

An explicit OWL representation of ISO/OGC Observations and Measurements

Simon J. D. Cox

CSIRO Land and Water
PO Box 56
Highett, Vic. 3190 Australia
simon.cox@csiro.au

Abstract. We have developed OWL ontologies for the ISO/OGC model for Observations, and for other standard geographic information schemas (geometry, time, metadata) upon which it depends. Translation from the original UML to OWL follows the ISO 19150-2 rules. The ontologies have been prepared standalone, to respect the ‘upper ontology’ implied by the ISO UML profile and ISO General Feature Model, and thus avoid introducing external bias. Mapping to other ontologies, such as the SSN ontology, can be done subsequently in RDFS and OWL axioms, and maintained as linksets separate from the structure model. A key issue is whether the OWL representation should exactly reproduce the frame-based UML model from the standard, or be an open-world OWL representation of some underlying model. This affects property scoping and object property restrictions. The latter choice requires more interpretation during conversion. Two incompatible ontologies have been developed through following both approaches.

Keywords: observation, ontology alignment, sensor, UML, OWL, OGC, ISO, Semantic Sensor Network

1 Introduction

An information model for observations and measurements (O&M), including features used in sampling, was developed as part of the Open Geospatial Consortium’s (OGC’s) Sensor Web Enablement Initiative (SWE) [1, 2, 3]. Following OGC’s standard practice, the model is formalized in UML. Subsequently, O&M was further developed in version 2.0 as an ISO standard [4]. A GML-conformant XML Schema is also available [5], based on the UML→XML Schema transformation rules described in ISO 19136 [6]. SensorML provides a complementary model and schema for describing observation production systems [7].

An early ontological analysis of O&M was provided by Probst [8, 9]. However, this was compromised by misinterpretation of some key elements of the model, probably triggered by reliance on draft versions of the OGC documents.

The W3C incubator project on Semantic Sensor Networks developed the SSN ontology for sensors and observations [10, 11, 12]. The SSN project reviewed a large number of existing or provisional sensor and observation ontologies, several of which had been inspired by O&M, or at least had taken elements from it. The SSN ontology itself is aligned with DOLCE Ultralite (DUL) [13], requiring the classes derived from O&M and SensorML to be placed into the DUL hierarchy. The resulting ontology adjusts both terminology and relationships relative to the original SWE UML models.

One of the recommendations from the Report on the work of the SSN Incubator [11] is to ‘Foster the adoption of the SSN Ontology in the OGC community’. OGC has subsequently dipped its toe in the water of ontologies through its publication of the GeoSPARQL standard [14]. While GeoSPARQL focuses on spatial query extensions to SPARQL, by necessity it includes a lightweight ontology for some elements of the ISO/OGC General Feature Model. It is not linked to any existing ontology. Adoption of the SSN ontology in the OGC community is thus immediately challenged by the mismatch between its DUL-basis and the OGC work with its UML and General Feature Model basis.

OGC has a close relationship with ISO Technical Committee 211 (ISO/TC 211), and uses various ISO standards as its ‘Abstract Specification’, many of which have used UML for formalization. Project 19150-2 in ISO/TC 211 is currently developing rules for use of OWL for designing geographic applications, and will provide an OWL version of its models in support of this.

In this paper we describe OWL ontologies for observations which are based directly on the UML model, using transformation rules defined in ISO 19150-2 [15]. This provides an OWL view of the O&M model unbiased by alignment with any external ontology, and supports development of a more explicit bridge between the SWE and SSN worlds.

2 UML-OWL transformation rules

Project 19150-2 in ISO/TC 211 is developing rules for transforming the UML models comprising the Harmonized Model into OWL ontologies, as well as rules for developing Application Schemas directly in OWL. This will be published as an ISO Standard, and is currently in Committee Draft (CD) status [15].

The so-called ‘Harmonized Model’ is a set of standard models for geometry, temporal, metadata, spatial fields, coordinate systems, etc, which may be used in the development of geographic ‘Application Schemas’, i.e. domain- and application-specific information models. O&M 2.0 is part of the Harmonized Model as it depends on the standard components and is published through the Harmonized Model code repository. The Harmonized Model is formalized using a UML profile described in ISO 19103 and ISO 19109. This profile uses UML as a “conceptual” modeling language, where the classes are generally intended to represent phenomena in the real world, and not merely the documents describing them, though it appears that the distinction was not clear when the TC 211 activities commenced, and the Harmonized Model is uneven in this respect. This approach may be contrasted with initiatives that provide a

UML profile for graphical representation of RDF and OWL ontologies (e.g. OMG's ODM [16]). Note that Berardi et al. [17] analysed UML and determined that it corresponds to a description logic in its own right.

The ISO 19150-2 rules define the mappings and some URI patterns. As expected, UML package → OWL ontology (and RDF namespace); UML class → OWL class with specialization modeled as sub-classing; UML attribute and association-role → RDF Property.

A key limitation of UML is a lack of expressivity regarding relationships between properties, which are not normally first class resources in UML models, so no use is made of property specialization, which is a powerful RDFS capability. The ISO 19150-2 rules also leave open some questions regarding the scoping of properties. Different conventions apply in UML and OWL: UML is a frame-based system, in which properties are strictly scoped to classes, while in RDF and OWL properties are first class entities, and are effectively scoped only to the RDF namespace (i.e. the URI stem). Nevertheless, two mechanisms are available to bind RDF and OWL properties to a class:

- by specifying the RDFS domain of a property;
- by using an OWL restriction class with cardinality constraints.

