Situation-aware navigation assistance for people with dementia

Henkel, Ron¹; Koldrack, Philipp¹,²; Zarm, Katja²; Teipel, Stefan²,³; Kirste, Thomas¹

Abstract
Among the most effective measures against the decline of cognitive abilities due to dementing disorders is engagement in cognitively stimulating activities. Cognitively demanding outdoor and social activities are helpful to provide emotional support. However, Alzheimer's disease as the most frequent cause of the dementia syndrome early affects skills for spatial orientation while it simultaneously impedes planning and error compensation abilities - both necessary skills to overcome disorientation in unfamiliar environments. Due to concerns in their orientation abilities in unfamiliar or even familiar environments, people with dementia progressively limit their life-space and diversity of activities. Providing appropriate guidance is helpful in disoriented situations to avoid dangers, while not, in addition, complicating normal mobility in order to maintain a person's life-space, activity spectrum and cognitive health.

Nowadays, smartphones as technological basis for mobility support seem to be a working solution for the now younger next generation of dementia patients - who are used to utilize modern technology. Today's possibilities of mobility support offer an effective alternative to the strategy of self-limitation of live-space. However, for the mobility support to be less invasive as possible it is desired to detect states of disorientation in a patient's mobility pattern. Computational Causal Behavior Models seem to be applicable to the problem. We propose a study design to enable model building, parameterization and evaluation. Our study investigates a base for a learning system capable of detecting disorientation, stepping in, and offering guidance - and thereby enhances a patient's independence and quality of life.

1. Introduction
The extent of outdoor mobility [1,2] and the engagement in social activities [3,4] decreases with progressing cognitive decline due to dementing disorders. In interviews led by Brorrson et al. [5], people with dementia reported a change of attitude towards the use of public space. They pointed out to prefer a limitation of outdoor activities to familiar environments. The stated causes for this development are, on the one hand, motivational changes and, on the other hand, growing security concerns. The authors emphasize the experiences of lacking ability to stay in control, made by their informants. In light of the immediate risk and dangers of getting lost due to dementia symptoms, avoiding such incidents by restricting mobility is reasonable. However, mobility itself is quite cognitively challenging and also a major prerequisite for demanding social activities [6]. As regular cognitive stimulation is known to be a protective factor against progressive loss of mental abilities, a medium result of less mobility may be an accelerated disease progression. Counteracting this development and potentially preserving health, by providing assistive technology for mobility, should concentrate on strengthening the user's ability to stay in control when moving outdoors. Approaches to stimulate motivation might lead to dangerous situations, if a person is encouraged to go beyond her limits, while pure security appliances, like tracking devices, just prevent the most severe consequences but enable no active target-oriented mobility.

To remain in control of a complex situation can be understood as deciding and acting properly, steering a situation along a desirable course. An essential precondition is the operator's situation awareness (SA), which has been conceptualized by Endsley [7]. According to the author, decision-making in dynamic environments is usually based on a twofold process. First acquiring SA by eliciting essential situational attributes. Then pattern-matching against prototypical situations stored in the long-term memory. The first step of elicitation is the most difficult part and heavily depends on sensory skills to perceive environmental attributes, attention control and working memory to separate out the vital situational aspects and further cognitive skills to infer future developments and access higher order knowledge. People with dementia, especially due to Alzheimer's disease (AD) usually experience problems on each layer of acquiring SA in outdoor environments. Lithouš et al. [8] provide a comprehensive overview of orientation skills affected in AD. Visual deficits come along with lower performance in perception of self-motion and recognition of landmarks. The compromised short-term memory impedes learning new routes, while deteriorating cognitive facilities for the representation of spatial layouts interfere with the ability to dynamically navigate, even in familiar environments and progressively also to remember episodic landmark-direction associations, used on known path. Field studies by Passini [9] and Rainville [10] have revealed disabilities regarding goal-directed mobility in topologically accessed environments. Those originate, among others, from problems in sorting out irrelevant data, combining environmental information with

¹ University of Rostock - Institute of Computer Science, Germany
² German Center for Neurodegenerative Diseases, Rostock-Greifswald, Germany
³ University of Rostock - Clinic of Psychosomatic and Psychotherapeutic Medicine, Germany
knowledge, or deriving information using inference. Making plans, refining and executing plans is also often not successful. Assistance to enable acquiring SA for proper decision-making will have to take individual ability characteristics and situational attributes into account. An appropriate model formalism must therefore be able to represent essential cognitive processes related to the task, environmental attributes and physical actions of the person, while being individually parametrizable. We hypothesize symbolic models for Computational Causal Behavior Models [11] to be adaptable to the problem and propose a study design to enable model building, parameterization and evaluation.

