Combining Process and Sensor Ontologies to Support Geo-Sensor Data Retrieval

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1. Introduction

The Sensor Web Enablement (SWE) framework specifies how to access web-enabled sensors and sensor data on a syntactical level. Nevertheless, it is difficult to discover a sensor that fulfills certain criteria from a huge set of available sensors; effort is required to retrieve, interpret, and combine sensor data based on heterogeneous schemas. Semantics-based approaches promise to overcome these challenges (Bermudez and Piasecki 2004, Babitski et al. 2009, Kuhn 2009, Janowicz et al. 2010), but so far most work has focused on ontologies for sensors and their observations. We propose a combined approach which relates a sensor ontology to a process-centric domain ontology and hence takes into account how observation data was created and what types of features it relates refers to.

In accordance with the OGC specifications and related work (Compton et al. 2009, Kuhn 2009, Stasch et al. 2009), our sensor network ontology is not limited to physical devices but is constructed such that any entity (e.g., physical sensors, computational process) observing a phenomenon can be represented as a sensor. In contrast to existing hydrology ontologies (Bermudez and Piasecki 2004, Beran 2007, OrdnanceSurvey 2007, Vilches-Blázquez et al. 2009), we focus on a process-centric ontological approach. Process-centric means that the domain ontology is developed by first identifying geo-processes, entities (i.e., objects and matters), and their properties, followed by the relations between them. These relations are used as basis to handle naming heterogeneities and hence support sensor data retrieval.

The following sections of the paper describe our ontologies. We will use the concept of Evapotranspiration (ET) as running example as it is a key component is in the Hydrological Sensor Web research by the CSIRO Water for a Healthy Country Flagship initiative. For details, see (Guru et al. 2008).

2. Ontology Development

In this section, we introduce our sensor and hydrology ontologies. Note that we use *italics* to denote ontological categories.

2.1 Design and Development of the Sensor Network Ontology

Figure 1 depicts the core components of the Sensor Network Ontology (Neuhaus and Compton 2009). *System* abstracts computational processes as well as physical entities such as devices. *Procedures* are abstract descriptions of a sequence of operations, which may have *Input* and *Output*. Such a sequence of operations might be realized by a particular physical arrangement of a device, a computer program, or a lab procedure. For example, a *Device* can play the thematic role of being a *Sensor* using the *playRole* relation. This means that the *Device* implements the algorithm described by the *Procedure*. To sense some property is to follow a process that results in an observation, hence, *Sensor* is *subClassOf* of *Procedure*. Not only technological devices can sense – rather, a sensor is an entity that estimates or calculates a value for a physical quality, either through physical stimulus or as a calculation on previous observations.

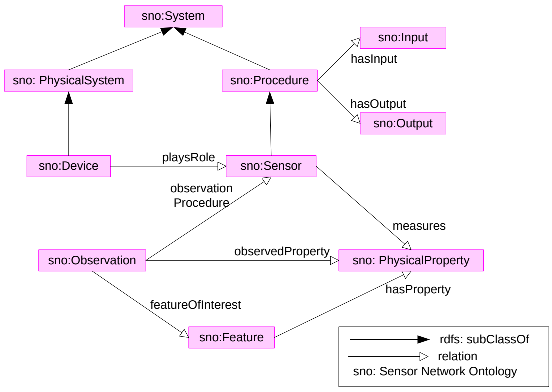

Figure 1. The partial view of the sensor network ontology.

The sensor network ontology, which is implemented in the Web Ontology Language (OWL) draws from the SensorML and Observation and Measurements (O&M) specifications. The ontology leaves the observed domain unspecified (to be supplied in an application) and instead, in accordance with top-level ontologies, allows abstract representations of real world entities, which are not observed directly but through their observable qualities. Domain concepts, units of measurement, time and time series, as well as location, can be imported from other ontologies.

