The Semantic Sensor Network Ontology: A Generic Language to Describe Sensor Assets

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Abstract.
We introduce a novel approach for describing sensors and their capabilities. Although existing standards for describing sensors and their capabilities as well as their measurements, produced by Open Geospatial Consortium's Sensor Web Enablement activities (OGC SWE), achieve syntactic interoperability, they do not provide facilities for computer logic and reasoning. We argue that ontologies are an adequate methodology to model sensors and their capabilities. Ontologies enable reasoning, classification and other types of automation to extend the SWE standards of the OGC. A semantic sensor network would allow the network and its components to be organised, queried, and controlled through high-level specifications. The ontology proposed here is not an ontology that organises all the facets and concepts of sensing, but rather one that provides a language to describe sensors in terms of their capabilities and operations. This paper introduces an initial version.

Keywords. semantic interoperability, ontology, semantic sensor network

Introduction

There are many ways sensors generate observation data. Differences include data formats, units, spatio-temporal resolution, domain, purpose at time of deployment, which quality of a given phenomena is observed (*e.g.* tips of a bucket versus acoustically estimated raindrops), and the characteristics of the data over time, *e.g.* the amount of gaps or drop-outs in the data. All these heterogeneous factors affect the integration of data from different sensors measuring the same phenomena. Also, more and more, sensors are linked together to build sensor networks.

Semantic interoperability has been identified as a key issue regarding geographic data sharing between different geospatial information communities [1]. The Open Geospatial Consortium's Sensor Web Enablement (OGC SWE) [2] activities have produced standards for describing sensors and their capabilities as well as their measurements. Those standards aim to enable developers to make sensors, transducers, and sensor data repositories discoverable, accessible and usable via the Web. However, those standards only achieve syntactic interoperability, they do not provide facilities for computer logic and reasoning.

To address the issues described above, we are in the course of developing an ontology as a general model to encode and reason about sensor assets. An ontology is a specification of a set of entities in terms of the concepts involved and the relationships between those concepts. The ontology proposed by us is not an ontology that organises all the facets and concepts of sensing, but rather provides a language to describe sensors in terms of their capabilities and operations.

Motivation for the Use of Semantics in Sensor Networks

The main shortcomings of the OGCs Sensor Web Enablement standards are discovery of data sets from registries, the heterogeneity of descriptions and the lack of semantics or reasoning [3]. SWE services based infrastructures lack semantically rich discovery mechanisms. Search algorithms facilitating semantically enhanced queries from users would be of great benefit for retrieving useful information out of Sensor Web registries and services. Also, related concepts, subgroups of sensor types, or other dependencies cannot be explored and the integration of domain ontologies, semantic queries and semantic transformations in Sensor Web infrastructure have to be addressed. Ontologies of sensors have the potential to be a key component of semantics for sensor networks.

What should be in the Sensor Description

There are several key aspects to be accounted for when marking up sensor assets. For discovery, it seems desirable to be able to do more than "just" a keyword search. Hierarchical search as well as search by synonyms is also advocated: Maué *et al.* [4] argue "that GIR [Geographic Information Retrieval] using semantic-enabled catalogs can improve user experience and usefulness of such IR [Information Retrieval] systems significantly".

One aspect of describing sensors are the "technical" aspects. Information about the sensor's calibration information, its temporal resolution (sampling frequency – how often does it measure) are as relevant as what it measures (*i.e.* categorising sensors) as well as its accuracy.

Another important aspect is access to the sensor. This is not only required for data retrieval but also for sensor control or reconfiguration. Thus, a semantically correct description of the access procedure has to exit.

The location of a sensor is of special interest, and in particular, the location of the sensor with regard to the feature it is observing.

Equally important as its format is the meaning of the data. This is about the way the sensor performs its measurement, *i.e.* which quality of the desired phenomena is being measured (*e.g.* tips of a bucket versus acoustically estimated raindrops). In case of the sensor as physical instrument, the chain of processes usually is "physical stimulus – sensor – data". Each transducer hardware has a specific response characteristic[1] to a given phenomenon. Also, the way the input is related to the output is not always linear, as described by the so-called transfer function.

Related work

A framework for sensor network modelling based on general features identified through analysis of existing sensor networks is proposed by Jurdak *et al.* [5]. This framework focuses on sensor network routing protocols, not on sensor capabilities. Another project bringing ontology to sensors is the Marine Metadata Interoperability Project (MMI). Bermudez *et al.* [6] present a sensor ontology based on NASA's Semantic Web for Earth and Environmental Terminology (SWEET-ontology) instruments and platforms. The detail of description ends at the categorization level. Russomano *et al.* [7] describe the approach to building OntoSensor, a prototype sensor knowledge repository. OntoSensor includes definitions of concepts and properties adopted in part from SensorML, extensions to IEEE SUMO[2] and references to ISO 19115 [8]. It does not provide constructs to describe sensors as processes similar to SensorML. Tripathi and Hassan [9] present the extension of the SWEET ontologies to include part of the hydrogeology domain. A hybrid approach for the development of an ontology in the hydrographical domain is presented by López-Pellicer [10]. For the development of "hydrOntology",an approach merging top-down and bottom-up techniques is being followed.

Proposed Semantic Sensor Network Ontology

The ontology, Figure 1, is organised around four core clusters of concepts: those concepts describing the domain of sensing (`Feature`); those describing the sensor (`Sensor`); those describing the physical components and location of the sensor (`SensorGrounding`); and those describing functions and processing (`OperationModel` and `Process`), both processing on a sensor and processing that can create a sensor (perhaps without a physical realisation) from any number of data streams.

