

# An Ontology-based Context Model in Monitoring and Handling Agitation Behaviour for Persons with Dementia

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## Abstract

*This paper presents a new approach that exploits Semantic Web standards to provide a reusable middleware support for flexible event representation, query and reasoning, and standardized schemes for automated intervention triggering and activity planning to handle agitation detected in persons with dementia. The proposed context model enables the development of sophisticated systems that facilitates caregiving and clinical assessment of dementia patients in a context enlightened fashion. In particular, we describe the use of the Web Ontology Language (OWL) to model agitation quantification using Scale to Assess Observed Agitation in Persons with Dementia of the Alzheimer Type (SOAPD), intervention and social contexts to build an integrated monitoring and intervention system that exceeds the current state-of-the-art in robustness, intelligence and scalability.*

## 1. Introduction

There is mounting worldwide interest to apply recent developments in pervasive computing, context-aware systems and sensor networks for healthcare. One specific area of focus is to develop activities-of-daily-living (ADL) behavior understanding systems to facilitate caregiving and clinical assessment of demented elders within their own homes. In this paper, we describe a novel and integrated approach towards this end by providing a reusable middleware based on Semantic Web standards that can process and relay information in a context-aware fashion to both professional and familial caregivers, provide diagnostic basis for treatment, just-in-time intervention and therapy. This is illustrated with the scenario below.

*Jane, an insurance agent, is the primary caregiver for her father, Bob who is exhibiting early dementia*

*symptoms. Jane lives with Bob in a home fitted with an intelligent context-aware monitoring and intervention system. Through audio and visual cues, the system's acoustic and video sensors detects an unusual degree of ranting and pacing by Bob - common behaviors exhibited by a demented person feeling agitated. Jane receives an automated SMS asking if Bob's favorite Kenny G music should be played to provide relief. After punching in the authorization code, soothing Kenny G music could be heard within the home. Bob calms down considerably and soon falls sleep. In another occasion, Bob became agitated while Jane was at work. Through an interface to Jane's digital calendar, the system is made aware that she was at an important meeting. The SMS alert was relayed to her brother instead. When the meeting ended, Jane received a delayed alert and promptly called her brother who was already attending to Bob at home.*

*Every week, significant changes to Bob's behavioral patterns are consolidated and emailed to Dr Lee who treats Bob. Using the weekly summaries, not only can Dr Lee identify daily patterns of agitation onset so that he can adjust the drug therapy to pre-empt these episodes, he can also make accurate assessments of the rate of Bob's cognitive decline.*

Core to realizing the above is the development of a context-aware ADL behavior understanding system that can manage and react to various ad-hoc situations. The focus of this paper is to provide the context model and middleware architecture for its implementation. The rest of the paper is organized as follows: Section 2 discusses related work. Section 3 describes our context model, followed by architecture design in Section 4. Section 5 concludes with a discussion on future work.

## 2. Related Works

Previously, a number of system architectures have been

developed to support context-aware and pervasive computing such as the Context Toolkit [1], Schilit's context-aware architecture [2], Microsoft's EasyLiving [3] and HP's CoolTown [4]. These projects have greatly contributed to the research in smart spaces by exploiting different features of pervasive computing.

There are also projects that specifically address support for monitoring of people and the elderly. These include MIT's PlaceLab [5] which saw development of portable sensors capable of studying its resident's vital signs, Carnegie Mellon University's CareMedia [6] which uses video and audio information to automatically track and label persons, and characterize selected actions and activities. There is also Georgia Tech Institute of Technology's Aware Home Research Initiative [7], which built technologies and applications such as support for the elderly. With Harvard University's CodeBlue [8], a sensor network system for emergency response was developed to integrate a multitude of sensors and wireless nodes into a disaster response setting, with a software architecture providing facilities for ad-hoc network formulation. While these applications share our focus on monitoring, they usually cater to a specific application and sensor suite. Also, intervention support is based on rules which may mean an inability to cope with unknown situations. Furthermore, none provide social context support that takes into account the patient's or the caregivers' unique social network to accommodate support specific to them. Thus, while these systems have progressed in various aspects of pervasive computing, they remain weak in knowledge sharing, context reasoning support and are inadequate for our purpose.

