SEMANTIC MEDIATION ON THE SENSOR WEB

Arne Bröring, Patrick Maué, Christian Malewski

University of Münster
Institute for Geoinformatics
Münster, Germany

Krzysztof Janowicz

University of California
Geography Department
Santa Barbara, USA

1. INTRODUCTION

This work[1] enables an automated integration of sensors and services on the Sensor Web. The Sensor Web is defined as an infrastructure which enables the interoperable usage of sensor resources by providing services for (1) *discovery*, (2) *access*, (3) *tasking*, as well as (4) *eventing & alerting* [2]. The notion of the *Sensor Web* has been largely influenced by the developments of OGC's Sensor Web Enablement (SWE) initiative [3], however, there are also other implementations complying to the Sensor Web idea, such as Sensorpedia [4], SensorMap with its underlying SenseWeb infrastructure [5], SensorBase [6], or Cosm[2] (formerly known as *Pachube*).

Approaches such as USB enable the integration of a hardware sensing device with computer systems on the lowest level. However, to integrate sensors with the Sensor Web, one needs to go beyond the connection of the hardware device as provided through a driver mechanism. In applications such as disaster management, early warning, or environmental monitoring, the integration of the sensor with the model of a specific application plays a crucial role. The SWE standards Observations & Measurements (O&M) [7] and Sensor Observation Service (SOS) [8] are examples for data or service models that serve as generic foundations of application specific models.

Sensor Web services shall be able to subscribe for sensors based on their characteristics. For example, in an oil spill scenario, such as the *Deepwater Horizon* disaster in 2010, an SOS should be able to subscribe for the retrieval of oceanographic sensor data for the 'Gulf of Mexico' to monitor an oil spill. Therefore, it declares interest in sensor data for the feature 'Gulf of Mexico' and properties observed by sensors such as 'sea water salinity' or 'fluorescence'. The key challenge here is to assure that the characteristics advertised by a sensor *match* those required by a service. A sensor may characterize itself by stating its identifier, name, or model number, but also *spatial*, *temporal*, and *thematic* characteristics may be specified.

Temporal characteristics include the sampling rate or the lifetime of a sensor. Spatial characteristics include the position of a sensor, a path along which it is traveling, or a geographic region within which it can function. The central thematic characteristic of a sensor is the observed property (e.g., water temperature) and the unit of measure (e.g., Kelvin). Other thematic characteristics are the sensor configuration (e.g., the calibration) or sensor deployment (e.g., mobile/stationary sensor). Matching sensor characteristics with the requirements of a service is challenging and requires suitable mediation techniques; a detailed analysis of these matching challenges has been described by Bröring et al. [9].

2. A SEMANTIC MEDIATION MECHANISM FOR THE SENSOR WEB

To cope with the above described challenges, this section describes a mechanism for the automatic semantic mediation of sensors and Sensor Web services. The approach is based on an encapsulated component, the *mediator*[3]. The mediator acts as a central component on the Sensor Web, or within a local Sensor Web infrastructure. It allows Sensor Web services and sensors to register and it realizes their correct integration via semantic mediation. Therefore, sensors can advertise their characteristics, and services can specify requirements regarding sensors, based on which the mediator computes possible matches. Through some means of communication (e.g., via XMPP or AMQP) messages can be exchanged between the mediator and the sensors / services. Those are the *ConnectSensor*, *SubscribeService*, and *Mediate* message. Examples of those messages are given below. The syntax is intentionally kept simple and self-explanatory (a '*' is used to separate message parts).

The *ConnectSensor* message allows to register a sensor at the mediator. It carries only one argument, which is the URL of a metadata description document of the sensor (see Listing 1 for an example). This metadata document contains a detailed description of the sensor and is encoded conform to

---

[1] This short paper extracts and extends work from our previous article [1] by encapsulating a stand-alone mechanism for the semantic mediation on the Sensor Web.

[2] http://cosm.com

[3] The mediator concept has been implemented as open source software as part of the 52°North Sensor Bus project; http://52north.org/sensorBus.

the SWE standard SensorML [10]. This SensorML document needs to be semantically annotated, so that the mediator is able to gather the meaning of the contained information. Listing 2 shows an excerpt of such a SensorML document that describes the output of a sensor. In this case, the sensor observes temperature, semantically annotated by a concept from the SWEET ontology [11], and provides those measurements in degree Celsius, as defined by the according UCUM [12] code.

```
ConnectSensor * http://myserver.org/sensor/s1.xml
```

Listing 1. Excerpt of the used SensorML document.

```
<sml:output name="temp">
  <swe:Quantity
     definition=
"http://sweet.jpl.nasa.gov/1.1/property.owl#Temperature">
    <swe:uom code="Cel" />
  </swe:Quantity>
</sml:output>
```

Listing 2. Excerpt of the used SensorML document.

