# PROVIDING CONTEXT-AWARE SERVICES TO DEMENTIA PATIENTS AND CAREGIVERS

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## Abstract

As a result of increased human lifespan, dementia becomes a national public health and social care priority worldwide. Although, there is no cure for dementia, the wandering behavior of dementia patients can be managed by an ambient assisted living system. In this paper, Wandering Behavior Ontology (WBO) used for dealing with wandering behavior seen in early stage dementia patients is proposed. WBO is used in iCarus, which is an intelligent ambient assisted living system, for providing context-aware services to dementia patients and their caregivers. Knowledge sharing, knowledge reuse and logical reasoning are provided by using ontologies. iCarus aims to reduce the problems and financial burden associated with a wandering episode for the patients and their caregivers. It provides longer independent living for the elderly people and a cost-effective way of remotely monitoring them. The actions that are to be taken are determined by rule-based reasoning. These actions are sequential and they are defined in the developed ontology. These actions include warning the patient and informing the caregiver and the emergency service.

**Keywords:** Context-awareness, rule-based reasoning, ambient intelligence, ambient assisted living.

## 1. Introduction

As a result of increased human lifespan, dementia becomes a national public health and social care priority worldwide. World Alzheimer Report 2016 estimates that 47 million people live with dementia and that this number will rise to 131 million by

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2050. Also, the total estimated cost of dementia has reached 818 billion US dollars worldwide, and by 2018, it will become a trillion dollar disease [1].

Dementia is the loss of cognitive functioning, resulting in impaired memory, difficulty in communication, and reduced cognitive ability. This affects the person's daily life and capabilities such as thinking, remembering and reasoning. Alzheimer's disease is progressive and gets worse over time. It destroys the brain slowly, while decreasing quality of life and finally leading to death [2, 3].

As a result of cognitive decline, people with early stage dementia may suffer from unpredictable wandering behavior. They have a tendency to leave their residences and get lost. This can result in malnutrition, sleep disturbances, accidents, injuries and in some cases death [4-6]. Studies show that approximately 67% of dementia patients may suffer from wandering behavior, and half of those not found within a day suffer serious injuries or death. Wandering behavior might take place as a result of getting lost from spatial disorientation or getting lost due to goal-oriented behavior (e.g. a person trying to go to his old house or working place) [6, 7].

Dealing with this behavior requires continuous vigilance and being on alert all the time. The patient is a person and has the right to live autonomously as long as possible; however, the dignity of the patient should be preserved, but these are conflicting issues [6]. Caring for a dementia patient is very stressful, and the caregivers feel depression as a result of degenerating behavior of the patient [6, 8].

Although, there is no cure for dementia, the wandering behavior of dementia patients can be managed by using Information and Communications Technologies (ICT) [8]. ICT forms the basis of Ambient Intelligence (AmI) systems. AmI promotes an anthropomorphic human-centric computer interaction, where devices weave themselves into the fabric of everyday life, so that they are virtually invisible to humans [9-11]. Essential for AmI is the recognition of objects and their situational context, and the delivery of services that are personalized, adaptive and anticipatory [8, 12].

Ambient Assisted Living (AAL) is the application of AmI technologies in the health domain. AAL systems aim to enable people with specific needs (e.g. elderly or handicapped) to live independently for longer periods of time [12].

It is hard to think an AAL system without the context-awareness, since the context-awareness is a key factor in AmI and AAL systems [13-15]. Systems in these kinds of emerging fields need to have a higher understanding of the situations to deliver services or functionalities and to adapt accordingly [13]. Simply, the context-awareness means being aware of the current location and surrounding environment [15], and the it is crucial for delivery of personalized, adaptive, and anticipatory service in AmI and AAL systems [8, 12].