Then, there are the context broker architecture [9] and semantic space [10] projects which build pervasive context-aware architectures for intelligent meeting room and location services. Our work is similar in that it also uses semantic web technologies and provides a reusable framework to ease application development. But it is different from, and perhaps outperforms for our task of developing an application for dementia patients, especially for crisis/intervention management with relevance to the social networks of the patient and implicated persons. Besides, providing an ontology-based intervention knowledge base that can adapt to various situations, we also provide the protocol infrastructure with a generic mechanism for context querying using a declarative language and inferring higher level context based on rules. Lastly, we provide a methodology to measure agitation in a patient for drug therapy and activity planning. By implementing

ideas in each area, we can expect an order of huge magnitude improvement in the effectiveness of agitation measurement and quality of life from the perspective of the patient and his caregivers.

### 3. An Ontology-based Model

In this section, we will describe our design considerations and modeling concepts.

#### 3.1. Design Considerations

A model that supports distributed heterogeneous sensing capabilities, provide scalable monitoring provisioning and support standardized schemes for automated intervention management, activity planning and drug therapy management is required. The requirements of the context model is two-fold: capture all the characteristics of context information relating to agitated behavior monitoring in persons with dementia and intervene by processing and relaying information in a context-aware manner. That is, we need a model that supports the knowledge management system that interfaces with a multitude of other systems that actuate specific interventions, e.g. music therapy system, or provide context information to a caregiver's digital calendar and/or decision-making aid. Lastly, privacy should be preserved during information propagation.

#### 3.2. Context Ontology

The wide range of context relevant to automated agitation quantification is categorized into – SOAPD/ observation specific, intervention and social semantics.

**3.2.1. SOAPD Ontology.** For our prototype, SOAPD, developed by Ann Hurley et al. [11] has been adopted to classify the degree of agitation experienced by a demented person. The tool (see Figure 3.2.1.a) consists of seven scale items where each item is an observable behavior. Every five minutes, duration of the subject's bodily movements and vocalizations is rated. For Repetitive Motions in Place and Outward Motions, intensity of the behavior is also rated. Total score for an observation session is derived as the sum of the weights of all observed behaviors.

Presently, trained clinicians undertake this hugely laborious task. But with system directed observations, not only can we enable continuous evaluation which need no longer be confined to clinical settings, we can also expect objective outcomes.

Scale Item	Duration	Intensity
Total Body Movements		N.A.
Up and Down Movements		N.A.
Repetitive Motions in Place		
Outward Motions		
High Pitched/Loud Words		N.A.
Repetitive Vocalization		N.A.
Negative Words		N.A.

:Superscript number denotes corresponding rating  
Duration::= 1\* <Not Present<sup>0</sup> | Short<sup>1</sup> | Medium<sup>2</sup> | Long<sup>3</sup>>  
Intensity::= 0\* 1 <Not Present | Mild | Moderate | Extreme>

Figure 3.2.1a SOAPD

However, before codifying SOAPD prior definitions of observation (Figure 3.2.1b), spatial and temporal concepts is required. Semantic lexicons (e.g. WordNet) are expected to be incorporated later to provide English language support for natural user-system interaction.