The *SubscribeService* message is sent to register a service at the mediator. Besides the service's endpoint URL, required sensor characteristics can be passed as arguments of the message in key-value pairs. In the example of Listing 3, a service subscribes at the mediator by requiring that the observed property of the sensor is some quantity related to temperature[4] and the unit of measure is Kelvin ('K' is the according UCUM code).

```
SubscribeService * http://mySensorWebService.org
* observedProperty
* http://sweet.jpl.nasa.gov/1.1/property.owl
    #TemperatureRelatedQuantity
* unitOfMeasure
* K
```

Listing 3. Example of a *SubscribeService* message.

After a new sensor or service has registered, the mediator starts the mediation process, which consists of two main steps, (1) the concept creation and (2) the semantic matchmaking. In the first step, an ontological description of the advertised or required characteristics, respectively, are created. These ontological descriptions are based on W3C's SSN ontology [13] and stored internally by the mediator. In the second step, the created ontological description is automatically compared to all existing descriptions, i.e., a new description of sensor characteristics required by a service is compared to all registered descriptions advertised by connected sensors, and vice versa. This automatic comparison is done by injecting the new ontological description into the existing ontology maintained by the mediator. Then, the mediator triggers a subsumption reasoner to reclassify the ontology. Thereby, only in case the advertised sensor characteristics are reclassified as *equivalent to* or as *subconcept of* the required sensor characteristics. In consequence, a match is inferred and the sensor can be linked with the service.

Figure 1 illustrates an example. Subconcepts of the SSN ontology have been created by the mediator for the advertised and required sensor description. External terms from the SWEET ontology are used to describe the observed properties of both sensor descriptions. They do match, due to a subclass relationship. However, for the unit of measure, individuals for Celsius and Kelvin were added, which results in a mismatch. The service cannot directly ingest measurements from the advertised sensor, since the utilized unit does not comply with what it expects.

Our approach deals with such mismatches by relying on SWRL rules with associated conversion formulas. These rules are part of the ontology and are executed during reasoning. They automatically attach conversion formulas, e.g., for unit or data type conversions, as properties to the individuals of the advertised sensor description. In the above example, a conversion formula for calculating Kelvin values from degree Celsius is attached. The formula is encoded in executable MathML and needs to be applied to the sensor values before insertion.

After finalizing the second step, and in case the matchmaking was successful, the mediator sends a *Mediate* message to service and sensor. The message states which advertised sensor output relates to a property required by a certain service. Thereby, it establishes the connection of sensor and service by advising a sensor at which service it shall register. Optionally, the message can contain a conversion formula which needs to be applied by the service. In the example of Listing 4, a Mediate message is shown that advises the service with the given URL to a consume the temperature data from the specified sensor for the requested temperature related properties. Additionally, a MathML conversion rule is defined, that needs to be applied by the service to transform from Celsius measurements to Kelvin.

```
Mediate
  * http://myserver.org/sensor/s1.xml
  * http://mySensorWebService.org
  * http://sweet.jpl.nasa.gov/1.1/property.owl
      #Temperature
  * http://sweet.jpl.nasa.gov/1.1/property.owl
      #TemperatureRelatedQuantity
  * <math>
      <mrow>
        <mi>VAL</mi>
        <mo>+</mo>
        <mi>273,15</mi>
      </mrow>
    </math>
```

Listing 4. Example of a *Mediate* message with conversion rule.