In this paper, Wandering Behavior Ontology (WBO), used for managing wandering behavior in dementia patients, is described. WBO is encoded in OWL (Web Ontology Language) and it is available online through a GitHub repository from [16]. WBO is used in iCarus, which is an intelligent ambient assisted living system, for providing context-aware services to dementia patients and their caregivers. Knowledge sharing, knowledge reuse and logical reasoning are provided by using ontologies. Ambient assisted living is provided through the ambient intelligence and context-awareness paradigms. iCarus aims to reduce the problems and financial burden associated with a wandering episode for the patients and their caregivers. It provides longer independent living for the elderly people and a cost-effective way of remotely monitoring them. The actions that are to be taken are determined by rule-based reasoning. These actions are sequential and they are defined in WBO. These actions include warning the patient and informing the caregiver and the emergency service.

The system is rule-based and has expert system properties. The caregivers are able to compose their own rules and extend the functionality of the system with regards to their needs. Constructing new rules is accomplished by an innovative interface used by the caregivers. The users do not need to know the syntax of the used rule language. In this approach, the context reasoning is decoupled from the source code of the system. New functionalities can be added to the system without changing the source code. Thus, a flexible and extensible system is developed. WBO is used to provide the delivery of personalized, adaptive, and anticipatory services.

## 2. Background

### *2.1 Ambient Intelligence (AmI)*

Weiser [11] envisioned a paradigm in which computers disappear seamlessly embedded into the environment. AmI is built upon pervasive and ubiquitous computing paradigm where access to resources, data, and information is possible anytime and anywhere. Facilitated by the miniaturization of electronics, many mobile devices are available with sensing and computing capabilities, which takes the computational paradigm out of the desktop. These devices are portable, accessible, and affordable. This has flourished new opportunities while interacting with technologies, bringing them closer to people's daily life experiences [13].

AmI uses artificial intelligence to further enhance the use of surrounding, unobtrusive computing devices. AmI emerged to build intelligent environments such as smart homes, smart hospitals, and etc. AmI systems are expected to be sensitive, responsive, adaptive, transparent, ubiquitous, and intelligent. The context-awareness is a key factor in providing these features [14]. In iCarus, strong emphasis is placed on context and context-awareness.

*2.2 Context-awareness*

Different researchers have made different definitions of context in mobile computing. Dey [17] defines *context* as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" [18].

Schilit and Theimer [19] refers to *context-aware computing* as software that "adapts according to its location of use, the collection of nearby people and objects, as well as changes to those objects over time" [17]. Thus, context-aware software can be defined as software that adapts to its context and changes which occurs in this context [18].

Existing efforts to model context can be classified into three categories [20]: application-oriented approach, model-oriented approach and ontology-oriented approach. From these categories, in the application-oriented approach, no formalism and knowledge sharing between different systems are supported. Because it is not formal, it is specific to an application and lacks expressiveness. The model-oriented approach is formal, but knowledge sharing and the context reasoning are not supported. On the other hand, the ontology-oriented approach has the formal basis and the knowledge sharing in addition to supporting the knowledge reuse and the context reasoning [20]. In order to perform the reasoning over ontologies, we can use the rule-based reasoning and/or description logic reasoning.

In iCarus, the ontology-oriented approach is used because it has many advantages over the other approaches as it is mentioned earlier. WBO, used by iCarus, also includes metadata to improve certainty and accuracy of data similar to [21]. The software or hardware components used for sensing data are also modeled, and their precision and accuracy are included in WBO.

*2.3 Ambient Assisted Living*

One of the applications of AmI is in AAL domain which tries to exploit proper technologies to support citizens with specific needs (e.g. elderly or handicapped) to live in their preferred environment independently for a longer period of time. Thus, the costs of caring for the patient are reduced, and the quality of the patient's life is preserved [10].

AAL systems obtain knowledge about their surroundings with sensors, autonomously act on behalf of their users, or they interact with their users in an unobtrusive and intuitive manner. Especially, AAL systems should extend the time people spent in their homes, increase their autonomy, and mobility, help them maintain better life, enhance their security, and assist caregivers and families [22].

## 3. Overview of iCarus

In this section, iCarus is described briefly. For a detailed description of iCarus and its architecture, please refer to [23].