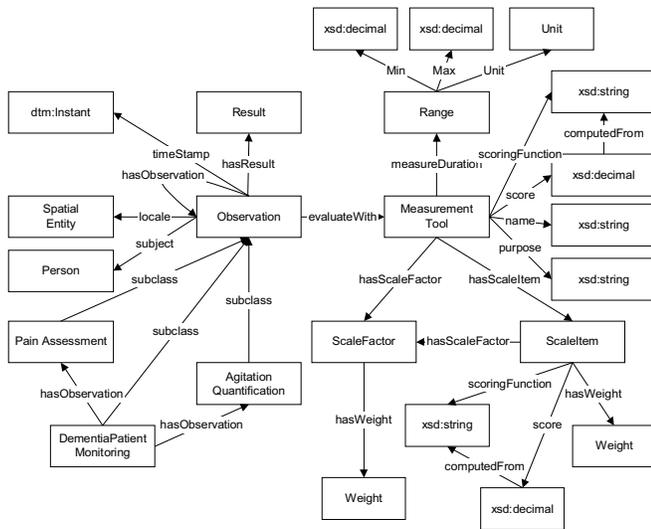


Figure 3.2.1b

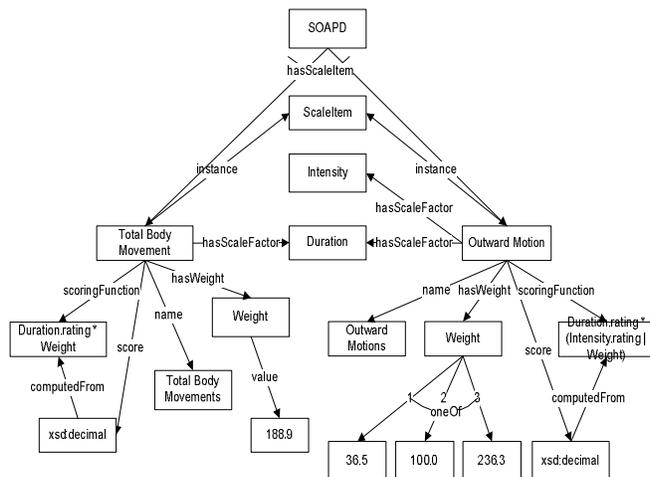
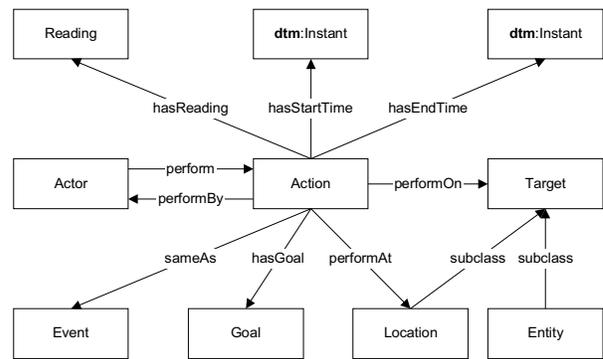


Figure 3.2.1c

Figure 3.2.1c illustrates a fragment of the SOAPD ontology through two representative scale items: Total Body Movement (Duration only) and Outward Motions (Duration and Intensity). For Total Body Movements, the assigned weight is 188.9 with its score computed as duration rating (e.g. Medium=2) multiplied by the weight (i.e. 377.8). With Outward Motions, its weight is dependent on the intensity rating (e.g. Intensity=mild => weight=36.5) which is then multiplied by the duration rating (e.g. Long=3) to derived the item score (i.e. 109.5). An arbitrary symbol (“|”) in the scoring function denotes this weight selection so that a specialized software module may dynamically interpret the function and compute these scores.



