The COSE Ontology: Bringing the Semantic Web to Smart Environments

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Abstract. The number of smart appliances and devices in the home and office has grown dramatically in recent years. Unfortunately, these devices rarely interact with each other or the environment. In order to move from environments filled with smart devices to smart environments, there must be a framework for devices to communicate with each other and with the environment. This enables reasoners and automated decision makers to understand the environment and the data collected from it. Semantic web technologies provide this framework in a well-documented and flexible package. In this paper we present the Casas Ontology for Smart Environments (COSE) and accompanying data from a test smart environment and discuss the current and future challenges associated with a Smart Environment on the Semantic Web.

Keywords: Semantic Web, OWL, Ontologies, Smart Environments, Ubiquitous Computing

1 Introduction

The concept of a smart environment necessarily requires a multitude of sensors in order to determine the environment's state and take action as necessary. Real-world devices available now range from smart phones to intelligent dishwashers. This heterogeneity among devices has led to a fractured sensor landscape. Because of this, the machine learning algorithms and reasoners currently used in smart environment must be tailored to a specific set of sensors. Such tight coupling inhibits the deployment of new technologies into the environment, which in turn significantly reduces the environment's long-term usefulness. In order to address this, smart environment data should be mapped to a set of core semantics which can be used by agents and algorithms to operate in a variety of environments. An example of this would be the mapping the output of a gyroscope to the concept of angular acceleration. Activity recognition algorithms learning in this context can focus on the semantics of motion and interaction, without becoming dependent on a specific set of sensors.

Ontologies provide a method to maintain facts about the nature of the world in a logical form. Common-sense ontologies codify the general nature of things, e.g. that water is a liquid and liquids are amorphous. Naturally, these ontologies are very large and require significant computing resources to fully utilize. In order to minimize the computing resources required for a smart environment, we propose extending these ontologies with ontologies smaller smart-environment focused domain ontologies using the Semantic Web [10]. Using this hierarchical approach we can minimize local computing requirements without sacrificing useful general knowledge. Our contribution here is to present a smart environment domain ontologies with mappings back into the OpenCyc[12] common sense ontology.

2 Ontological Reasoning

The term ontology can, at times, be ambiguous. One of the most well cited definitions for the use of the term in Computer Science is that an “ontology is an explicit specification of a conceptualization” [6]. The curious reader is encouraged to also read [9],[8],[5] for a more comprehensive discussion of what exactly constitutes an ontology. In this paper we will use the term “common-sense ontology” to refer to an upper ontology which provides general knowledge not specific to smart environments. Domain specific ontologies specify the concepts for a given domain. The full topic of ontological reasoning is well beyond the scope of this paper; rather herein we will describe the practical uses of ontological reasoning in a smart environment.

3 Previous Work

Using ontologies in smart environments has been discussed before in [16],[2],[1],[15],[7],[11]. Each such proposal and experiment uses a different ontology with differing purposes. Unfortunately, these ontologies are not interoperable in the same way that differing syntactic protocols are not necessarily interoperable. Moving knowledge from one ontology to another requires mapping those two ontologies. Automatic ontology mapping is still an active research area and manual mapping is a time-consuming process. Also, domain ontologies do not cover the kind of common-sense knowledge that can enable a smart environment to interact naturally with a resident.

This provides the impetus for the use of common-sense knowledge bases as a basis to standardize common terms used in domain ontologies. Well known upper-level ontologies include Cyc [12] and the DOLCE [4] suite of ontologies. The massive effort required to build a comprehensive upper ontology naturally limits the number of them available. Using OWL ontologies [13] we can manually map from a domain ontology into one of these larger common-sense ontologies. This allows those developing ontologies for smart environments to focus their efforts on environment modeling rather than modeling the universe in general.