In iCarus, the patient's environment is partitioned into zones. Zones can be defined in both the spatial and temporal dimensions. Defining zones is caregivers' duty. There are 3 types of zones:

i. Green zone: This is the safe zone. The patient's home may be considered as a green zone.
ii. Red zone: Areas that are dangerous for the patient are defined as red zones. An example of a red zone is a busy cross road.
iii. Orange zone: The orange zone is considered as a green zone, if the temporal constraint related to the zone is met. Otherwise it is considered as a red zone.

iCarus also supports considering other contextual information such as age, stage of dementia, weather, the proximity to the caregiver, stage of dementia, day of week, time spent in a zone, and other parameters. In addition, new zone types can be defined by caregivers according to their needs. A novel user interface can be used to construct rules without knowing the syntax of the rule language.

iCarus is a rule-based system. In case a wandering episode occurs, rule-based reasoning is used to decide on the actions. The situation's severity and the user preferences have an impact on the actions. The available actions are warning the patient by text and audio, helping the patients with navigation assistance for returning back to safe zone or home, notifying the caregiver, providing tracking mechanisms for the caregiver and emergency service, establishing voice communication and texting the caregiver and the emergency service.

The server receives the current location of the patient and the time stamp from the patient mobile application. Then, it specifies the zones where the patient is in, calculates speed and heading direction. This information is added to the ontology in order to construct the current context of the patient. Other dynamic context information is also added to the ontology. Then, rule-based reasoning is applied resulting in a sequence of actions. This sequence of actions includes a combination of the following actions:

- Warning the patient: The patient is requested to return back to the safe zone by text and audio notifications. In order to help the patients return back to the safe zone, audio, visual and text directions are presented on a map. If the patient does not comply in a certain amount of time, the application proceeds to the next action.
- Sending alert notification to the caregiver(s): An alert is sent to inform the caregiver of a wandering episode, to establish bidirectional communication, and to share the patient's location and navigation information. The caregiver can track the patient on a map, when an alert message is received. If the caregiver does not respond, the application proceeds to the next action.
- Calling the caregiver with the speakers on: The smart phone of the patient calls the caregiver with the speakers turned on. This action assumes that the patient will respond to a familiar voice.
- Sending notification to an emergency service: The patient application sends a message, notifying the authorities about the circumstance and navigation information of the patient through SMS or e-mail.

- Calling an emergency service with the speakers on: The patient application calls the emergency service with the speakers turned on. The caregiver can also command the patient's phone to call the emergency service.

The sequence of actions is sent to the mobile device of the patient, which in turn, the patient application processes the actions one by one sequentially. In the default setting, first the patient is prompted to return back to the safe zone. If the patient does not return to the safe zone, an alert is sent to the caregiver. Alternatively, the patient can send an alert to the caregiver at any time if he/she is lost or there is an emergency. The caregiver can track the patient on a map through the caregiver mobile application, desktop application, or web application. The location, heading direction, and speed of the patient are shown to the caregiver. If the caregiver concludes that there is no danger for the patient, and the patient is not in a wandering episode, then the caregiver can cancel the alert. If the patient is located in the red zone and the caregiver does not respond, the application informs or calls the emergency service, because there might be a life danger.

If the caregiver concludes that there is a life danger, he can inform the emergency service or the police and give them a code which is valid for a limited amount of time. Now, the emergency personnel can track the patient on a web browser.

## 4. Wandering Behavior Ontology

As mentioned previously, WBO is encoded in OWL and it is available online through a GitHub repository from [16]. Domain ontologies are defined and shared across different platforms and people by using OWL. An ontology refers to a formal representation of a set of concepts in a domain and the relationships between those concepts [24, 25].

Protégé [26] ontology editor is used to develop WBO. A partial view of WBO from Protégé editor is shown in Figure 1. During the development, the best practices from other related work [20, 21, 25, 27-29] are adopted.

