Maps are *hybrid representation systems* (Habel, 2003). Compare figure 5(b) for an illustration of a prototypical hybrid representation system. Maps differ from this representation in that they are not only hybrid due to their labeling, but also due to the interpretation relying on map concepts being hybrid themselves.

It is plausible to assume that tactile maps work in the same way as visual maps, even though the map concepts vary due to the representational possibilities of the tactile map setup, that is, the resolution and complexity is reduced due to haptic perception and the need for the integration of sequential percepts. As in the visual scenario, within the VETM component one layer is spatial-geometric. This layer provides the information necessary to realize a spatial-analog map explorable using the haptic device. To allow this, map concepts stored in the propositional layer are linked with geometric specifications on the spatial-geometric layer (compare figure 4). Further, information about how to depict a map concept is stored for each map concept selected for depiction[5] (compare Maaß (1994) for a similar approach). The hybrid representation within the VETM component enables to compute the information to be verbalized in the Generation of Verbal Assistance component. As the representation is hybrid, both, spatial reasoning and propositional reasoning are possible (compare Habel, Kerzel, & Lohmann (2010) application scenarios of spatial reasoning done with visual routines). As the assistance has to be given situated, the exploration of the user is used as an input for the Generation of Verbal Assistance. To enable reasoning, the input is categorized into semantic categories in the MEP Observer component.



	San Francisco	Los Angeles	Salt Lake City
Los Angeles	381		
Salt Lake City	736	689	
Las Vegas	571	270	420

(a) Mileage chart

(b) Distance map with labels

(c) Distance map

Fig 5. A propositional (a), a hybrid (b) and an analog representation (c) (partly derived from Habel (2003))

4 THE MEP OBSERVER

A map-exploration procedure (MEP) is an abstract semantic description of the user's exploration movements linked to the desired knowledge about the map. Examples for MEPs are *track-MEP* (the term track is used as a general term for street-like structures involved in route planning) and *distance-MEP*. The first describes an exploration process for tracks and consists basically of straight movements along the track, while the *distance-MEP* is an estimation of the distance between two map entities, for example, a track and a landmark. When knowledge about a track is needed, this entity is explored using typical movements that, on an abstract level, form a *track-MEP*. The basic set includes four MEPs related to the desired knowledge: *track-MEP*, *landmark-MEP*,

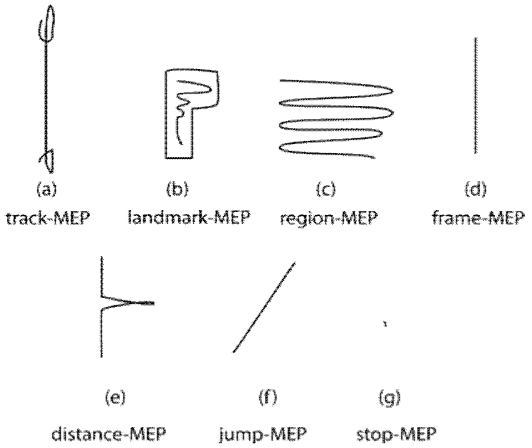


Fig 6: Movement patterns (preliminary set of MEPs)

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[5] We use 'depiction' as technical term corresponding to Kosslyn's use of 'depictive representation' (see, e.g., Kosslyn, Thompson and Ganis, 2006). Thus depictions are not restricted to the visual modality, but are also fundamental for the generation of haptic representations.

region-MEP, and *frame-MEP*. An extended set includes three additional MEPs: *distance-MEP*, *jump-MEP*, and *stop-MEP* (See figure 6 for the movement patterns in exploring printed tactile maps. Habel, Kerzel and Lohmann (2010) discuss MEPs in more detail).

The aim of the MEP Observer is to recognize the users' MEPs in order to make assumptions about what information they have already gathered from their interaction with the map and what their current informational needs are. The MEP Observer is a core component in incremental conceptualization:[6] The stream of data from the haptic device is segmented into *Perceptual Units (PUs)* that represent the position of the interface point in the virtual environment with a fixed temporal and spatial resolution, abstracted from the actual hardware. These perceptual units are aggregated into conceptual representations in a hierarchical process resulting in assumptions about the MEPs executed by the user. As it is the aim of VAVETaM to provide verbal assistance accompanying the haptic exploration of the virtual-environment tactile map, it is important that the MEP Observer recognizes MEPs as early as possible, even if they are not yet finished. For example, if the user is tracing a track, the system should be able to recognize the resepctive *track-MEP* and could thus provide verbal assistance while the user is still exploring the track (compare figure 7 for a depiction of the aggregation hierarchy).