3. CONCLUSIONS AND OUTLOOK

This paper outlines an approach for performing semantic mediation on the Sensor Web between sensors and services. This

[4] For this the following SWEET concept can be chosen: http://sweet.jpl.nasa.gov/1.1/property.owl#TemperatureRelatedQuantity

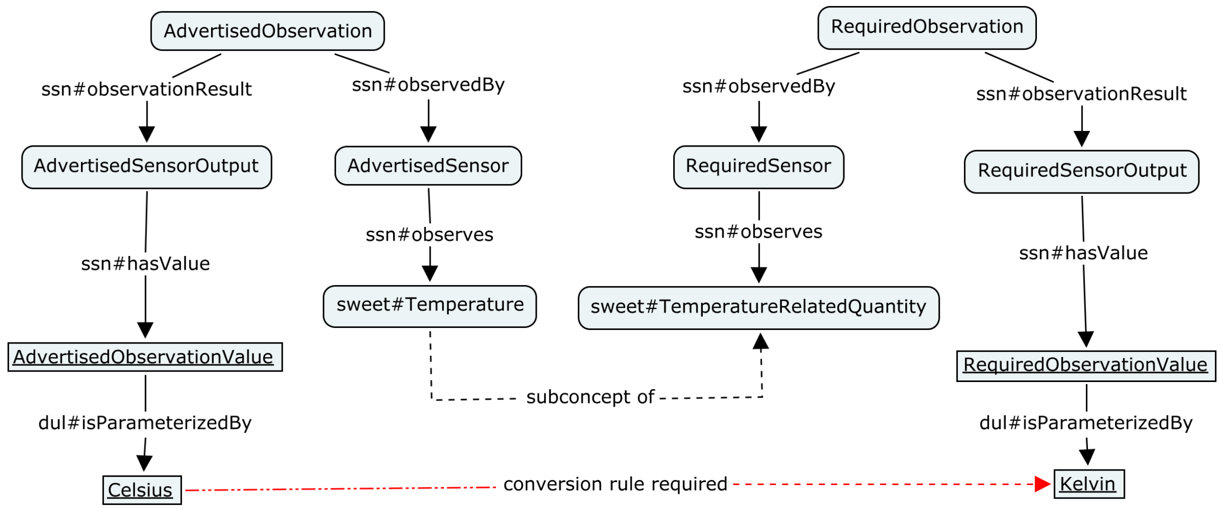

Fig. 1. Matchmaking between advertised and required sensor description (based on: [1]).

mediation is done through the creation of ontological descriptions and semantic matchmaking. For specifying the ontological sensor description, the W3C SSN ontology acts as a basis. While here the SWEET ontology was used to represent environmental phenomena, also other domain ontologies can be incorporated. For mediating between non-matching concepts, SWRL rules can be added to the ontology which link to executable conversion formulas.

So far, the design of the mediation mechanism relies on subsumption reasoning to compute the matching. All major reasoners offer such taxonomic reclassification functionality. However, the design also allows the usage of other reasoning methodologies, e.g., semantic similarity measurement. This would improve the mediation by offering ranking information for the matchmaking [14]. The developed mechanism is similar to formerly developed approaches for the semantic matchmaking of client requirements against Web service capabilities (see e.g., [15, 16]). The mediation mechanism proposed here, is optimized for the matchmaking of sensors and services on the Sensor Web.

In the future, the approach will be extended to better support reasoning on quantitative sensor characteristics. So far, the mediator sorts values of quantities and quantity ranges of characteristics such as accuracy, precision, or survival range as ordered or nested concepts into the ontology. This sorting logic has to be computed by the mediator in the creation phase to prepare for the reasoning step. Alternatively, this could be delegated to the reasoner by modeling the quantities as individuals and using SWRL rules to select the correct sensors for a requesting service.

4. ACKNOWLEDGEMENTS

This work has been financially supported by the project *Flexible and Efficient Integration of Sensors and Sensor Web Services* funded by the ERDF program for NRW (contract number N 114/2008), the EC funded project *ENVISION* (contract number 217951), as well as the *52°North Initiative for Geospatial Open Source Software*.

5. REFERENCES

[1] Arne Bröring, Patrick Maué, Krzysztof Janowicz, Daniel Nüst, and Christian Malewski, "Semantically-enabled Sensor Plug & Play for the Sensor Web," *Sensors*, vol. 11, no. 8, pp. 7568–7605, 2011.

[2] Arne Bröring, Johannes Echterhoff, Simon Jirka, Ingo Simonis, Thomas Everding, Christoph Stasch, Steve Liang, and Rob Lemmens, "New Generation Sensor Web Enablement," *Sensors*, vol. 11, no. 3, pp. 2652–2699, 2011.