Providing knowledge sharing, knowledge reuse, and logical reasoning support are among the advantages of using ontologies. Jena [30] is used to manipulate ontologies and to perform logical inference. A general view of WBO depicting most important classes and the relationships between them is shown in Figure 2. Some of the classes are omitted in this figure, because there are a huge number of classes.

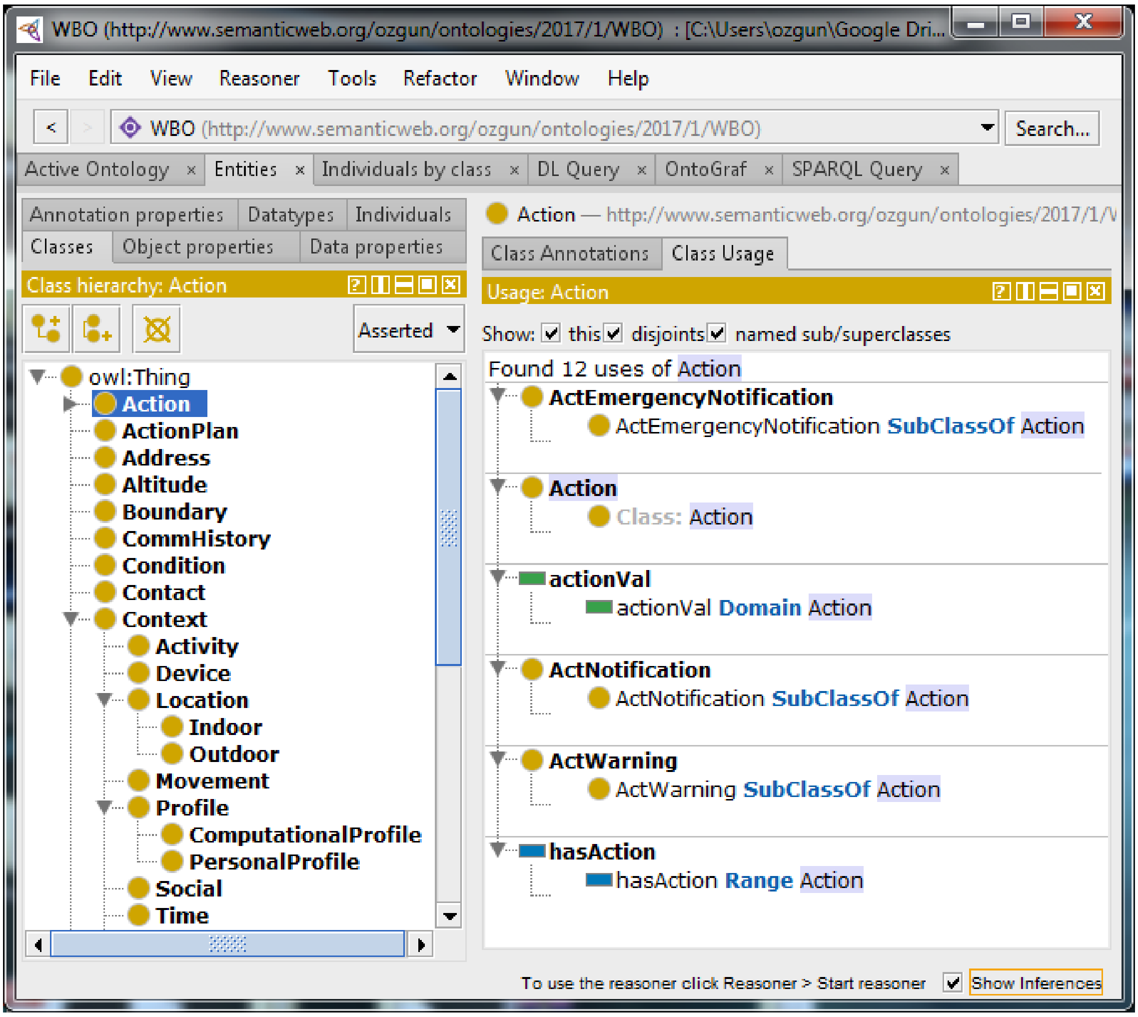


Figure 1. A partial view of WBO from Protégé editor.