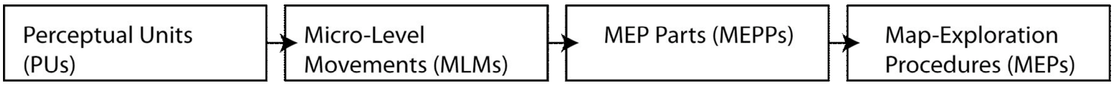

Fig 7: Aggregation hierarchy from PUs to MEPs

This is accomplished by first segmenting the perceptual units into *Micro-Level Movements (MLMs)* utilizing both procedures for gesture recognition by the Haptic-Movement Observer and pre-segmentation depending on the position of the interface point in relation to the different objects in the virtual-environment tactile map by the MEP Categorization component, i.e., the interface point touching the surface of an object representing a track, a landmark, the empty map surface in between or the empty space above the tactile map. MLMs represent basic user movements in relation to objects of the virtual-environment tactile map, e.g., touching a track, tracing a track or leaving a track. Once an MLM is recognized subsequent perceptual units can still be associated with the same MLM, i.e., a *trace-track-MLM* is recognized while the user is still tracing the track, further tracing of the track will not create another *trace-track-MLM* but will be associated with the already recognized *trace-track-MLM*.

MLMs are stored in the Exploration Memory and are further aggregated to *MEP Parts (MEPPs)*, which represent the basic building blocks of MEPs. For example, an MEPP describing a single track being explored would be constituted by the MLMs of touching, tracing, and finally leaving the track in question. MEPPs are further combined—in a hierarchical manner—to form MEPs (kindred to Guhe et al., 2000). Figure 8 shows a visualization of an exploration, consisting of exploring a track t_1 and subsequently exploring a track t_2, with track t_2 being connected to track t_1. In processing this exploration, the MEPP for exploring a track t_1 and the subsequent MEPP for exploring a track t_2, with track t_2 being connected to track t_1, constitute the *track-MEP*(t_1,t_2) as shown in figure 9. Like MLMs, both MEPPs and MEPs need not be complete in order to be recognized. The *track-MEPP*(t_2) and the *track-MEP*(t_1, t_2) is constructed although the final *cease-touch-track-MLM(t2)*, which is depicted in grey, is still missing and more perceptual units can get associated with the *trace-track-MLM*(t_2). In other words, the snapshot depicted in figure 9 is the result of a process of building a plausible hypothesis, which possibly has to be modified or to be changed later.

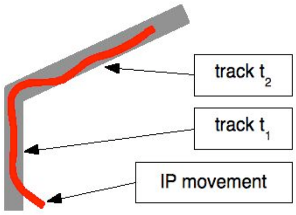

Fig 8: Subsequent exploration of two connected tracks

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[6] The VAVETaM conceptualizer – a subcomponent for the Generation of Verbal Assistance (GVA), see figure 4 – will be based on the INC approach (see, Guhe et al, 2000). Guhe and Habel (2001) discuss the incremental conceptualization in the kindred domain of verbalization of 'acts of drawing line configurations'.

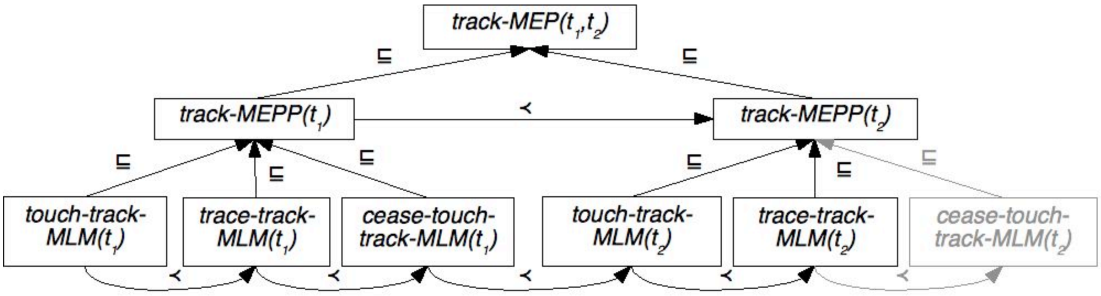

Fig 9: Hierarchical structure of a *track-MEP* (□ indicates part of relation, □ indicates subsequent MLMs or MEPPs)

5 THE GENERATION OF VERBAL ASSISTANCE

The user's exploration is an active interaction with the VAVETaM. As the MEP Observer generates an abstract semantic representation of the user's exploration stored in the Exploration Memory, assumptions about the knowledge the map user has gained can be made in the Map Knowledge Reasoning component. This component also keeps track of the pre-verbal messages send to the Formulator and Articulator. The Generation of Verbal Assistance (GVA) basically provides output with respect to three types of assistance tasks: (a) the user explores a part of the map for the first time and has a need for labeling information, e.g., a name of a street or a building, (b) the user gets information about global spatial relations, which are difficult to detect preforming local explorations, or (c) guidance for exploration is needed, such when the user has not yet explored a salient landmark like an audio-enabled traffic light along the route which will probably be helpful for later wayfinding.[7]