2. Methods, Sensors and Study Design

2.1 Study Design
Participants are selected from a pool of dementia-diagnosed patients. A psychologist determines their mental state using the standardized mini-mental state examination (MMSE). In addition, an assessment about the patients’ environment, attitude towards modern technology, outdoor navigation, and imagination of assistive navigation technology is conducted. Only patients with autonomous outdoor activities and a positive attitude towards technology are selected for the study.

The study design is split into two separated assessments. First, a long time assessment (minimum of 4 weeks) of daily outdoor activity. And second, an accompanied 20 minutes walk along a predefined cognitively demanding route with potentially stressful outdoor situations. The long time assessment is recorded via GPS, accelerometry, and a mobility diary. The participants are instructed to wear a bandage containing GPS and accelerometer every time they leave their home. In addition they are briefed to add an entry to their mobility diary; containing date, time, destination, stopovers, means of transport, incidents, and stating if the trip was accompanied. After approximately two weeks the participant receives a personalized, smartphone based, navigation assistant to gather data on usage behavior and usability. In addition, we monitor the handling of the sensors given to the participants’ by calling them in a three day period.

After the long time assessment the participants are invited to a 20 minutes accompanied walk. Here, sensors to measure electrodermal activity and electrocardiography are worn in addition to GPS and accelerometer. Both additional sensors are necessary to conclude the stress level during the walk. For later analysis, the walk is videotaped. Prior to the recorded and videotaped part of the walk, the participant and the attending psychologist meet at a defined public location. The psychologist guides the participant to a tram station approximately one kilometer away. Aside from the usually crowded tram station, the route contains a four-way crossing of two main streets, as well as narrow streets in a residential neighborhood. The participant is asked to memorize the route. Starting from the tram station, the participant is asked to walk back on his own. While walking back, the psychologist stays in the background, observes and protocols behavior, and only interacts with the participant in case of unresolvable disorientation.

2.2 Sensor Systems
To record our participant’s movements we rely on a GPS receiver (Qstarz Travel Recorder XT, BT747). We limited the recorded GPS sentences defined by the National Marine Electronics Association to the recommended minimum (RMC) and essential fix data (GGA). With an interval of 5 seconds, values for Latitude, Longitude, Altitude, Speed, FIX, Date and Time are recorded. To collect acceleration data the Move II activity sensor from Movisens is used. Acceleration data is recorded for three axes with 64 Hz. The sensors are placed in a bandage worn on the left ankle. The edaMove sensor from Movisens measures the electrodermal activity of the skin with 32Hz. The edaMove is worn on the left wrist. A single channel electrocardiography is recorded by a Movisens ekgMove sensor (256Hz), attached to the chest.

2.3 Behavior Models
Computational Causal Behavior Models (CCBM) have been shown to effectively recognize goal oriented behavior [11] from noisy or ambiguous sensor data. In order to provide situation awareness within our study we apply CCBM for activity and context recognition. A causal action model is created by means of precondition and effects. To later detect potential disorientation such states have to be included in the behavior model. A dynamic Bayesian network is then synthesized from this model where nodes represent environment states and edges represent actions. The sensor model, necessary to infer user action, is created from annotated training data. Probabilistic filtering methods are then applied to recognize the situation.

3. Results
To develop a CCBM and train its sensor model, a pool of movement data and annotated behavior have to be available. In the following, we first describe our developed ontology followed by the set-up to acquire movement data. In addition, we provide a first evaluation about quality and usefulness of collected data.
3.1 Ontology
In order to develop a CCBM able to recognize a participant’s activities and detect states of disorientation, it is necessary to understand and annotate a participant’s behavior and movements. An Ontology comprising concepts of outdoor activities for dementia patients is an essential knowledgebase for such an annotation task. While various ontologies for human motion are present, mostly the focus is on annotating positions of body parts for motion capturing [12] or dancing [13,14]. In contrast, our task requires an Ontology capable to represent outdoor movement, intention, interaction with outdoor objects and subjects, location specifics, and, most importantly, observed disorientation. Consequently, we developed an Ontology containing 66 classes in 8 orthogonal branches, shown in Figure 1.