dtm=<http://daml.umbc.edu/ontologies/cobra/0.3/dam1-time>

Figure 3.2.1d Action Ontology

Given that Total Body Movements is an aggregation of other bodily activities such as disturbed pacing, additional terminology to model activities (Figure 3.2.1d) need to be included too. To instantiate an Enter event occurring on 1<sup>st</sup> October 2005 at 9:16:31pm, the associated OWL snippet would be:

```
<Enter rdf:ID="Enter_20051001_211631">
  <performedBy rdf:resource="#Patient"/>
  <performedOn df:resource="#MasterBedroom"/>
  <hasOccurrence
    rdf:resource="#Reading_20051001_211631"/>
</Enter>
```

```
<PresenceDetectionReading
  rdf:ID="Reading_20051001_211631">
  <hasTimeStamp>
    <dtm:Instant
      rdf:ID="Instant_20051001_211631">
        <dtm:years>2005.0</dtm:years>
        <dtm:months>10.0</dtm:months>
        <dtm:days>1.0</dtm:days>
        <dtm:hours>21.0</dtm:hours>
        <dtm:minutes>16.0</dtm:minutes>
        <dtm:seconds>31.0</dtm:seconds>
      </dtm:Instant>
    </hasTimeStamp>
  </PresenceDetectionReading>
```

**3.2.2. Intervention Management Ontology.** Now that the system can automatically discern when a patient is emotionally disturbed, we can then make provisions for timely therapeutic interventions. For instance, relaxing music is purported to soothe an agitated person.

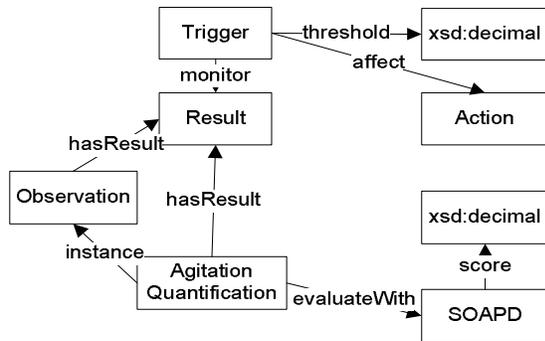


Figure 3.2.2a Intervention Ontology

To do this, we need to model the intervention options (see Figures 3.2.2a and 3.2.2b). Triggers specifying the course of action to pursue given a particular observation result can then be easily formulated. In our example, when Bob is observed to be mildly agitated (e.g. SOAPD score < 1127.9), the system automatically administers music therapy to calm him down as Jane had previously defined.

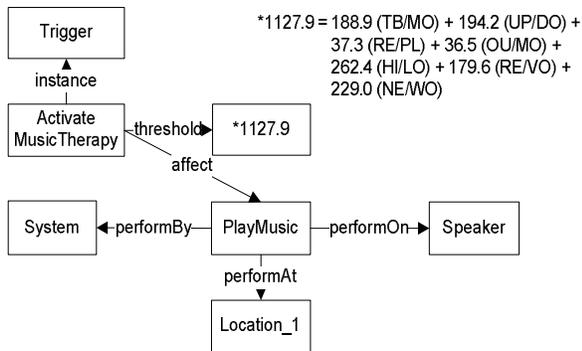


Figure 3.2.2b Intervention Ontology

**3.2.3. Social Context Ontology.** It is expected that several triggers corresponding to various degrees of agitation will be defined. For example, when Bob fails to respond to the music therapy and gets increasingly agitated, a potential crisis is averted when another trigger (Figure 3.2.3a) kicks in to request a SMS to be sent to Jane or her brother should she be unavailable. This social context can easily be modeled using FOAF.

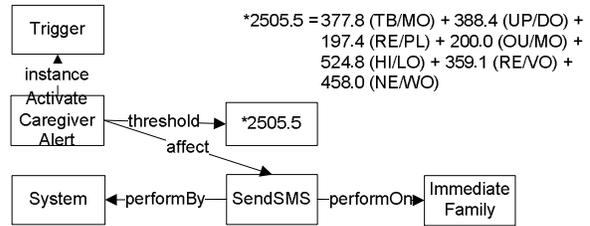


Figure 3.2.3a Trigger instance

### 3.3. Context Reasoning

To augment ambient intelligence for the application, we will explore the use of DL Implementation Group (DIG) compliant classifiers, specifically RACER reasoner to make inferences over our ontology base. Context reasoning will largely be employed to detect mid-to-long term patterns of disturbed behavior (e.g. time of occurrence) and cognitive decline as well as short-term analysis relating to new drug administration.