2.2 Design and Development of the Hydrology Ontology

The interpretation of observed properties requires understanding the geo-processes which influence them (Devaraju and Kuhn 2010). Our domain ontology represents concepts that relate geo-processes to the properties measured by sensors. We align the domain vocabularies to the DOLCE foundational ontology (Masolo et al. 2003). *Endurant*, *Perdurant*, *Quality* and *Abstract* are the four top categories of DOLCE. *Endurants* (e.g., *Physical Object*, *Amount of Matter* and *Feature*) exist in full at an instant of time. *Qualities* are the entities we perceive or measure. *Perdurants* are partially present at any time, at which they exist. DOLCE distinguishes different kinds of perdurants (e.g., *State*, *Process*, *Achievement*, and *Accomplishment*) based on two notions: (a) A perdurant is ‘cumulative’ if the mereological sum of two instances of the same perdurant-type maintains the same perdurant-type; (b) A perdurant is ‘homeomeric‘ if all its temporal parts are instances of the same most specific perdurant. *Processes* (e.g., the water evaporating process) are cumulative and weakly non-homeomeric. (i.e., some temporal parts of them are instances of the same most specific occurrent, and some are not). Eventive perdurant like *Accomplishment* (e.g., a grassland evapotranspiration) is the category of anti-cumulative perdurants which are non-atomic. The following Table 1 describes basic ontological relations between the domain categories.

Table 1. Basic ontological relations (Masolo, Borgo et al. 2003).

Relation	*Description*	*Example*
proper-part-of	An endurant is a proper part of another if the first is part of the second and not vice versa. This relation also applies to pairs of perdurants.	An instance of *LateralRoot* is *proper-part-of* some instances of a *Plant*.
generic-constituent	Constitution depends on some layering of the world (e.g., scientific granularities or ontological 'strata') described by the ontology.	An *AmountofWater* constituting a *Lake*.
participant-in	This relation holds between the endurants and perdurants	An instance of *Plant* is *participant-in* an instance of a *Transpiration* process.
host-of	Feature is a 'parasitic entity' that cannot exist without its host.	An instance of *Leaf* is *Host-Of* an instance of *Stomata*.
has-quality	A physical quality is inherent in a physical endurant. A temporal quality is inherent in a perdurant.	An amount of *Air has-quality* like *AirTemperature*; A *Wind* process *has-quality* such as a *WindDuration*.

In Figure 2, we present the categories describing evapotranspiration concept. See (Devaraju and Kuhn 2010) for further details and design decisions. The physical properties are classified based on units relevant to hydrology in SI measurement.

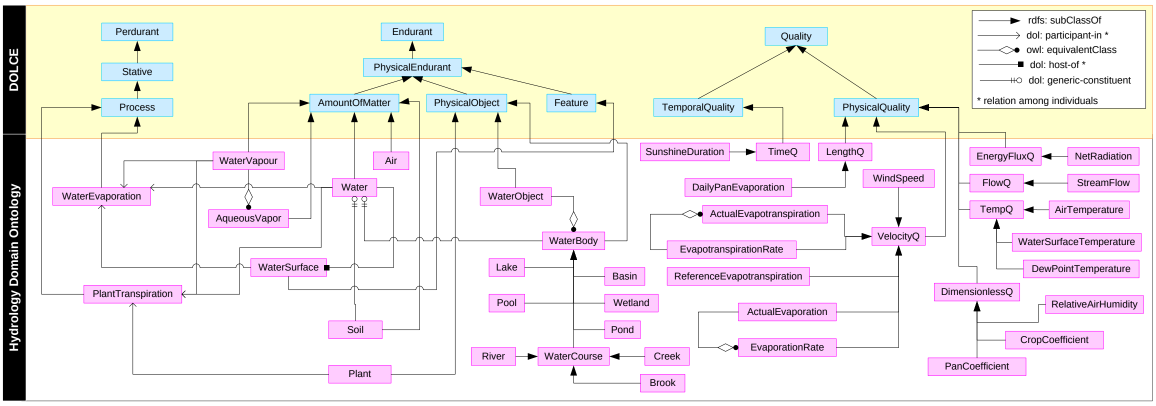

Figure 2. The partial view of ET- related categories.

Table 2. Examples of physical endurants and their physical properties.

Category	PhysicalQuality
WaterBody	ActualEvaporation, WaterSurfaceTemperature
Air	AirTemperature, RelativeAirHumidity
Vegetation	CropCoefficient, NetRadiation

3. Relating the Sensor and the Hydrology Domain Ontologies

In this section, we describe how our approach assists in resolving naming ambiguities and the description of derived properties - thus easing the retrieval of geo-sensor data.