3.2 Long Term Assessment
From the long time assessment of two AD diagnosed participants (X001 and X002) datasets were collected. A data set includes GPS and accelerometric data, points of interest defined by the participant and a mobility diary. Evaluating the quality of the collected data and mobility diary is mandatory to use the data later on for a CCBM. We thus assessed if the mobility diary entries reflect the recorded GPS positions. A record is correct if an mobility diary entry is provided and the corresponding start and end time of an outdoor activity indicated by GPS is not off by more than 30 minutes. Expectedly, a significant amount of daily outdoor activities is not represented in the data, either because of missing mobility diary entries or GPS data. Only 36% (X001) and 41% (X002) of GPS recorded activities where stated accurately in the mobility diary. As aforementioned, the participants were asked to state points of interest (POI). For the assessment duration the GPS data shows that X001 only visited one POI, X002 visited all except for one POI.

3.3 Accompanied Walk
By choosing a cognitively demanding route we actively try to invoke disorientation during the accompanied walk. It is essential to collect data reflecting states of disorientation in order to annotate such disorientation and train the CCBM’s sensor model. To annotate the data, a human curator is inevitable. However, disorientation during the accompanied walk is not guaranteed. Thus, we also look for potential disorientation in our participant’s long time assessment. To ease annotation a video-stream is created for each outdoor activity that occurred during the longtime assessment, showing the participants movements on the left and the according accelerometric data on the right (see Figure 2). The annotation is based on the concepts specified in the aforementioned Ontology and comprises information extracted from the mobility diary and identified states disorientation. In future, annotation together with the collected data will be used to develop a CCBM and train its sensor model.

Figure 1: This Ontology excerpt shows the main branches used to annotated participants’ movements and behavior.

Figure 2: This Figure shows a snapshot from Google Maps overlaid with a participant’s movements, extracted from collected GPS data (left). Acceleration data (top) and speed (bottom) is shown on the right side.
3.3 Problems
We will briefly outline a movement pattern that likely shows disorientation and was observed in one of the longtime assessments: The participant leaves home, walks slowly on the sidewalk while stopping and waiting once in a while. In the following, the participant enters a wooded area and moves randomly within a small area. The walk continues on the sidewalk and, shortly after, across a field heading home. Even though this looks like disorientation, the mobility diary entry reveals that the participant was walking the dog. This illustrates the importance of a-priori knowledge extracted from, for example, the mobility diary. Using GPS, accelerometric data and the mobility diary together with a CCBM, prospectively allows distinguishing movement patterns looking like disorientation from real disorientation.

4. Conclusion
To keep patients suffering from dementia mobile and thus healthy as long as possible is a valuable goal in an aging society. Today’s possibilities of mobility support offer an effective alternative to the strategy of self-limitation of live-space. For the mobility support to be as less invasive as possible it is required to recognize activities, environment states and intentions, as well as states of disorientation in a participants' mobility behavior. We aim at using Computational Causal Behavior Models (CCBM) for such recognition. In this manuscript we described the study design and observations from two participants’ long time assessments. Subsequently, we explored the data gathered from our two pilot participants. We showed that the accuracy of matching activities with corresponding mobility diary entries is very low, in our case regardless if the participant or the caretaker kept the diary. Due to the low accuracy, data from the mobility diary is probably not suitable to be used without manual prior pre-processing.

In addition we sketched an Ontology developed to annotate outdoor activities of patients suffering form dementia. Using knowledge about location and environment of potential disorientation allows us to investigate further, i.e. by talking to the participant in question, and validate or discard a disorientation assumption. We plan to annotate the datasets and use this knowledge to develop a CCBM and enable its sensor model to recognize participants’ daily outdoor activities and potential states of disorientation. Such a CCBM may be able to observe a patient, recognize disorientation and offers help depending on what activity was interrupted by the disorientation. Altogether, such a system may increase a patient’s mobility, strengthen his self-confidence, and, subsequently, improve the patient’s health and ease the work of the caretaking family members.

Acknowledgments
The authors acknowledge the BMBF for funding the SiNDeM Project (16SV7091).

Contact: Ron Henkel, ron.henkel@uni-rostock.de, 0381-4987521

References