

Building Semantic Sensor Web: Knowledge and Interoperability

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Abstract. Semantic Sensor Web would be an evolving extension of Sensor Web that introduces a semantic layer in which semantics or meanings of information are formally defined according to well-defined semantic schemas (Ontology). Semantics should improve the capabilities of collecting, retrieving, sharing, manipulating and analyzing sensor data (or associate phenomena) providing a new interoperability model: semantic interoperability introduces the interpretation of means of data allowing the engineering of novel architectures based on standard reasoners.

1 Introduction

The idea of sensor networks, disseminated everywhere around the world as part of everyday life, implicitly assumes they are not connected between them as well as associated information systems are not integrated. This scenario can be summarized as a great amount of data but a poor knowledge.

The term Sensor Web was first used in 1997 [1] to describe a novel sensor system model where individual and autonomous nodes could act and coordinate as a whole performing stand alone observations or cooperative tasks. Sensor Web is commonly defined as 'Web-accessible sensor networks and archived sensor data that can be discovered and accessed using standard protocols and application interfaces'.

Sensor Web is a general purpose concept that is progressively assuming great importance within several application domains: large scale geographic information system (GIS), social sensors and all sensor systems working in accordance with complex business models that assume the cooperation of remote services could be easily suited within Sensor Web. Sensor Web is a progressive concept mainly limited, at the moment, by the lack of standardization of access infrastructures and data models as well as by weak business models.

Semantic Sensor Web would be an evolving extension of Sensor Web that introduces a semantic layer in which semantics or meanings of information are formally defined. Semantics should integrate web-centric standard information infrastructures improving the capabilities of collecting, retrieving, sharing, manipulating and analyzing sensor data (or associate phenomena) as well as potential interoperability between systems through semantic interactions [4], [5].

The paper proposes a discussion about some of most relevant open research issues addressed by Semantic Sensor Web with special focus on interoperability and knowledge engineering. Also related challenges are briefly discussed. On the contrary, an exhaustive analysis of last generation semantic technologies, even if interesting, is out of paper scope.

The paper is structured in order to first provide an overview on Semantic Sensor Web model. Then, the interoperability model and related issues (Semantic Actors and Shared Vocabularies) are introduced. In the last part of the paper, semantic knowledge is analyzed with special focus on most common applications. Both resource-centric (Domain Ontology) and data-centric (Data Ontology) semantic schemas are considered.

2 Related Work

At the moment, semantic technologies are applied in several sensor architectures. Common applications have the aim of provide advanced support to information description and processing [3], data management [6], interoperable networking [5], dynamic representation of situations and system states [7], advanced analysis of data [9] and classification [10].

Semantic Sensor Web [4] would be a generalized concept in which semantic technologies allow interoperable interchanging of semantic data. A semantic environment for Sensor Web addresses several research issues and challenges. Probably, the engineering of semantic knowledge is the most interesting for its central and key role as well as for the fundamental lack of standardized methodologies.

3 Semantic Sensor Web

The reference semantic environment for this work is showed in Figure 1: physical systems are provided with a semantic representation according to a well-defined semantic schema (ontology). Generic Semantic Actors are able to semantically interact among them and with any external system through the interchange of semantic data; these actors are designed on the top of the technologic ground provided by standard reasoners and, so, they can work within a semantic interoperable context.

A semantic reasoner, reasoning engine, rules engine, or simply a reasoner, is commonly defined as ‘a piece of software able to infer logical consequences from a set of asserted facts or axioms’. The notion of a semantic reasoner generalizes that of an inference engine, by providing a richer set of mechanisms to work with. The inference rules are commonly specified by means of an ontology language, and often a description language.

Several research issues are addressed by semantic environments for the various application domains. In the context of this work, semantic interoperability (among sensor systems) and semantic sensor knowledge engineering are considered.