We use type (c) to exemplify how the Generation of Verbal Assistance interacts with the MEP Observer and the Map-Knowledge Reasoning. To produce assumptions about the current informational needs of the user, the GVA-component has to be able to reason about the map, the represented environment, and the exploration process (Habel, Kerzel, & Lohmann, 2010). Thus, MEPs are associated with informational needs. Once the MEP Observer recognizes an MEP, the associated informational need is used by the Generation of Verbal Assistance to extract information for verbalization from the VETM. This set of information is compared with the Map-Knowledge Reasoning in order to find the subset of information novel to the user.

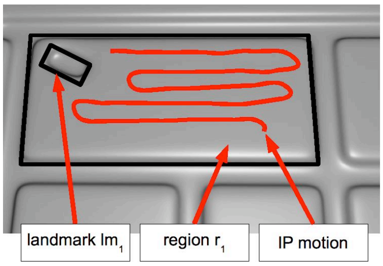

Fig 10. Assisted exploration: user overlooked lm_1 in region r_1

As an example, figure 10 shows a visualized extract of a virtual-environment tactile map. The red line symbolizes the position of the interface point over time. The shape of movement is characteristic for a *region-MEP*, which is used to explore a region represented in the virtual-environment tactile map for unknown features. In this example the user has 'overlooked' landmark lm_1. Once the *region-MEP*(r_1) is recognized by the MEP Observer, the Generation of Verbal Assistance consults the VETM component, storing the map representation, to inspect the region r_1 for landmarks. In this case only landmark lm_1 is contained in the inspected region. Now the Map-Knowledge Reasoning is consulted. If landmark lm_1, e.g., a fountain, is neither mentioned in a preceding verbal assistance nor is the user's haptic interaction with lm_1 recorded in the Exploration Memory, the Generation of Verbal Assistance sends this information to the Formulator and Articulator, which generates a verbal assistance such as '*You have missed the fountain in the upper left corner of the region you are exploring*.'

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[7] Scenarios (a) and (b) are exemplified in section 1.

6 OUTLOOK

The VAVETaM presented aims to the generation of helpful verbal descriptions that communicate street names and other information usually found as textual labels on visual maps and, added to this, verbalize information about global spatial relations and fill in knowledge gaps like unexplored entities. This is realized by analyzing the user's exploratory procedures in the MEP Observer in an abstract semantic manner using an MEP categorization related to the desired map knowledge. As two memory components keep track of the knowledge representations provided to the user by VAVETaM, assumptions about the user's map-exploration progress and the knowledge gained are made. Hence, useful verbal descriptions can be given. These verbal descriptions are not restricted to the verbalization of labels like street or building names, rather they also provide assistance with the exploration and the integration of the spatial information perceived sequentially.

The examples given in section 1 give hints to an important research question to be addressed in the future. Free map exploration to build up survey knowledge is in the focus of research. Nevertheless, a plausible usage scenario for free map exploration is to enable planning a route from a point A to a point B. During planning a route, humans make use of different levels of granularity, as shown by (Timpf & Kuhn, 2003) for the highway domain. It is very likely that granularity transformations also happen during route planning by visually impaired or blind people, and the verbal assistance should adapt to this fact. To use the example of the four buildings described above: When planning a route simply passing by the museum buildings, it may be sufficient to say that there are buildings, whereas when planning a route to the Hishhorn Museum, much more information about the location and the spatial relations towards the other buildings must be given verbally. To realize this goal, issues such as plan recognition have to be addressed.

A further scenario that is yet to be tested for its usefulness is user-triggered output, e.g., the user clicking one of the buttons of the haptic device to show the need for information. This information can be of the categories described above: Either repeating labeling information, providing exploratory guidance or global spatial knowledge.

REFERENCES

De Felice, F., Renna, F., Attolico, G., and Distante, A. (2007). A haptic/acoustic application to allow blind the access to spatial information. In *World Haptics Conference* pages 310-315.

Espinosa, M.A., Ungar, S., Ochaita, E., Blades, M., and Spencer, C. (1998). Comparing methods for introducing blind and visually impaired people to unfamiliar urban environments. *Journal of Environmental Psychology*, *18:* 277-287.

Golledge, R. G., Rice, M., and Jacobson, R.D. (2005). A commentary on the use of touch for accessing on-screen spatial representations: The process of experiencing haptic maps and graphics. *The Professional Geographer*, *57*(3), 339–349.

