What Now and Where Next for the W3C Semantic Sensor Networks Incubator Group Sensor Ontology

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Abstract. This short paper accompanies the keynote given at SSN'11. It reviews the initiation of the Semantic Sensor Networks Incubator Group and the ontology produced. Also, examples of the use of the ontology, potential extensions and options for future use are briefly discussed. The ontology is available at:

http://purl.oclc.org/NET/ssnx/ssn.

1 The SSN-XG and the Sensor Ontology

The Semantic Sensor Networks Incubator Group (the SSN-XG) was formed by CSIRO, Wright State University and the OGC in early 2009, formally commencing on March 4, 2009. The group's charter

http://www.w3.org/2005/Incubator/ssn/charter

lists the development of an ontology for sensors and semantic annotations as its two key areas of work. This paper discusses only the work on ontologies and the resulting SSN ontology.

At the the group's inception, there was already interest in semantic sensor networks, including a number papers and ontologies for sensors, reviewed by the group [5], as well as projects such as SemsorGrid4Env[1] and SENSEI.[2] Further, there was a growing realisation that semantics could complement and enhance standards, such as the OGC SWE suite (in particular, in this context, SensorML [2] and O&M [6,7]), that largely provide syntactic interoperability; see, for example, the analysis by Cameron et al. [3]. Indeed, the notion of a Semantic Sensor Web [9] had already been developed.

The introduction of a Web of things and linked knowledge fragments, that interacts with and represents the real world, presented a further vision for semantic sensor networks, in which sensors are things that observe other things.

[1] http://www.semsorgrid4env.eu/
[2] http://www.sensei-project.eu/

The possible size, complexities and heterogeneity of such a Web indicates potential for specification, search, linking, reasoning, and the like, all supported by semantics. Indeed, the SSN-XG charter states that "A semantic sensor network will allow the network, its sensors and the resulting data to be organised, installed and managed, queried, understood and controlled through high-level specifications."

The SSN-XG closed in September 2010, with 41 people from 16 organisations having joined the group. 24 people are credited in the SSN-XG Final Report. The group met weekly via teleconference and once face to face, coinciding with ISWC/SSN 2009 in Washington. The group's members represented universities, research institutes and multinationals. The activities of the group are recorded on a wiki

`http://www.w3.org/2005/Incubator/ssn/wiki/Main_Page`,

from which the group's final report

`http://www.w3.org/2005/Incubator/ssn/XGR-ssn/`

can also be reached.

1.1 The SSN Ontology — `http://purl.oclc.org/NET/ssnx/ssn`

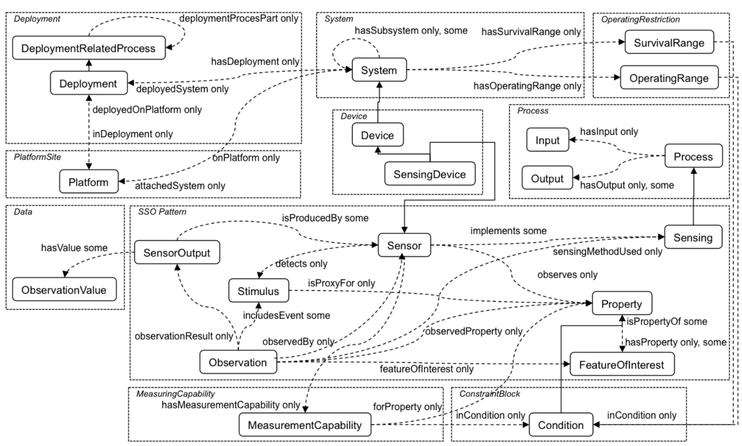

Fig. 1. Overview of the SSN ontology and the ten conceptual modules (not all concepts and properties shown).

The SSN-XG produced an OWL2, $\mathcal{SRIQ}(\mathcal{D})$, ontology for describing the capabilities of sensors, the act of sensing and the resulting observations. The ontology, called the SSN ontology is available at `http://purl.oclc.org/NET/ssnx/ssn`.

The SSN ontology was produced by group consensus; discussion and votes on extensions were taken at meetings and by email. The ontology has 41 concepts and 39 object properties, organised into the ten conceptual modules shown in Figure 1.

Navigable documentation on the group's wiki

`http://www.w3.org/2005/Incubator/ssn/wiki/SSN`

is largely automatically derived from the ontology. Each concept and property is annotated with rdfs:comment, rdfs:isDefinedBy, rdfs:label, rdfs:seeAlso and dc:source comments, which include SKOS mappings to sources and similar definitions.

The ontology is aligned to DOLCE UltraLite,[3] which further explains concepts and relations and restricts possible interpretations.

The ontology can be seen from four related perspectives: a sensor perspective, with a focus on what senses, how it senses, and what is sensed; an observation, or data, perspective, with a focus on observations and related metadata; a system perspective, with a focus on systems of sensors and deployments; and, a feature and property perspective, focusing on what senses a particular property or what observations have been made about a property.