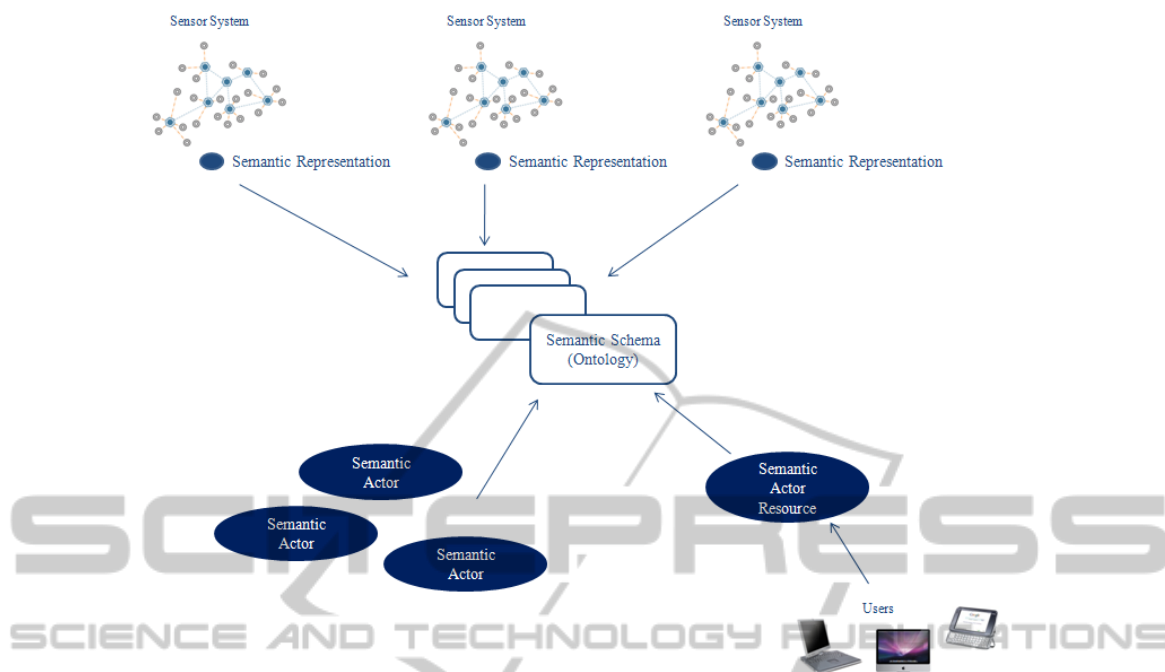


Fig. 1. Schematic view of the Semantic Sensor Web model.

3.1 The Interoperability Model

Semantic interoperability would improve common interoperability models: basic interoperability assumes the interchange of messages among system without any interpretation; functional interoperability integrates basic interoperability model with the ability of interpreting data context under the assumption of a shared schema for data fields accessing; semantic interoperability introduces the interpretation of means of data. Semantic interoperability is a concretely applicable interaction model under the assumption of adopting rich data models (commonly called Ontology) composed of concepts within a domain and the relationships between those concepts.

Semantic technologies are partially inverting the common view at actor intelligence: intelligence is not implemented (only) by actors (that are understood as interpreters) but it is implicitly resident in the knowledge model. In other words, schemas contains information and the “code” to interpretate it.

Semantic interoperability is based on the capability of interoperable actors (called Semantic Actors) built on the top of standard reasoners and able to interpretate generic semantic schemas.

3.1.1 Semantic Actors

The availability of standard languages for ontology definition and specification (e.g. Ontology Web Language, OWL [11]), as soon as extensible reasoners (e.g. Jena,

Pellet [8]) able to automatically process semantic structures, allows the engineering of intelligent semantic actors.

As showed in Figure 2, ontologies defined according to standard and interoperable technologies (e.g. RDF or OWL) are inputs for actors designed on the top of standard reasoners able to automatically interpretate ontology semantics; extended intelligence layers could be designed providing actors with domain-specific querying and/or added capabilities (e.g. learning or multi-ontology computation).

Ontology-driven interaction takes advantage by semantic rules and relationships implemented by ontology: the actor receives in input the ontology, it is able to interpretate it; so, it does not need to implement semantic rules and relationships (commonly in dependence of reference data model) that, now, are expressed in the schema according to an interoperable model.

Several software layers can be built as extension of the model represented in Figure 2; these layers can be designed for reaching several goals; common solutions provide extended functions for supporting ontology-aware computation: actors are able to switch their behavior and functionalities in function of the input ontology.

Further extended functionalities are learning (actors are provided with a memory that allow them to build knowledge on the base of their activities) and multi-ontology computation.

