A Semantic Environment for Data Processing in Embedded Sensor Networks

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Abstract. Sensor Networks have the critical role of technological bridges between the real world and information systems, through always more consolidated and efficient solutions that enable advanced heterogeneous sensor grids. Sensor Networks have been increasingly adopted in the context of several disciplines and applications and they are currently disseminated everywhere. The relevance of their role is growly increasing in the everyday life. Data processing is one of the critical and key issues for sensor networks. An advanced semantic environment for event-driven data processing is proposed in the paper.

1 Introduction

During last years, sensors have been increasingly adopted in the context of several disciplines and applications (military, industrial, medical, homeland security, etc.) with the aim of collecting and distributing observations of our world in everyday life.

Sensors progressively assumed the critical role of technological bridges between the real world and information systems [1], through always more consolidated and efficient solutions that enable advanced heterogeneous sensor grids [16].

Sensors are currently disseminated everywhere and the relevance of their role is growly increasing in the everyday life.

They can work as independent stand-alone objects or as part of complex networks, performing cooperative tasks in order to reach common goals.

Current sensor networks are able to detect and identify simple phenomena or measurements as well as complex events and situations.

Complex systems build their own knowledge on the base of sensor data and, eventually, considering other available data. Due to the specificity of the knowledge for each system, also the process for building it is commonly considered a domain specific task that requires ad-hoc infrastructures. Semantic Technologies [5][8][14] could allow an innovative approach for the problem.

Semantic Technologies are able to improve the machine-to-machine interaction through an innovative model of interoperability (Semantic Interoperability [12]) that assumes rich schemas for knowledge representation.

Semantic Interoperability integrates the common Functional Interoperability model introducing the interpretation of means of data [12]. This model allows a new perspective and an innovative approach for the systems because the "intelligence" is no longer implemented by actors (that are similar to interpreters) but it is implicit in the information (Ontology-driven computation [12]).

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Semantic Knowledge implicitly needs rich schemas that include structured concepts, related properties as well as complex relationships among them [11]. Standardized methodologies for knowledge (semantic knowledge in this case) building are a current open research issue. Mapping real knowledge on semantic schemas is, probably, the most creative task for the concrete engineering of Semantic Systems [12].

The description of the proposed semantic environment is structured in two main parts: first the infrastructure, based on standard reasoners [8], is described and, then, the Ontology, implemented in OWL [11], is proposed.

2 Related Work

At the moment, semantic technologies are applied in several sensor architectures in order to reach different goals.

Common applications have the aim of providing advanced support to information description and processing [2], 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 [12]. 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 [12].

Data processing is one of the most common and key issue for embedded sensor networks; the convergence of semantic technologies could enable the development of advanced semantic interoperable environments in which abstract knowledge is directly built on the top of sensor data with a completely transparent approach for higher layers of systems. Furthermore, the knowledge can be defined and represented according to several perspectives and abstraction levels.

3 An Interoperable Layer for Event-driven Sensor Data Processing

An infrastructure for event-driven sensor data processing can be modeled according to the schema represented in Figure 1.

The lower layer of the architecture (*Data Manager*) has the role of collecting (synchronized) sensor data, integrating it with data available at the moment in the system.

This information is processed by an engine that implements the "intelligent" layer of the system and has the key role of processing available data providing the system with the related knowledge. The engine needs a representation for both data and knowledge.

The knowledge built by the data processing engine is available for the *Control Systems*, understood as the layer that implements high-level applications.

In common architectures all represented layers are implemented as ad-hoc infrastructures.

