Context Modeling in OWL for Smart Building Services

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Abstract

This article presents an approach to context-aware services for "smart buildings" based on Web and Semantic Web techniques. The services striven for are first described, then their realization using Web and Semantic Web services is explained. Finally, advantages of the approach are stressed.

1 Introduction

An automated recognition of the people's location in a building (at desk, in a room, underway, etc.) as kind of so-called "contexts" [Dey01] makes it possible to offer advanced services such as

1. context-aware message delivery,
2. context-aware access control,
3. context-aware services for disabled persons, and
4. context-aware management of the technical infrastructure.

Such context-aware services are referred to as "smart building" services.

As a first working hypothesis it is assumed that data on room occupancy, people's locations, and people's activities (e.g. working at one's own desk using a desktop computer, sitting at a conference table, etc.) are collected using cheap sensors such as RFID sensors. Especially RFID sensors can be placed at various locations such as in a gangway, on a chair, etc. The restriction to cheap sensors such as RFID sensors, excluding, e.g., video cameras, is convenient because such sensors are easy to install and to maintain, and processing such sensor data is simpler than, e.g., image processing.

As a second working hypothesis it is assumed that sensor data is expressed in Semantic Web formalisms such as OWL [W3C04]. A Semantic Web approach to the "smart building" perspective is convenient because the Web provides with an widespread and easily deployed data interchange infrastructure, and the emerging Semantic Web provides with an increasing number of versatile data modeling and reasoning methods.

This article describes an approach to such "smart building" services relying on the Web and on Semantic Web formalisms and methods. Central software components of this approach are described: The modeling of knowledge is realized in different ontologies called Micro-Theories written in OWL. The Micro-Theories are used to specify domain specific knowledge, e.g., of the furniture of a building. Such ontologies are integrated into one "Upper Ontology" specifying common sense knowledge such as the ways how to use the furniture. The next component is the derivation of context. As last component, data retrieval is realized through simple queries and ontology reasoning using Semantic Web Query Languages.

Finally, this article explains why standards (1) for the data, sensors might collect in buildings, (2) for an ontology of common life objects, properties and action, and (3) for an interface between the afore mentioned formalisms make it easier to reason on such data and knowledge.

2 Context-aware Services for a "Smart Building"

An automated recognition of people's location (at desk, in a room, underway, etc.) in a building makes it possible to offer advanced services, especially:

Context-aware message delivery. Nowadays one can communicate from every place in an office building, and additionally one can choose between various kinds of communication technologies. Written text or spoken voice can be transmitted synchronous or asynchronous via a mobile phone. The flexible availability of users leads to a bigger extend of communication, catching one's attention frequently. While the sender can choose the time and the technology for communication depending on his context, e.g., while walking or being in the office, the receiver cannot.

Obviously, a smart delivery of messages depending on the receiver's context, would make communication more convenient. A manager attending a meeting wants to get messages only, if they are relevant either for him personally or for the meeting. Hence, instead of arriving during the meeting, a less important email could be delivered after while walking back to his or her office. Since reading email while walking is not convenient, the message could be delivered as spoken text automatically.

Context-aware access control. Office buildings are not open to the public for security reasons. Hence, different strategies such as using different door keys provide access control. This technique causes especially two problems:

1. Providing access to parts of such a building demands a special set of keys necessary, and
2. changing access rights would mean (time-dependant) changing the set of keys.

A feasible solution offers a "smart building" for instance a hotel. Being recognized by the "smart building", the guest living in the hotel has access to his or her room. Since the room is located in an upper floor, the guest may also access the rooms connecting the entrance of the hotel as well as the room such as the stairway or the elevator. Obviously there are other access policies for employees of the hotel. The room service, e.g., has no access to rooms automatically, while guests are inside. In case of an emergency like a fire, the access rights could change for everybody immediately. Everybody could be given access to parts of the hotel, that guide to an exit, such as the stairway, whereas the access to elevators is not granted.

Context-aware services for disabled persons. Orientation in buildings can become difficult for disabled people, if information is needed, that is only available via senses they are impeded. Blind people could be helped while walking through unknown rooms, e.g., walking to a meeting. Since having no knowledge about barriers such as furniture and doors of a room, a blind person could just guess the right way.

An advanced guidance being aware of a person's position in a building could give advise via synthesized speech. Collisions especially with moving barriers could thus be avoided. Arriving at the meeting room, more information could be offered due to the change of context. For example names of the present persons and their relative positions to the blind person could be read out using a voice synthesizer.

Context-aware management of the technical infrastructure. Office buildings are equipped with technical infrastructure such as lamps and jalousie for controlling the brightness and heating or with an air conditioning for managing temperature and humidity. Such sophisticated technical infrastructure is hard to control efficiently with a minimum of power consumption including a high level of convenience.

When a speaker giving a talk in a "smart building" enters the underground car park the lights will be switched on automatically there. As a second consequence of his arrival the air conditioning will start tempering the conference room for the talk in an upper floor. After leaving his or her car the speaker walks through the building to the conference room. On his way the lights will turn on in the current corridors only. While at first the lights in the conference room are bright, later the light intensity is reduced to a lower level during the presentation.

3 A Semantic Web / RFID approach to "Smart Buildings"

Micro-Theories. Obviously, a system offering domain specific services needs to be aware of its domain. In the present case knowledge about the domain of a building needs to be modeled. Several languages such as Topic Maps [Top01] or DAML&OIL [W3C01] and OWL have been developed to specify so called ontologies for knowledge representation. Being the recommendation of the W3C as ontology language we decided to use OWL because there are a lot of tools available for editing ontologies such as Protege [NSD$^+$01], and tools for data retrieval and management such as the Jena Semantic Web Framework [HP05].