WBO is modeled through classes, object properties, data type properties and restrictions. *Entity* class represents things that can be related to a context. *Entity* class has four subclasses: *Person*, *Place*, *Object* and *ComputationalEntity*. *ComputationalEntity* has many subclasses such as *Agent*, *SmartPhone*, *MobileDevice*, *Computer* and etc.

*Entity* is related to *Context* class. Zone, location, time, weather, social situation, device, activity, network and profile are subclasses of *Context* class.

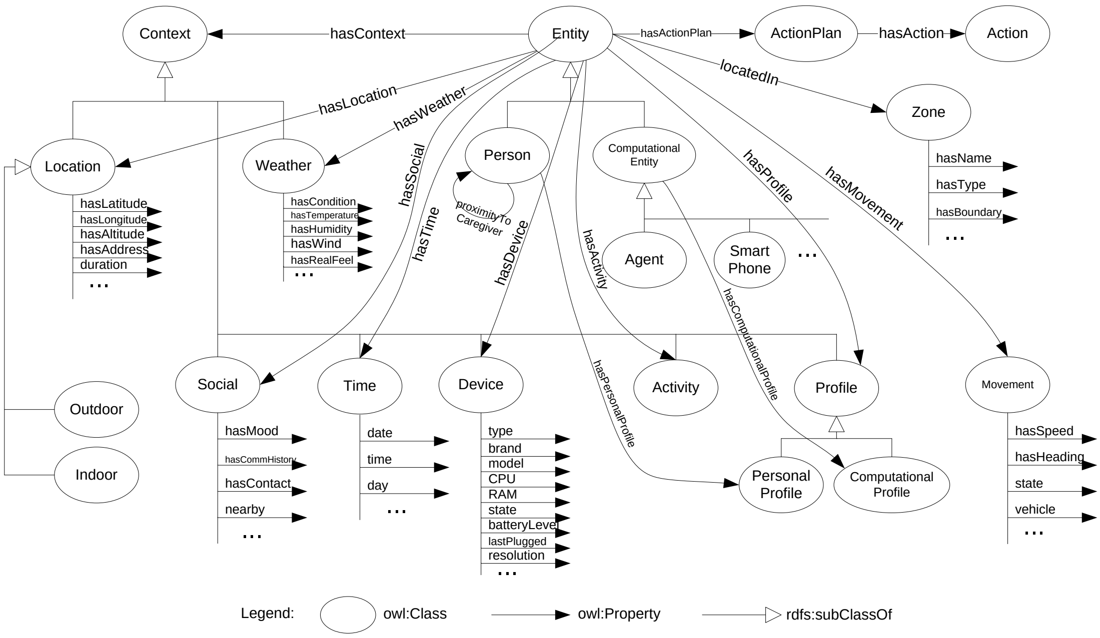


Figure 2. A general view of WBO.

*Location* is composed of *Latitude*, *Longitude*, *Altitude* and *Address* classes. Time spent at a place is stored in *duration* data type property. Time context consists of date, time and day of the week values. Device context includes device type, brand, model, CPU, memory, device state, battery level, last plugged time and screen resolution of the device. Network (not included in Figure 2) context models communication costs, network type, and other quality parameters such as network bandwidth, ping, packet loss rate, error rate, throughput, latency and jitter. *Profile* class stores entity ID, description, name and etc. *PersonalProfile* and *ComputationalProfile* are derived from *Profile* class. *PersonalProfile* models personal information such as name, surname, age, occupation, birthdate and other demographic information, whereas *ComputationalProfile* models computational information of a computational entity. *Person* class is associated with *PersonalProfile* class. Similarly, *ComputationalEntity* is associated with *ComputationalProfile* class. Every entity must have one and only one profile which is enforced by restrictions. All of these classes can be further extended to meet other requirements.