The observed domain

A single ontology cannot capture in any sufficient detail all the concepts of every possible domain. The sensor ontology leaves the observed domain unspecified, to be supplied in any application, and instead, in accordance with upper level ontologies, allows abstract representations of real world entities (`Feature`: *e.g.* lake or rain), which are not observed directly but through their observable qualities (`PhysicalQuality`: *e.g.* temperature or depth).

[1] "response" describes in this case the effect of a driving force or signal upon the device
[2] Suggested Upper Merged Ontology

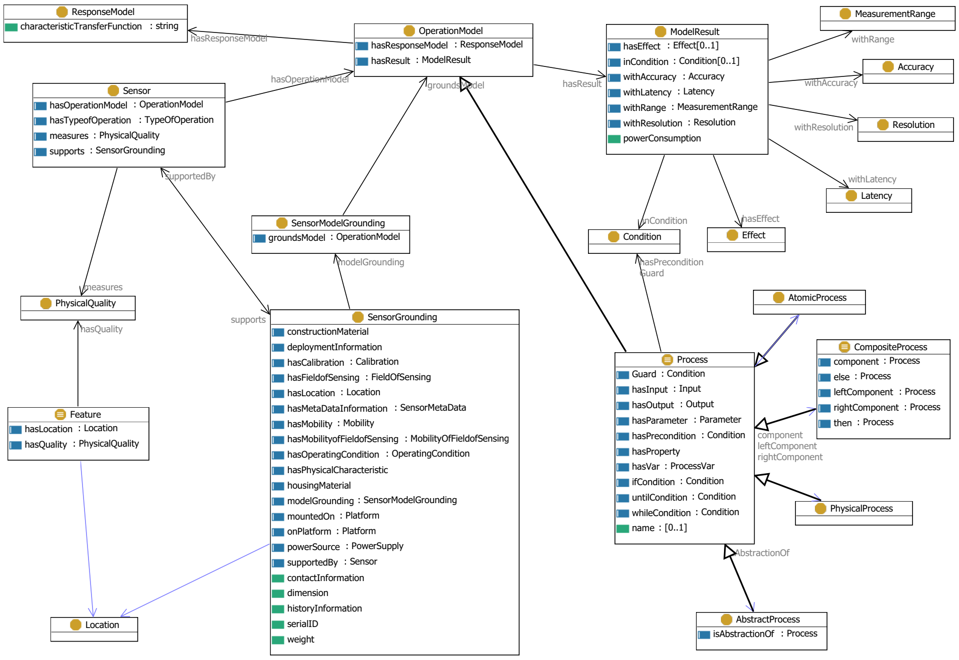

Figure 1. The core concepts and relationships of the semantic sensor network ontology.

The sensor

To provide wide application of the ontology, `Sensor` has to include more than just the physical instrument but also the associated processing chain included in the measurement. In accordance with literature on sensors [11] and SensorML [2] we use the following definition of a sensor.

A sensor is a source producing a value within a value space representing a phenomenon in a given domain of discourse.

The representation of a sensor in the ontology links together what it measures (the domain), the physical sensor (the grounding) and its functions and processing (the models).

The concrete sensor

The `SensorGrounding` models the concrete realisation of a sensor. The grounding represents, in the case of an instrument, its physical implementation, including size, shape, materials and location. And also models the concrete aspects of accessing data from the sensor, including the types and expected formats of input when calling functions, the format of output and the details for accessing the sensor (radio, network or physical access, for example).

The `OperationModel` (described next) specifies functions and their results, while the grounding specifies the physical device, if it exists, and how to access the functions. Separating the two, distinct but clearly related groups of concepts, means that descriptions of types of sensors, functions and the like can be shared among specifications and also that a single sensor type can have multiple concrete descriptions, promoting reuse and allowing for differences in deployment.

The abstract sensor

The `OperationModel` describes how the sensor actually performs its measurement. Processing itself may seem distinct from sensing, but, for provenance and for understanding measurements, the sensor description at least needs to describe the available functions of a sensor and their meaning; these descriptions then need to be combined and organised if one is to describe more complicated instruments (a wind chill sensor, for example, that makes its measurement based the measurements of a temperature sensor and a wind speed sensor); and processing itself becomes important in modelling and describing 'bigger' sensors, such as habitat prediction models, rainfall run-off models or climate models.

The need to model single sensors, compound sensors and larger processing chains and models suggests a continuum of abstractions for describing functions and processes. The `Process` concept models processes from abstract and atomic to compound (in a similar, but different, way to OWL-S), allowing for a single specification to be described at multiple levels of abstraction and to use multiple different types of abstractions in describing its processing.

Conclusion and future work

We are currently in the stage of encoding some examples to ensure that the ontology actually enables the description of sensors. Further research will be conducted in the application of the sensor ontology in existing sensor networks. One use case will be in the Tasmanian South Esk river catchment, where several sensor systems of different types are deployed for measuring hydrological phenomena. These sensors provide a data rich environment for continuous flow forecasting using Data Driven Modelling (DDM). When integrating data from different sources or mapping data to sensor (or measurement) information models, the semantics of the data need to be well understood [12].

The W3C Semantic Sensor Network Incubator Group (SSN-XG)

The recently initiated SSN-XG [13] will work on two main objectives: (a) the development of ontologies for describing sensors, and (b) the extension of the Sensor Model Language (SensorML), one of the four SWE languages, to support semantic annotations. The ontology presented here contributes to the first objective of the Incubator Group. Its initial version has been posted on the Wiki of the Incubator Group[3] on March 20, 2009. The SSN-XG will also investigate mapping between OGC standards and OWL specifications of sensors.

[3]http://www.w3.org/2005/Incubator/ssn/wiki/images/4/42/SensorOntology20090320.owl.xml (last accessed on 2009-04-07)

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