Using OWL, an ontology of a "smart building" service can be designed in a bottom-up approach beginning from the basic concepts of an office building such as a chair or a conference room and relations to each other. A chair, e.g., is located next to a table in a room. Further on this room has a direct connection to the conference room via a door, etc. This ontology is restricted to knowledge that is specific to a office building. Common sense knowledge such as a chair is a "touchable thing" is not represented here. Due to this restriction this ontology is referred to as a micro-theory.

Upper Ontology. Instead of modeling knowledge like a "barrier" is a "touchable thing" in micro-theories such common sense knowledge can be derived from a so called upper ontology. On the one hand application development becomes much easier drawing on an approved ontology, and on the other hand various services become scalable much easier, if they are using the same upper ontology. Several ontologies written in OWL have been developed to represent common sense knowledge such as the Wordnet [Fel98] or OpenCYC [Ope]. In this project, we decided in favor of the OpenCYC ontology because it offers widespread knowledge and especially good support for the implementation of "smart building" services.

For making common sense knowledge available to a "smart building" service the micro-theories and the upper ontology need to be connected. Therfore, concepts of a micro-theory can be integrated to the upper ontology using the OWL subclass property. A chair in the micro-theory, e.g., can be defined as a subclass of a OpenCYC seating device and hence a chair inherits all its characteristics like being touchable. In that manner, all other concepts of the micro-theory can be integrated into the upper ontology.

Context Acquisition. "Smart building" services are supposed to act depending on the building's context. To gain context information according to Dey [Dey01] a bridge between the system of the service and reality is needed. In this project, RFID sensors are considered for sensing the attendance of persons. As a working hypothesis, it is assumed that all relevant entities in a building such as persons are known to the formerly introduced ontology. Further it is assumed that each relevant entity is equipped with an unique so called RFID tag. This tag makes entities visible to RFID sensors of other entities, and furthermore each tag can be identified unambiguously.

Connection to Semantic Web. As a next step the sensor data need to be connected to the ontology of a "smart building" service making it context-aware. For that reason all sensor data is collected using a central so called sensor proxy server. The core tasks of this server are

1. the evaluation of the raw sensor data depending on the sensor type and
2. the integration of the evaluated sensor data into the "smart building's" ontology.

The evaluation of raw sensor data depends on various characteristics such as the sensor type as well as the unit, the accuracy and the validity of data. Therefore, an ontology for sensors called OnSen was developed using OWL within this project. The ontology is inspired by the Physical Meta Language PML [MIT01] and by sensorML [UAH04]. Depending on the sensor specifications in OnSen, raw sensor data is processed and provided for the integration into the "smart building's" ontology.

Besides specifying a sensor's characteristics, OnSen allows to allocate a sensor and a "smart building" entity. Using that information, sensor data can be integrated easily into the "smart building's" ontology using OWL properties. A sensor attached to a conference room, e.g., can sense a RFID tag attached to a person located in that room. As contexts can change frequently, especially if people are walking, the context information needs to be refreshed often.

Data Retrieval using Queries. Having an up-to-data ontology an interface for accessing it is needed. A rather simple approach to query OWL ontologies is querying the underlying representation of OWL data encoded in RDF[W3C99] format combined with a reasoner.

The RDF format allows to specify relations between resources by triples. Each RDF triple consists of a subject, a predicate and an object. Using that triple encoding a relation between a chair and a seating device could be modeled in the following manner:

```
(smartbuilding:chair, owl:subclassOf, opencyc:seatingDevice)
```

Many approaches for querying RDF data discussed in [Mea02] such RDQL, RDFPath, TRIPLE or Versa have been developed. In this project, RDQL is used for specifying queries because its syntax is easy to learn because it is similar to the widespread SQL syntax. A query, e.g., selecting all subclasses of a seating device could be specified as follows:

```
SELECT ?subject
WHERE (?subject, owl:subclassOf, opencyc:seatingDevice)
```

Since `subclassOf` is a transitive property, the query could yield more subclasses like `canvas chair` being a subclass of `chair`. Due to limited memory capacity and/or limited computational power, the set of answers querying the RDF representation of an OWL ontology can be restricted by controlling the capabilities of the ontology reasoning. Instead of full OWL reasoning deriving all possible RDF triples, in many cases deriving the transitive closure of the subclass relation only is sufficient.

Complex Context. More complex context information that goes beyond the context level of one entity such as "There is a meeting in the conference room, if more than five persons are present." is needed for "smart building" services. Such context can be generated using a rule language as supported for instance by the Generic Reasoner of the Jena Semantic Web Framework, e.g., by the following rule:

```
(smartbldng:conference smartbldng:takesPlaceIn smartbldng:conferenceRoom ) <-
   (smartbldng:conferenceRoom smartbldg:personsInside ?persons),
   greaterThan(?persons, "5"))
```

4 Advantages of the Approach and Conclusion

The approach to the "smart building" perspective briefly introduced in this article has the following advantages:

1. It is easily deployable because of the ubiquity of the web especially in an office building.
2. It is rather generic because it relies on common software namely Semantic Web and Web Software.
3. As a consequence of its genericity the approach makes maintenance easy.
4. The approach will benefit of the ongoing improvements and developments of the Semantic Web especially because context modeling and context reasoning are concerned.

The approach has been fully implemented in the NTT Communication Science Labs in Japan. The communication with sensors has been simulated in a prototypic implementation.

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