Central to the ontology is the Stimulus-Sensor-Observation (SSO) pattern, Figures 1 and 2. The SSO pattern is explained next, followed by the four perspectives.

Stimulus-Sensor-Observation Pattern The SSO pattern [8] is designed as a minimal set of concepts, and minimal ontological commitments, that encapsulate the core concepts of sensing: what senses (Sensors); what is detected (a Stimulus, that in turn stand for properties of features);[4] and what tells us about a sensing event (Observations).

The pattern can serve as a basis for more complex ontologies, like the full SSN ontology, is simpler and more easily understandable than the full ontology and could serve as a minimal ontology for linked sensor data.

Sensor Perspective The SSN ontology takes a liberal view of what can be a sensor, allowing anything that senses a real-world property using some method. Hence, devices, whole systems, laboratory set-ups, even biological systems can all be described as sensors. Sensor is described as skos:exactMatch with sensor in SensorML and skos:closeMatch with observation procedure O&M.

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[3] `http://www.loa-cnr.it/ontologies/DUL.owl`

[4] Properties are observable aspects of real world things, while FeaturesOfInterest are things that we might like to observe properties of: for example, the temperature or depth (properties) of a lake (a feature).

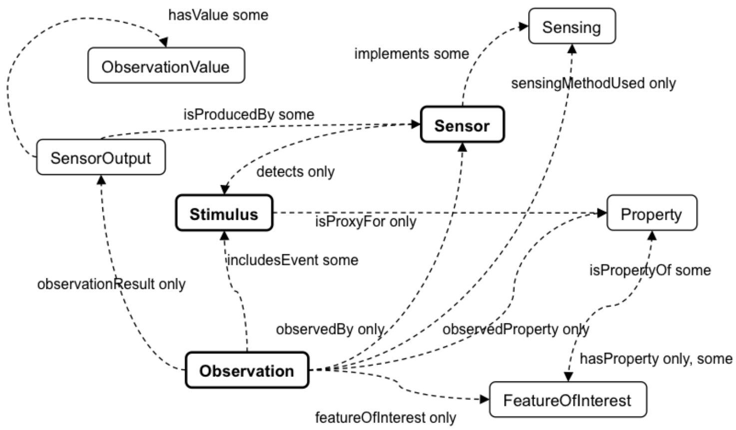

Fig. 2. The Stimulus-Sensor-Observation pattern. The pattern shows the central role of stimuli, sensors and observations and how these concepts relate to features, properties and other key sensing concepts.

The ontology can also be used to describe capabilities of sensors, Figure 3. A MeasurementCapability specifies, in given conditions, the Accuracy, DetectionLimit, Drift, Frequency, Latency, MeasurementRange, Precision, Resolution, ResponseTime, Selectivity, and Sensitivity of a sensor. These properties are themselves observable aspects of the sensor, given some environmental conditions. For example, a specification could show that a sensor has accuracy of $\pm 2\%$ in one condition, but $\pm 5\%$ in another.

Observation Perspective In the SSN ontology, observations are situations that describe the stimulus and result of sensing, given a sensing method. That is, observations link the act of sensing, the stimulus event, the sensor, the sensed property and feature, and a result, placing these in an interpretative context. Observations are thus an explanation of an observing act and result — not the event itself. In the DUL alignment they are social constructs (situations).

The Observation concept is described as skos:closeMatch with observation in O&M. The same data is recorded in both; however, in O&M, an Observation is the act of sensing and a record of the result.

System Perspective Systems are units of organisation that may have subsystems, maybe attached to platforms and may be deployed, Figure 4. A system has operating and survival ranges that describe its intended operating conditions and conditions beyond which it is considered broken. As with MeasurementCapability for sensors, OperatingRange and SurvivalRange are observable properties of systems.

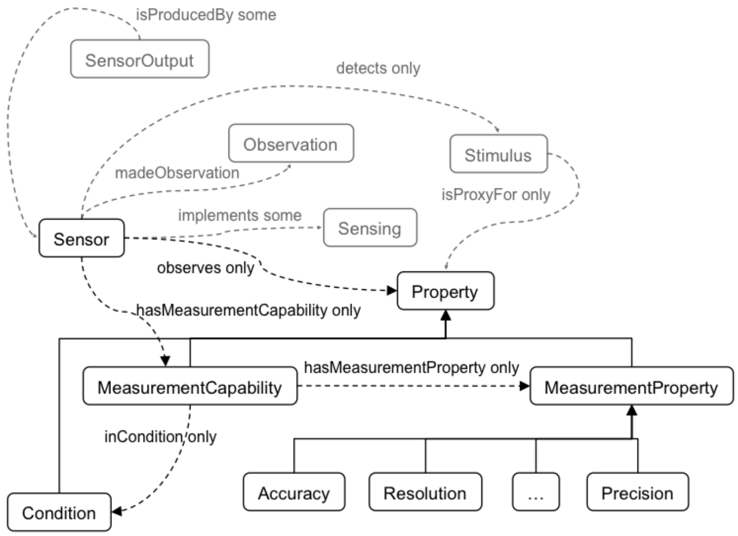

Fig. 3. Sensors are anything that sense: that implement some sensing method. The capabilities of a sensor are described as observable characteristics (Properties) using MeasurmentCapability.