3.1 Handling Naming Heterogeneity

One process can be distinguished from other processes by the *participation* relation. For instance, in contrast to *Evaporation*, the process of *Transpiration* has different participants, such as *Plant.* The *equivalentClass* relation is used in our framework to identify synonymous categories. For example, a user requesting evaporation data will be able to retrieve all the observations encoded as *EvaporationRate* as well as *ActualEvaporation* (Figure 2).

3.2 Supporting Sensor and Sensor Data Discovery

In the following we assume an application ontology that imports our sensor and hydrology ontologies and relates them as presented in the two following steps. In the first step (Figure 3), the categories defined in the domain ontology are related to the categories in the sensor network ontology as sub-categories, thus, describing the features (e.g., *Lake*) as well as the properties (e.g., *EvaporationRate*) measured by sensors (a device like *FloatingEvaporationPan*).

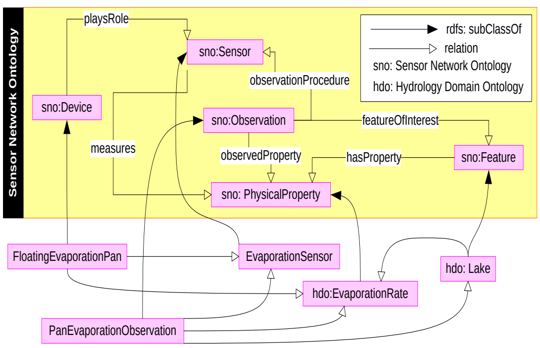

Figure 3. Importing domain categories into the sensor network ontology.

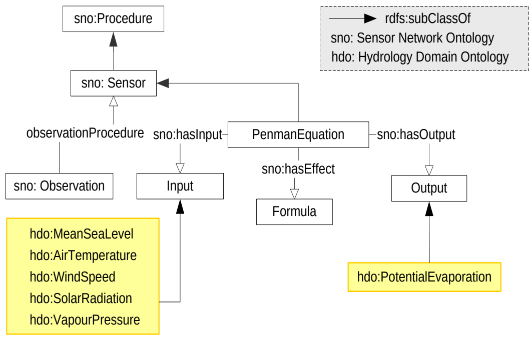

Figure 4. Penman Equation for Potential Evaporation (Eo).

In the second step (Figure 4), the domain categories are used to specify the parameters of a derived observation procedure. For existing reservoirs, the potential evaporation (Eo) can be measured using specific devices, or it can be calculated, for example with the Penman's equation. In the absence of a measured Eo, observation service can be configured to return the related daily weather data because the estimation of evaporation from meteorological variables has been specified.

4 Conclusions

This study is motivated by the need for an ontology of observable property-types to improve the discovery and retrieval of sensor data sources (OGC 2007). In this context, our approach argues for an 'integrated view' of the Semantic Sensor Web, instead of purely sensor-centric approaches. We illustrate this by an example that relates sensor concepts (i.e., how observations are performed) with domain concepts (i.e., observed properties and their associated real world entities). Our work provides new insights into the current research in semantic-based sensor data retrieval with the following developments:

a. Combining sensor concepts with domain concepts helps evaluate the design of both ontologies. The relation between features and their properties in the sensor ontology is consistent with the relations between respective categories in the domain ontology.

b. The sensor ontology distinguishes between sensing procedure and sensing devices. It represents a simple as well as multi-component sensors in terms of their operations, therefore describes the provenance information related to sensors. The idea of ‘roles’ allows any observing entity to be represented as a sensor. For example, an evapotranspirometer (lysimeter) or a soil water model that implements Penman-Monteith equation can be represented as a ‘sensor’ that estimates the amount of evapotranspiration. This allows sensor discovery queries through different types of sensors.
c. The process-centric domain ontology relates the geo-processes with the observed properties. These relations are used as a basis to handle the process and property naming heterogeneities, therefore improving the retrieval of sensor data. In addition, a complex observation request can be developed based on the relations between processes, their participants and their properties.

Further work will focus on extending the current ontological framework to describe time series observation and to restrict the possible interpretations of ‘feature types’ as defined in O&M.

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