*Weather* class represents the current weather around an entity. Weather context is acquired from a third party web service and consists of weather condition (such as sunny, cloudy, rainy, etc.), temperature, humidity, wind, and real feel temperature. Social context of the entity is composed of current mood, communication history, contacts, and nearby entities. *Movement* class models movement of the entity and it is associated with speed, heading, state and used vehicle.

In iCarus, individuals are created from the previously mentioned ontology classes, and the user specific context is constructed. Static context is composed of the user's personal profile and mobile device properties. Static context can be stored in a permanent storage. On the contrary, location, time, movement, and network parameters can change constantly in an application with mobile users and this information compose dynamic context. Dynamic context is handled on the fly programmatically. After the context is formed, the reasoning takes place. Reasoning is made over WBO to decide on the actions to take and the order of these actions.

*ActionPlan* class represents the action plan (interventions) composed of sequence of actions represented by *Action* class. As a result of the rule-based-reasoning, this class is linked to the context if there is a need to interrupt the patient. The OWL code for *hasActionPlan* and *hasAction* object properties is given in Figure 3.

*Zone* class represents the zone, the patient is currently located in. If the patient is not located in any one of the zones including user defined zones, then it is asserted that the patient is in the neutral zone, and this fact is added into the ontology. This serves as a syntactic sugar for better expressive power.

```
<owl:ObjectProperty
rdf:about="./ozgun/ontologies/2017/1/WBO#hasActionPlan">
    <rdfs:domain rdf:resource="./ontologies/2017/1/WBO#Entity"/>
    <rdfs:range rdf:resource="./ontologies/2017/1/WBO#ActionPlan"/>
</owl:ObjectProperty>

<owl:ObjectProperty
rdf:about="./ontologies/2017/1/WBO#hasAction">
    <rdfs:domain rdf:resource="./ontologies/2017/1/WBO#ActionPlan"/>
    <rdfs:range rdf:resource="./ontologies/2017/1/WBO#Action"/>
</owl:ObjectProperty>
```

Figure 3. The OWL code fragment for *hasActionPlan* and *hasAction* object properties.

WBO deals with quality of context similar to [20]. Physical sensors may produce incorrect or stale context data due to imperfect sensing and poor reliability. In WBO, quality is associated with a number of quality parameters, which capture different dimensions of quality. Each parameter is linked to one or more appropriate quality metrics. A metric contains a value, a type and a unit. Three types of quality parameters are defined: accuracy, resolution and freshness. As a result, quality parameters can play an important role in rules defined to be used for reasoning.

*4.1 Context Reasoning*

By rule-based reasoning, high level context is obtained from low level context. Supplementary rules are shown in Table 1. For the essential rules, please refer to [23]. The caregiver can contact the system administrator to modify these rules or add new rules. In the consequents of the rules given in Table 1, an action plan is represented by *AP*, an individual which is created before reasoning. Similarly, *ActWarning*, *ActNotification* and *ActEmergencyNotification*, represents warning the patient, sending notification to the caregiver and to the emergency service, respectively.

Table 1. The supplementary rules used in reasoning.

| **Rule description** | **Rule** |
|---|---|
| Speed limit | (?p hasMovement ?m) ∧ (?m hasSpeed ?s) ∧ (greaterThan(?s, 50)) ⇒ (?p hasActionPlan AP) ∧ (AP hasAction ActWarning) ∧ (AP hasAction ActNotification) ∧ (AP hasAction ActEmergencyNotification) |
| Hot and sunny weather | (?p locatedIn ?z) ∧ (?z hasType "NeutralZone") ∧ (?p hasWeather ?w) ∧ (?w hasCondition "sunny") (?w hasTemperature ?c) ∧ (greaterThan(?c, 35)) ⇒ (?p hasActionPlan AP) ∧ (AP hasAction ActWarning) ∧ (AP hasAction ActNotification) |
| Proximity limit | (?p proximityToCaregiver ?c) ∧ (greaterThan(?c, 20)) ⇒ (?p hasActionPlan AP) ∧ (AP hasAction ActNotification) |

The caregiver can activate or deactivate the supplementary rules, and he can also modify the limit values (speed limit, temperature limit and proximity limit) from the preferences.