Feature and Property Perspective Feature and property are woven throughout the SSO pattern, the sensor perspective, the observation perspective and the system perspective. Viewing the world from a feature and property perspective allows, for example, seeing a knowledge base in terms of questions like what observes property p, what has observations affected by p, what observations have been made about p and what devices withstand given environmental extremes.

Examples The SSN ontology doesn't have concepts for domain, time and place, features or properties. This additional context is included in the usual OWL way: import another ontology and show (with subconcepts and equivalent concepts) how the concepts are aligned. For example, one might import ontologies for features (and place these as subconcepts of Feature) and then define (as subconcepts of Sensor) all the relevant sensor types.

The group's wiki and final report give a number of examples. Such as linked open data examples from the SENSEI[5] project [1], semantic annotation from Kno.e.sis,[6] a SmartProducts[7] example and sensor datasheets.

[5] `http://www.sensei-project.eu/`
[6] `http://knoesis.wright.edu/`
[7] `http://www.smartproducts-project.eu/`

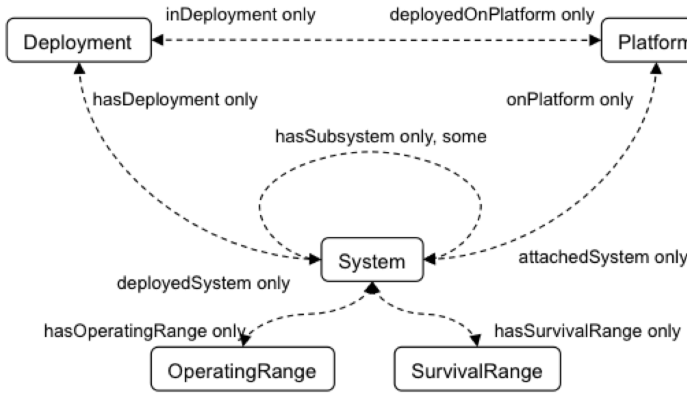

Fig. 4. Simplified view of systems, deployments, platforms, and operating and survival conditions. Sensors, along with other things, maybe systems.

Additionally, the SSN ontology is used in the SemsorGrid4Env project,[8] the SPITFIRE project,[9] the EXALTED project,[10] at 52north[11] and at CSIRO.[12] It was also used in publishing linked data from the Spanish Meteorological Agency.[13] Known uses and papers were listed at

`http://www.w3.org/2005/Incubator/ssn/wiki/Tagged_Bibliography`.

2 Future Directions

In developing the ontology, the group worked to include only the sensor specific concepts and properties, thus the need to include domain and other concerns when using the ontology. However, concepts from the systems perspective (System, Deployment, Platform, etc.) arent extensions of the SSO pattern, and this leads naturally to questioning their place in the ontology.

Clearly the system perspective is often needed, so it's natural to have included it, but these concepts aren't sensor only. Similarly, time series and other concepts not in the ontology are often used, but not sensor only. This suggests a more modular structure, in which the central enabler (the sensor ontology) is as simple as possible and other frequently used concepts are provided in small 'stem' modules. This wouldn't facilitate further capability, but it does clean up the ontology and guide its use. The SSO pattern (8 concepts) would be the

8 `http://www.semsorgrid4env.eu/`
9 `http://www.spitfire-project.eu/`
10 `http://www.ict-exalted.eu/`
11 `52north.org/`
12 `http://www.csiro.au/science/Sensors-and-network-technologies.html`
13 `http://aemet.linkeddata.es/`

starting module, with the remaining sensor only concepts (largely measurement capabilities) in another module (14 concepts), then systems, timeseries and the like in small largely independent modules.

An open community, formed around the ontology and semantic sensor networks in general, could maintain the ontology as well as document use, examples and common patterns.

As for further use of the ontology, it's likely to at least be used further in CSIRO sensor and provenance projects, at 52 North and Kno.e.sis, in the SPITFIRE project and internet of things projects. The array of applications in which the ontology could enable includes provenance and decision making, scientific processing and reasoning, streaming data, and other management, querying and reasoning tasks. Internet of things applications also invite the option of linking sensing to actuation.

Ideally, manufacturers would provide machine-readable specifications of their sensor datasheets, using the SSN ontology.

3 Acknowledgements

An article [4], covering, in greater depth, the ontology, the group and the examples, will be available soon.

Without the time and effort of all the members of the incubator group the construction of the ontology and its many uses would not have been possible. The following are credited in the group's final report and upcoming article.

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