[3] M. Botts, G. Percivall, C. Reed, and J. Davidson, "OGC Sensor Web Enablement: Overview and High Level Architecture," in *GeoSensor Networks, 2nd International Conference, GSN 2006*, Silvia Nittel, Alexandros Labrinidis, and Anthony Stefanidis, Eds., Boston, MA, USA, October 2008, vol. 4540 of *Lecture Notes In Computer Science*, pp. 175–190, Springer.

[4] B. L. Gorman, D. R. Resseguie, and C. Tomkins-Tinch, "Sensorpedia: Information Sharing Across Incompatible Sensor Systems," in *International Symposium on CollaborativeTechnologies and Systems, CTS 2009*, Baltimore, MD, USA, May 2009, pp. 448–454, IEEE.

[5] A. Santanche, S. Nath, J. Liu, B. Priyantha, and F. Zhao, “Senseweb: Browsing the Physical World in Real Time,” in *International Conference on Information Processing in Sensor Networks (IPSN)*, Nashville, USA, 2006.

[6] K. Chang, N. Yau, M. Hansen, and D. Estrin, “SensorBase.org - A Centralized Repository to SLOG Sensor Network Data,” in *International Conference on Distributed Computing in Sensor Networks (DCOSS) / EAWMS*, San Francisco, USA, June 2006, UCLA.

[7] Simon Cox, *OGC Abstract Specification Topic 20: Geographic Information - Observations and Measurements*, Open Geospatial Consortium, Wayland, MA, USA, 2010.

[8] A. Bröring, C. Stasch, and J. Echterhoff, *OGC Implementation Standard 12-006: OGC Sensor Observation Service Interface Standard, Version 2.0*, Open Geospatial Consortium, Wayland, MA, USA, 2012.

[9] A. Bröring, K. Janowicz, C. Stasch, and W. Kuhn, “Semantic Challenges for Sensor Plug and Play,” in *Web & Wireless Geographical Information Systems, W2GIS 2009*, J.D. Carswell, S. Fotheringham, and G. McArdle, Eds., Maynooth, Ireland, December 2009, vol. 5886 of *Lecture Notes in Computer Science*, pp. 72–86, Springer.

[10] M. Botts, *OGC Implementation Specification 07-000: OpenGIS Sensor Model Language (SensorML)*, Open Geospatial Consortium, Wayland, MA, USA, 2007.

[11] Robert G. Raskin and Michael J. Pan, “Knowledge representation in the semantic web for Earth and environmental terminology (SWEET),” *Computers & Geosciences*, vol. 31, no. 9, pp. 1119 – 1125, 2005.

[12] Gunther Schadow and Clement J. McDonald, *The Unified Code for Units of Measure*, Regenstrief Institute and UCUM Organization, 2009, Online available: http://aurora.regenstrief.org/~ucum/ucum.html; last accessed 01/2012.

[13] L. Lefort, C. Henson, K. Taylor, P. Barnaghi, M. Compton, O. Corcho, R. Garcia-Castro, J. Graybeal, A. Herzog, K. Janowicz, H. Neuhaus, A. Nikolov, and K. Page, *Semantic Sensor Network XG Final Report; W3C Incubator Group Report*, W3C, 2011, Online available: http://www.w3.org/2005/Incubator/ssn/XGR-ssn/; last accessed 12/2011.

[14] K. Janowicz, C. Keßler, M. Schwarz, M. Wilkes, I. Panov, M. Espeter, and B. Baeumer, “Algorithm, Implementation and Application of the SIM-DL Similarity Server,” in *Second International Conference on GeoSpatial Semantics (GeoS 2007)*, F. T. Fonseca, A. Rodriguez, and S. Levashkin, Eds., Mexico City, Mexico, November 2007, vol. 4853 of *Lecture Notes in Computer Science*, pp. 128–145, Springer.

[15] Sven Schade, Arnd Sahlmann, Michael Lutz, Florian Probst, and Werner Kuhn, “Comparing approaches for semantic service description and matchmaking,” in *On the Move to Meaningful Internet Systems 2004: CoopIS, DOA, and ODBASE*, Robert Meersman and Zahir Tari, Eds., vol. 3291 of *Lecture Notes in Computer Science*, pp. 1062–1079. Springer, 2004.

[16] Eva Klien, Michael Lutz, and Werner Kuhn, “Ontology-based Discovery of Geographic Information Services - An Application in Disaster Management,” *Computers, Environment and Urban Systems*, vol. 30, no. 1, pp. 102–123, 2006.