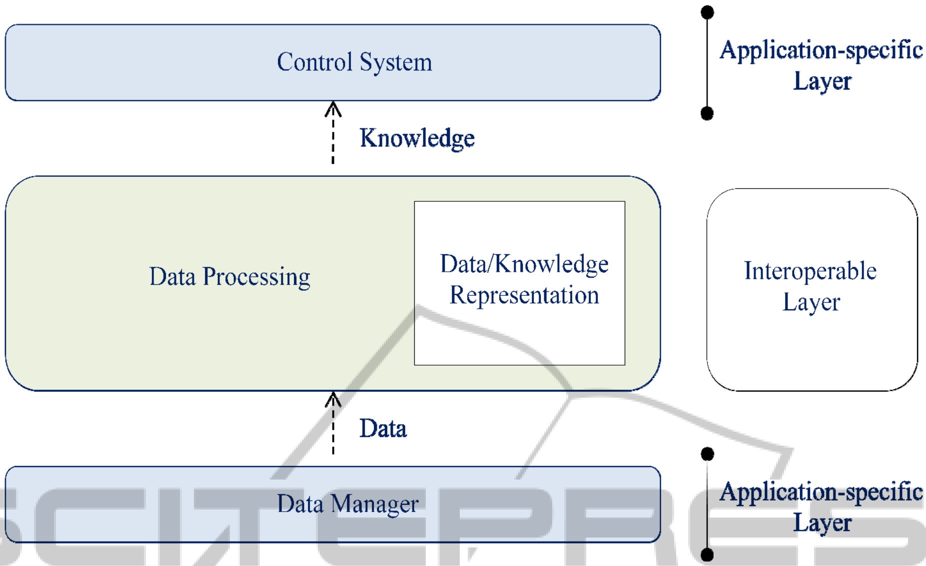

Fig. 1. Simplified vision of an interoperable layer for sensor data processing.

Semantic technologies allow the deployment of a novel semantic environment for data processing. This environment is able to work in a context of semantic interoperability because the rules for knowledge building are expressed by the Ontology. Each concrete system can so implement its own rules in its own Ontology that can be processed by standard reasoners.

A description of the proposed environment and a brief discussion about the related key issues is object of the following section.

4 Outline of the System

The description of the proposed semantic environment is structured in two main parts: first the infrastructure, based on standard reasoners [8], is described and, then, the Ontology, implemented in OWL [11], is proposed.

4.1 The infrastructure for Data Processing

The architecture for data processing is represented in Figure 2. It is implemented over Java Technologies. As showed, the core infrastructure is based on semantic reasoners. 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.

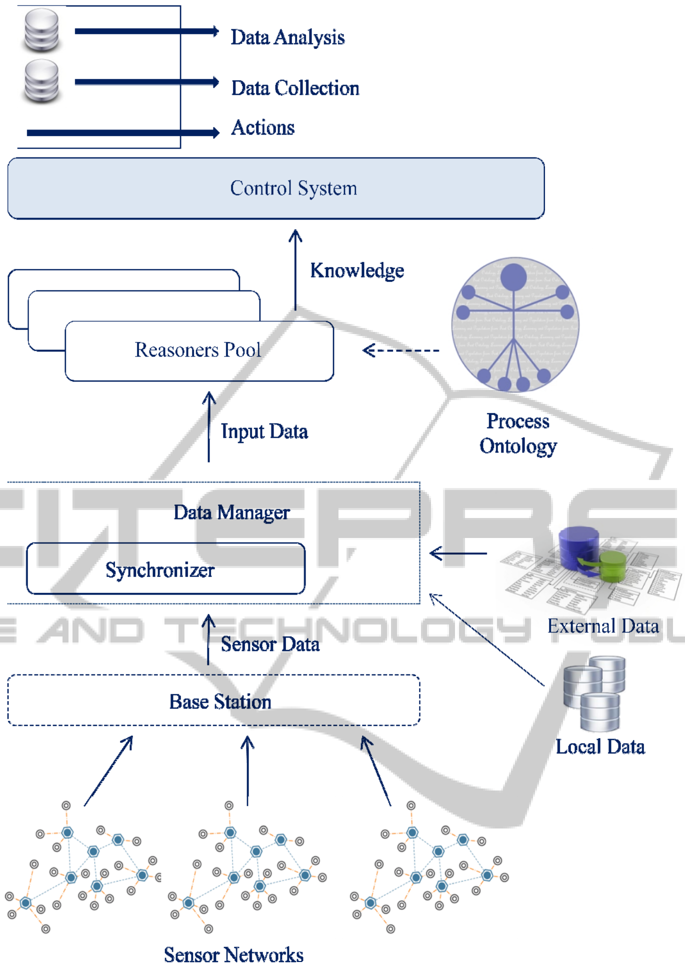

Fig. 2. Schematic view of the infrastructure for data processing.