The speed limit rule is for fast moving vehicles. If the patient is in a fast moving vehicle, he may end up far away from his home. If he takes an intercity bus, he may end up in another city. For these reasons and for the fact that the dementia patients shouldn't and may not be able to drive, this rule may be necessary. Sending a notification to the emergency service is included in this rule because the patient's life might be in danger like the case with the red zone. Also, the caregiver may have difficulty catching up with the patient and faster action must be taken if the patient is moving fast.

The hot and sunny weather rule is for protecting the patients from heatstroke. The weather condition is acquired from online weather services. If the patient is in the neutral zone, the weather is sunny and the temperature is greater than 35 °C, then warning the patient and sending a notification to the caregiver actions will be taken.

The proximity limit rule is triggered when the distance between the patient and the caregiver exceeds the limit. The only action in the consequent is sending a notification to the caregiver and the emergency service is not notified.

## 5. Related Work

In [20, 29], an OWL encoded context ontology (CONON) for modeling context in pervasive computing environments is proposed. Context reasoning is used to check the consistency and to derive high-level implicit context.

In [21], an ontology-based context model encoded in OWL is introduced. To assess the value of the context model, a scenario is described. In addition, a context ontology server is developed that manages and processes context information.

Rodriguez et al. [25] propose an ontological model to provide interventions for the wandering behavior. This model extends their Ambient Augmented Memory System (AAMS). AAMS provides the caregiver to define interventions based on the external memory aids to the patient provided by mobile devices. The ontology flexibility is demonstrated to personalize the AAMS system to support interventions for wandering through mobile devices. Context ontology and rule-based context reasoning is used.

In [27], the context model is composed of OWL encoded ontologies. The model consists of four related ontologies: users, devices, environment and services. The model supports logical inference to enhance the automatic context generation and the proactive behavior of some services.

In [28], ContextProvider, a framework that offers a unified and query-able interface to contextual data, is introduced. ContextProvider supports interactive user feedback, self-adaptive sensor polling, and minimal reliance on third-party platforms.

ContextProvider also enables the rapid development of new context and bio-aware applications.

In this paper, wandering behavior in dementia patients is modeled by WBO which is an OWL encoded ontology. Context is also modeled as a subset of this ontology. Best practices from the related work are adopted about modeling context. Quality of context is modeled, because of sensing errors and inaccuracies. Logical reasoning, knowledge sharing and knowledge reuse are provided by using an ontology.

## 6. Conclusion

As a result of increased human lifespan, dementia is a major health and social care challenge of today and the near future. Currently, there is no therapeutic solution for dementia. However, a solution for managing wandering behavior can be provided by using AmI. The context-awareness is a key factor in AmI, as it provides delivery of personalized, adaptive, and anticipatory services.

In this paper, WBO (Wandering Behavior Ontology), for dealing with wandering behavior in dementia patients, is described. WBO is encoded in OWL and by using ontologies, knowledge sharing, knowledge reuse and logical reasoning are facilitated. WBO is used by iCarus, which is an intelligent ambient assisted living system to provide context-aware services to dementia patients and their caregivers. The aim of iCarus is to provide independent living of the elderly people and a cost-effective way to monitor them in addition to reducing the adverse results and financial burden of a wandering episode for the patients and their caregivers. The interventions are deduced by rule-based reasoning. These interventions are sequential and they are defined in WBO.

In iCarus, the caregivers can construct new rules and extend the functionality of the system. Constructing new rules is accomplished by an innovative interface used by the caregivers. In this approach, the users do not need to know the syntax of the rule language and the context reasoning is decoupled from the source code. Without changing the source code, new functionalities can be added to the system. As a result, a flexible and extensible system is developed. By using WBO, the delivery of personalized, adaptive, and anticipatory services is achieved.

As a future work, it is planned to collaborate with dementia experts from other disciplines and use WBO in a real world setting.

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