4 The COSE Ontology

As mentioned previously, there are other ontologies for smart environments proposed in the literature. None of these can be directly accessed via a URL, and thus by a reasoner, which prevents them from being extended by other ontologies. In order to address this we have developed the Casas Ontology for Smart Environments, or COSE. This ontology is available at http://casas.wsu.edu/owl/cose.owl. This ontology conforms to the OWL Lite profile. The main concepts in the COSE ontology are: buildings, occupants, sensors and human activities. Figure 4 illustrates the sensor class hierarchy.

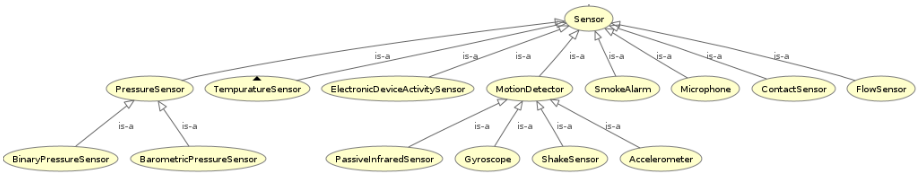

Fig. 4. Sensor hierarchy in COSE

We have also defined a mapping from concepts in COSE which are also present in the OpenCyc ontology. OpenCyc is a subset of the full Cyc knowledge base which has been made available under the Apache License, Version 2. This mapping is made available in a separate ontology because the mapping uses the owl:sameAs construct. This construct is only available in the OWL DL profile which is computationally more complex than OWL Lite.

In addition to COSE, we have developed an ontology[1] for the Kyoto smart apartment test bed. In this ontology we define only typed instances of object classes in the COSE ontology which are present in the Kyoto test bed. We have chosen to put these individuals into an ontology rather than RDF because they describe the environment rather than the state of the environment. The Kyoto testbed was chosen because there is a significant amount of published data available for this environment. We are in the process of converting this data into RDF format utilizing the COSE ontology. The first converted dataset is available at http://casas.wsu.edu/rdf/adlnormal.n3. This dataset contains 38,910 triples pertaining to 51 participants performing 5 activities. The data was taken as part of the experiment described in [3]. A sample of this dataset is presented in figure 5.

```
<p01> rdf:type cose:Occupant ; .
<p01.t1> rdf:type exp:Task13;
cose:activityInvolvedPerson <p01>; .
<M08_2008-02-27_12:43:27.416392>
  cose:dataSourceSensor kyoto:M08 ;
  cose:timestamp "2008-02-27 12:43:27.416392" ;
  cose:sensorInState cose:SensorOnState ;
```

[1] Available at http://casas.wsu.edu/owl/kyoto.owl

```
rdf:type cose:sensorChangeState ;
cose:sensorMeasurementRelatesToActivity <p01.t1> ;
cose:sensorMeasurementRelatesToPerson <p01> ; .
```

Fig. 5. A sample of the adlnormal dateset expressed in Notation 3 syntax

5 Future Directions and Challenges

In addition to these ontologies, we have begun work on semantically describing activities of daily living and the steps required to complete them. The ontology for this is available at http://casas.wsu.edu/owl/activity_experiment_1.owl. The adlnormal.n3 dataset depends on this ontology to provide a description of the tasks involved in the experiment described in [3]. This ontology is still in development and will be extended to provide a richer model of the tasks involved.

There is currently a lack of AI learning toolkits which natively support RDF data and OWL reasoning. While there are a number of tools for OWL reasoning, e.g. the Pellet reasoner [14], as well as RDF storage and querying; what is needed is a method for easily joining these tools to a learning agent. This is one of our directions for future research.

One of the open problems in smart environment research is activity recognition which essentially maps environment states to some semantic understanding of what is happening. We see this work as a synergistic parallel effort to activity recognition.

6 Conclusion

Smart environments are quickly turning into reality. In order to fully realize the potential of these technologies, devices must be able to communicate both syntactically and semantically. The Semantic Web provides a well-researched basis for the exchange and use of semantic knowledge. Using a hierarchical approach when defining the ontological basis for reasoning in a smart environment allows for extensive re-use of work and light-weight ontologies suitable for embedded environment reasoners. Our goal here is to lay a base to enable further work in this area.

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