As in common infrastructures, sensor data is received by a Base Station. The Data Manager has the role of preprocessing (if required) and synchronizing (if required) data input for the reasoner. Simple logic environments assume not related data from the various sensor nodes; on the contrary, complex contexts propose relationships among sensor data and, eventually, among data from internal or external information systems. Data Manager accept in input only data represented according to a semantic schema.

The effective data processing is the task implemented by the reasoner that receives in input synchronized data (from Data Manager) and the Process Ontology (described in the next section). The Process Ontology provides the reasoner with the semantic for the data processing. The reasoner implements three different and progressive software layers [12]: the first one is just an abstraction of the functionalities of a standard reasoner (Pellet 1.3 in this case) in order to support Ontology-driven computation; the second and the third one are domain specific extensions that respectively provide support for Ontology-aware computation (the reasoner performs its behavior in function of detected Ontology) and for advanced functionalities (e.g. Learning).

The architecture is structured in order to support parallel computation considering typical time constraints requirements of certain architectures. The output of each reasoner instance is available for the Control System that actively supports any high-level application. Output knowledge is the enabler for the event-driven engine that performs real-time actions. Both input data and output knowledge are stored in the in the information system and object of advanced data analysis.

4.2 A Process Ontology Model for Embedded Sensor Networks

As previously mentioned, the Process Ontology has a key role in the system because it has to provide the semantic for data processing.

In the common means, a process ontology specifies the behavioral view on physical systems. In the general case it is quite difficult to formalize what the notion of a dynamic process precisely entails. For example, Process Ontologies are currently used to define and specify complex business processes [15].

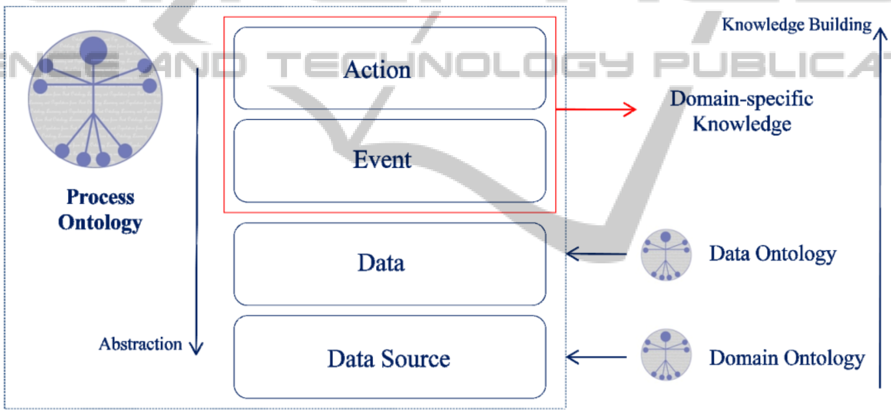

Fig. 3. The Ontology schema.

In the context of this work, the Process Ontology (Figure 3) would specify the semantic of the main interest concepts in a data process infrastructure as well as the relationships among them; at the moment the schema is composed of four main concepts (data source, data, event and actions) featured by an increasing degree of abstraction. All the mentioned concepts should be understood in the context of concrete systems. However, it is relatively suitable the generalization of data source and data models respectively through a resource-centric ontology (typically a Domain Ontology [13]) and a Data Ontology. On the contrary, even if several classifications are possible, the logically higher concepts (event and action) probably make sense only within concrete contexts. The most complex domain/ application specific aspect is the set of relationships among the various concepts composing the logic schema.