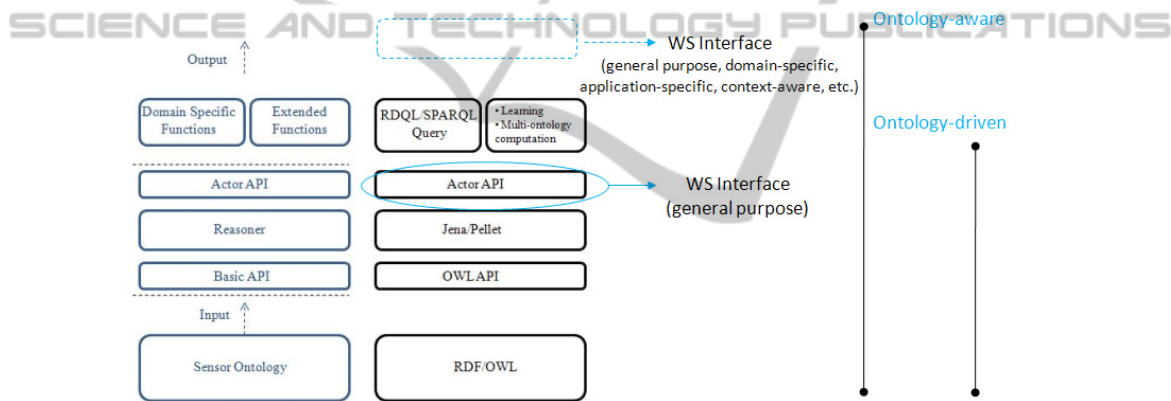


Fig. 2. Semantic Actor model for Ontology-driven and Ontology-aware computation.

3.1.2 Shared Vocabularies

Semantic interoperability assumes information related with different systems potentially represented according to different semantic schemas. This last aspect is one of the critical issues in order to assure semantic interoperability.

At the same time, the intrinsic presence of multiples semantic schemas to represent similar information could address several disadvantages: actors cannot be able to understand when concepts from different ontologies are referring to the same semantic concept; on the contrary, actors could assume that two concepts are referring the same semantic concept just because they have the same name.

These and other similar cases could generate ambiguous situations that could generate errors or other undesired/unexpected results.

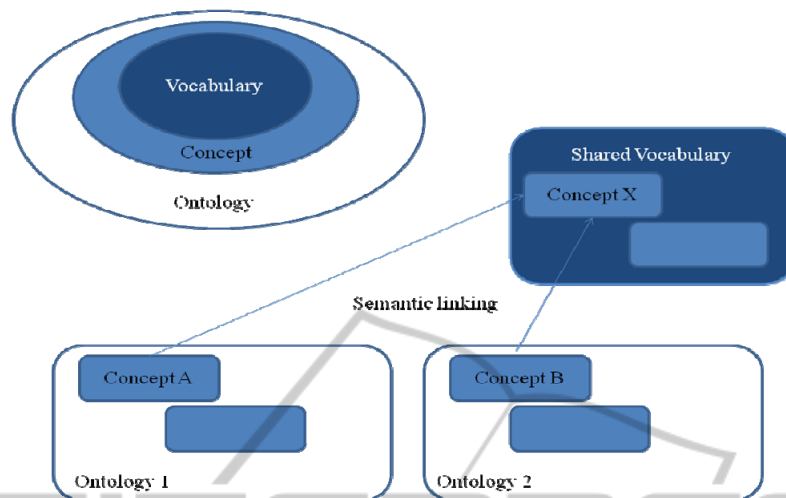


Fig. 3. Example of semantic linking among concepts using shared vocabularies.

If a strong level of interoperability is required, mentioned ambiguities could be solved for example through context-aware interpretation of semantic concepts.

Shared vocabularies could represent a suitable solution: as showed in Figure 3, concepts from different ontologies could be linked to concepts composing shared vocabularies.

Several ambiguities derived by intrinsic heterogeneity of information could be solved as well as both basic and advanced semantic computation could be favorably affected.

The main disadvantage is the intrinsic difficulty of defining and standardizing shared vocabularies.

3.2 Semantic Knowledge

Standardized methodologies for knowledge building [3] are a current open research issue. Semantic Knowledge implicitly needs rich schemas that include structured concepts, related properties as well as complex relationships among them.

Mapping real knowledge on semantic schemas is, probably, the most creative task for the concrete engineering of Semantic Sensor Web.

Semantic environment could provide an interesting perspective for knowledge building: first of all, semantic schema implies an “overall” concept of knowledge in which concepts and relationships among them converge in the same structure; furthermore, the semantic interoperability model allows knowledge building regardless by any predefined schema.

Sensor domain proposes several peculiarities that allow simplest approaches than for generic knowledge building. Even considering that each sensor system could have its peculiarities that could be reflected on semantic representations, the majority of systems could be represented according to two main semantic structures: the Domain

Ontology and the Data Ontology. The first one should support resource-centric interaction; the second-one data-centric interaction.