Guhe, M., and Habel, C. (2001) The influence of resource parameters on incremental conceptualization. In *Proceedings of the Fourth International Conference on Cognitive Modeling*, George Mason University, Fairfax, Virginia, USA. pages 103–108. Mahwah, NJ: Lawrence Erlbaum.

Guhe, M., Habel, C., and Tappe, H. (2000). Incremental event conceptualization and natural language generation in monitoring environments. In *Proceedings of the first international conference on Natural Language Generation,* Vol. 14, pages 85-92.

Habel, C. (2003). Representational commitment in maps. In Duckham, M. Goodchild, M., and Worboys, M., editors, *Foundations of Geographic Information Science*, pages 69-93. London: Taylor & Francis.

Habel, C., Kerzel, M., and Lohmann, K. (2010). Verbal assistance in tactile-map explorations: A case for visual representations and reasoning. *Proceedings of AAAI workshop on Visual Representations and Reasoning*. AAAI-Conference 2010 (Atlanta, GA, USA).

Jacobson, R.D. (1998). Navigating maps with little or no sight: An audio-tactile approach. In *Proceedings of the Workshop on Content Visualization and Intermedia Representations*, pages 95-102.

Jacobson, R.D. (2002). Representing spatial information through multimodal interfaces. In *Sixth International Conference on Information Visualisation*.

Kildal, J., and Brewster, S.A. (2007). Interactive generation of overview information using speech. In *Extended Abstracts of ACM CHI 2007* (San Jose, CA, USA), ACM Press.

Kosslyn, S. M., Thompson, W.L., and Ganis, G. (2006). *The Case for Mental Imagery*. Oxford University Press, New York.

Kostopoulos, K., Moustakas, K., Tzovaras, D., Nikolakis, G., Thillou, C., and Gosselin, B. (2007). Haptic access to conventional 2D maps for the visually impaired. *Journal on Multimodal User Interfaces*, *1*(2): 13-19.

Lahav, O., and Mioduser, D. (2000). Multisensory virtual environment for supporting blind persons' acquisition of spatial cognitive mapping, orientation, and mobility skills. In *Proceedings of the Third International Conference on Disability, Virtual Reality and Associated Technologies*, pages 23–25.

Levelt, W.J.M. (1989). *Speaking: From Intention to Articulation*. The MIT Press, Cambridge, MA.

Lobben, A.K. (2004). *Tasks, strategies, and cognitive processes associated with navigational map reading: A review perspective. The Professional Geographer* 56(2): 270–281.

Loomis, J.M., Klatzky, R.L., and Lederman, S.J. (1991). Similarity of tactual and visual picture recognition with limited field of view. *Perception*, 20(2): 167-177.

Maaß, W. (1994). From vision to multimodal communication: Incremental route descriptions. *Artificial Intelligence Review*, 8(2): 159-174.

Moustakas, K., Nikolakis, G., Kostopoulos, K., Tzovaras, D., and Strintzis, M.G. (2007). Haptic rendering of visual data for the visually impaired. *IEEE Multimedia*, 14(1): 62-72.

Palmer, S. (1978). Fundamental aspects of cognitive representation. In E. Rosch and B. Lloyd (Eds.), *Cognition and Categorization,* pages 259-303. Lawrence Erlbaum, Hillsdale, NJ.

Parente, P., & Bishop, G. (2003). BATS: the Blind Audio Tactile Mapping System. In *Proceedings of the ACM Southeast Regional Conference*.

Perkins, C. (2002). Cartography: progress in tactile mapping. *Progress In Human Geography,* 26(4*)*: 521-530.

Pirolli, P., and Card, S. (1999). Information foraging. *Psychological Review,* 106(3): 643–675.

Salisbury, K., Brock, D., Massie, T., Swarup, N., and Zilles, C. (1995). Haptic rendering: Programming touch interaction with virtual objects. In *Proceedings of the 1995 symposium on Interactive 3D graphics*, pages 123–130.

Timpf, S., and Kuhn, W. (2003). Granularity transformations in wayfinding. In Kuhn, W., Worboys, M.F. and Timpf, S. (eds). *Spatial Information Theory 2003*, pages 77–88. Springer, Berlin.

Ungar, S., Blades, M., and Spencer, C. (1993). The role of tactile maps in mobility training. *British Journal of Visual Impairment*, *11*(2): 59-61.

Wall, S., and Brewster, S. (2006). Feeling what you hear: Tactile Feedback for navigation of audio graphs. In *Proceedings of the SIGCHI conference on Human Factors in computing systems*, pages 1123-1132.

Wang, Z., Li, B., Hedgpeth, T., and Haven, T. (2009). Instant tactile-audio map: Enabling Access to digital maps for people with visual impairment. In *Proceeding of the eleventh international ACM SIGACCESS conference on computers and accessibility*, pages 43–50.