Considering the objective difficulty of generalization of domain/application specific aspects, the schema represented in Figure 3 is implemented in OWL (Figure 4) as a meta-ontology that can be particularized in function of concrete applications.

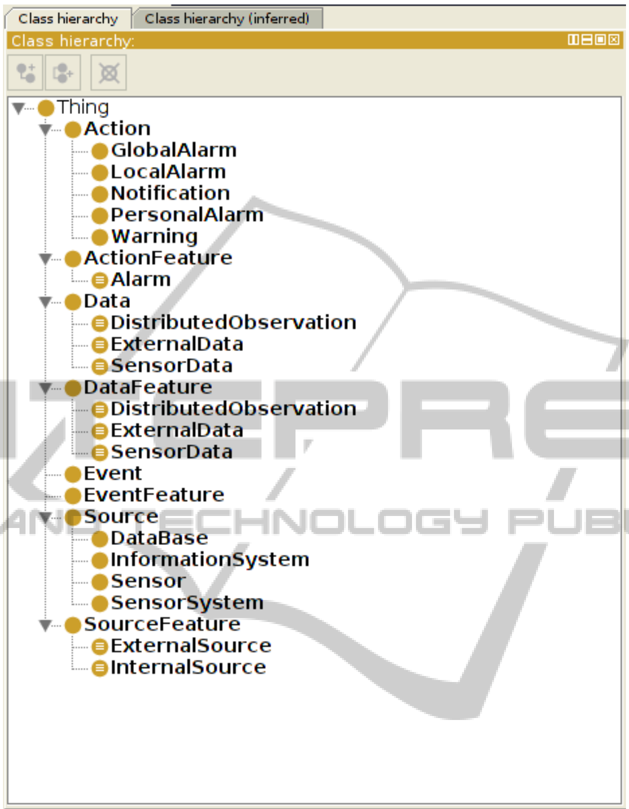

Fig. 4. Implementation of the Ontology (class hierarchy) in Protégé 4 [17].

The current version of the implementation is modeled according to a bottom-up schema for knowledge building (Figure 3). An extensible set of inferred properties and concepts is also provided. An exhaustive description of the implementation is out of paper scope.

The Ontology was validated using OwlSight [18] as showed in Figure 5.

5 Conclusions

Semantic Technologies propose an evolving extension of interaction and data processing models 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.

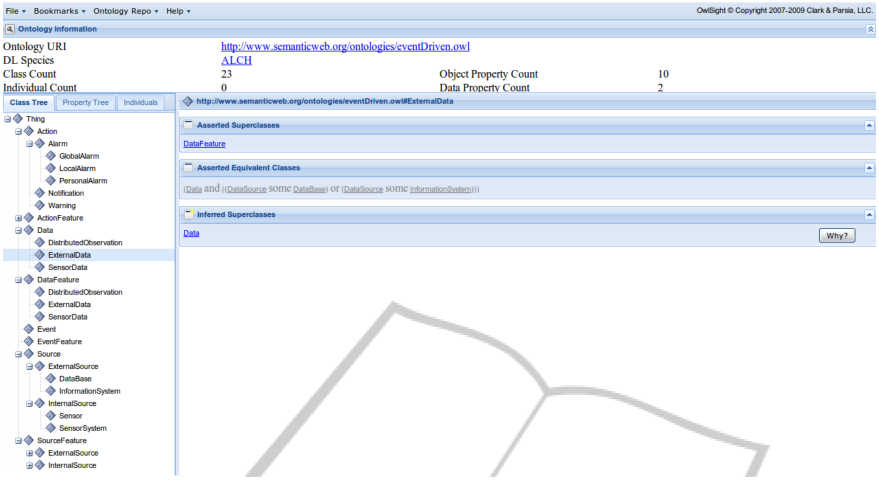

Fig. 5. Validation of the Ontology using OWLSight [18].

These novel interaction models allow the engineering of advanced semantic actors built on standardized technologies as well as an innovative vision of systems 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 environments.

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