A brief description of both Domain Ontology and Data Ontology is proposed in the following sections.

3.2.1 Domain Ontology

The main goal of the Domain Ontology is the model of sensor domain. The really extended sensor application domain advises the structuring of main domain in several sub-domain as well as structured classification of resource according to different perspectives.

In dependence of considered systems and applications, different aspects could converge in the reference ontology.

In few simple words, the Domain Ontology has to describe the reference system: in the majority of cases, not only physical resources are defined but also complex relationships with them or other resources as well as the definition of abstract concepts (e.g. logic resources).

Concrete implementations depend by interaction scope. Typically, the classification of resources according to several perspectives (e.g. functional) is required.

The Domain Ontology has a key role for allowing search, discovery and all interactions that assume there is not previous information about the considered system.

Under the realistic assumption of complex knowledge resulting by semantic relationship among physical resources and external semantic concepts, a possible reference model is showed by Figure 4; as represented, the central concept (Physical Resource) is the result of the convergence between domain specific semantics and inferred concepts representing relationships with external concepts (e.g. Network, Host); an abstract semantic layer includes high level features definition and logic resource; this last layer differs respect to lower layers because it does not define a full sub-domain/domain: composing concepts have finite means only in the context of the main domain (sensor domain).

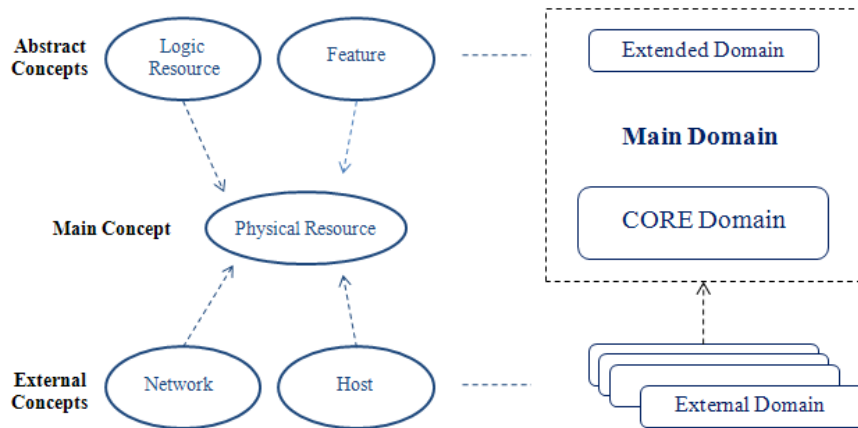


Fig. 4. Structuring sensor domain knowledge.

In other words the main domain assumes a core sub-domain and an extended domain built on the top. The relationships with external domains can be simple associations in some cases or extremely complex relations in other cases.

Knowledge engineering methodology is currently an open research issue: building knowledge on semantic ontologies could be relatively suitable considering interoperable schema and semantic annotation standards provided by current semantic technologies; there are several efforts oriented to promote a convergence among multiple semantic domains (for example the use of standardized vocabularies for ontology concepts[3]).

The reference model was built under the assumption that advanced information systems and/or large scale web-centric applications work on abstract semantic concepts (logic resource) and not only on basic concepts (physical resource).

3.2.2 Data Ontology

A great number of systems just need to interchange information, such as sensor data. In this last case, systems require ad-hoc structures in order to search, discovery or retrieve data. This class of semantic schema (Data Ontology) is conceptually different respect to Domain Ontology (resource-centric structure) because data-centric.

The main purpose of a Data Ontology is defining the model for interchanging data as well as the meaning of data.

Furthermore, semantic rules and relationships among the different fields and concepts could allow several innovative scenario as well as complex models for manipulation of data, intelligent filtering and other high level applications.

4 Conclusions

Semantic Sensor Web proposes an evolving extension of Sensor Web integrating common models for knowledge representation with formal description of semantic or meaning of information.

The most modern semantic technologies enable an innovative technologic environment in which systems can interact among them interchanging semantic data in a context of semantic interoperability. These novel interaction models allow the engineering of advanced semantic actors built on standardized technologies as well as an innovative vision of Sensor Web and related applications.

Regardless by concrete technologies or languages, Semantic Knowledge building can be considered as the most creative and critical issue for the concrete realization of Semantic Sensor Web. At the moment, it appears there are not concrete methodologies for knowledge building.

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