Thus, future work will likely look to facilitating effective drug therapy through side-effect monitoring. This is because most drugs used to treat dementia have many serious side-effects, hence determination of the best dosage (i.e. treat symptoms with least side-effects) is important. At present, dosage titration is based largely on incomplete information provided by familial caregivers through reviews. With automated monitoring and ontology relating to drugs and their side-effects, the system can be extended to monitor for behavioral changes in relation to the side effects.

## 4. Architecture Overview

Here, we describe our context middleware architecture (Figure 4a) and its components which aims to help application developers build context-aware healthcare applications more efficiently and effectively.

**Sensor/Actuators.** Sensors gather data about their surroundings while the actuators act as vehicles for intervention. These UPnP-enabled nodes are connected via wire or wirelessly to a sensor node server. Since our system will predictably involve the use of a wide range of sensors, UPnP with its standard-based, dynamic and flexible architecture supporting zero-configuration and automatic discovery will allow us to easily add/replace sensors/actuators and reconfigure them with minimal effort. This results in ease of actual deployment and subsequent maintenance of the system.

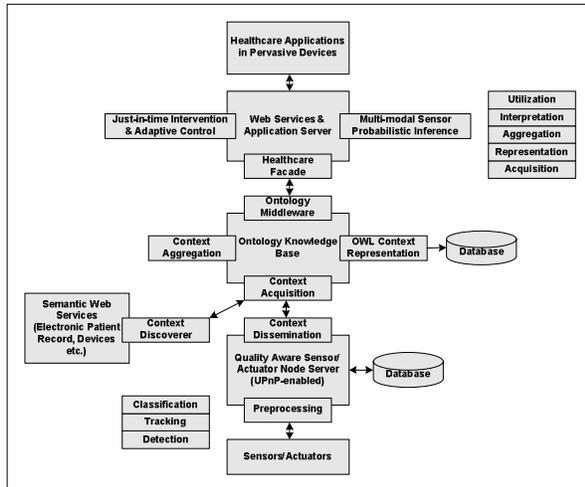


Figure 4a Overview of the Healthcare Architecture

**Quality Aware Sensor/Actuator Node Server.** The node server consists of a UPnP control point that coordinates the discovery of behavioral context among devices and disseminates this information to the ontology knowledge base using SOAP messages.

**Ontology Knowledge Base.** The ontology-base consists of a repository, query engine, inference engine, discoverer and aggregator. Sesame provides the context storage, with Sesame RDF Query Language (SeRQL) as the context query language. The query engine provides the abstract interface for applications to extract desired contexts. The inference engine consists of a variety of techniques ranging from rule based systems to neural networks and fuzzy logic, to aid in the decision making process by injecting rules or logic encoded into the inferencing stage. The discoverer unravels context and knowledge from both the node server and semantic web services. The aggregator aggregates this knowledge, and classifies them into one of three categories before insertion into the knowledge base.

**Web Services & Application Server.** Semantic Web services provide context of the patient and related personnel in terms of profiles, schedules, social networks, etc. Auxiliary sources for social context include email and calendar applications as well as online social networking sites that may lead to discovery of new implicit social connections. Synchronization and extraction of this information will likely be with some FOAF-compatible third party tool.

## 5. Conclusion

In this paper, we have presented a context model for monitoring and handling agitation behavior in persons with dementia in a context enlightened fashion. The use of OWL for modeling agitation-specific, intervention and social semantics is sufficient to support context representation, reasoning, querying, and knowledge sharing. We are now furthering work to assist doctors in drug therapy for agitation behavior while catering to specific needs the patients and their familial caregivers considering their profiles, schedule and social network. While development is still in its early stages, the joint effort with a local hospital should see us achieving our long-term objective to deploy the system in a real life setting to verify and validate it.

## 6. References

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