In the RDF/OWL world, it is conventional to either specify the RDFS domain of a property as a more general class, or not specify a domain at all. This supports maximum reusability of properties in new contexts. So in converting the Harmonized Model from UML to OWL there is an important choice to be made:

1. is the UML formalization of the Harmonized Model *canonical*? This requires us to strictly replicate the frame-based assumptions in the OWL representation; or
2. is the UML merely a *view* of some underlying model? In this case the limitations of the UML meta-model with its closed-world assumption are incidental, and it is valid to generate an OWL representation that follows open-world RDF and OWL assumptions.

An ontology developed under the former interpretation is primarily concerned with the classes. In UML each property is scoped to a class, and this determines the rule for the domain of the RDF property, and also provides a simple naming rule.

Under the latter interpretation an OWL representation of the Harmonized Model will provide both classes and properties for re-use in Application Schemas. Naming properties in this case is straightforward if UML attribute names and association role names are unique within a package, but requires workarounds where there are multiple properties on different UML classes with the same name, especially if their range is also different. An interpretation step is also required when choosing the best class to specify as the property domain – more or less general classes are consistent with the UML. The resulting ontology may be more familiar to users accustomed to the usual OWL assumptions and style, but will show some bias in relation to the original UML artefacts.

In this study we have prepared two ontologies, one following each set of assumptions. These are available online at the ontology URIs. In the following section we provide some specific details for each version.

3 Upper ontology

Re-use of elements from well-known RDF vocabularies is common when developing ontologies. In some cases this is not merely a matter of convenience, but involves a commitment to an existing system or Upper Ontology, such as DOLCE. The advantage of this approach is inheritance of a rigorous logical framework, and easy harmonization with other ontologies that use the same basis. However, there are risks from the potential introduction of cognitive bias inherent in the upper ontology, which may be in conflict with the subject material.

As its name suggests, the ISO Harmonized Model is a self-consistent set of models covering aspects of geographic information, which are maintained as a group. There are multiple dependencies between elements of the harmonized model.

Core packages that serve as dependencies in many applications include:

- ISO 19101, 19109, 19123 [18, 19, 20] – establish the ‘General Feature Model’ (GFM), a meta-model for object-oriented application schemas, and the model for spatial fields or ‘coverages’
- ISO 19103 [21] – provides primitive and base types, such as numbers, character-strings, measures, names and records
- ISO 19107, 19108, 19111 [22, 23, 24] – provide spatial and temporal classes, and coordinate reference systems
- ISO 19115 [25] – provides a detailed model for ‘metadata’, focused on dataset provenance, quality, access and discovery information

A key feature of the GFM is the disjoint nature of features and properties, which is consistent with the RDFS/OWL meta-model for classes and properties. Features and geometry/temporal classes are implicitly disjoint, following from the appearance of spatial/temporal classes as property ranges. The GFM and these other base packages provide what is effectively an upper-ontology for geographic application schemas. This role for the GFM is explicit in ISO 19150-2, where the rules of developing application schemas in OWL are all framed in terms of elements characterized using the GFM. Note that, in parallel with the preparation of ISO 19150-2, ISO 19109 is under revision (current status ‘Draft International Standard’ [26]), with support for OWL implementation as one of the motivations.

The GFM is not a comprehensive upper ontology in the manner of DOLCE. But it is nevertheless the standard framework within the geographic information community represented by the membership of OGC and ISO/TC 211. Given the existence of an upper-ontology indigenous to this community, and the fact that the models that define this ‘upper ontology’ appear as explicit dependencies in O&M, our strategy in developing OWL representations of O&M is to ground them in this framework, and avoid the premature introduction of a different cognitive bias from external frameworks.

Alignment with independent upper ontologies may then be done later as a separate exercise.

4 Ontology implementation details

4.1 Base ontology

A set of OWL classes corresponding to UML class stereotypes in ISO 19103/19109 are defined:

- `FeatureType` – the set of real-world features
- `DataType` – classes that do not support use by-reference. Individuals should be implemented as blank-nodes.
- `Union` – for classes that are explicit unions of otherwise disjoint classes
- `CodeList` – for extensible sets of terms.

For example (Turtle notation [27]):

```
h2o:FeatureType
  a owl:Class ;
  rdfs:label "Feature Type stereotype"^^xsd:string ;
  h2o:isStereotype "true"^^xsd:boolean .
```

```
h2o:CodeList
  a owl:Class ;
  rdfs:label "Code list stereotype"^^xsd:string ;
  rdfs:subClassOf skos:Concept ;
  h2o:isStereotype "true"^^xsd:boolean .
```

The rule is that an OWL class corresponding to a stereotyped UML class is implemented as a sub-class of the corresponding stereotype class. Note that the ISO 19103 stereotype `Enumeration` is handled differently, since OWL does not allow derivation of datatypes through sub-classing.

Datatype definitions from ISO 19103 are defined using OWL2 mechanisms. For example

```
basic:CharacterString
  a rdfs:Datatype ;
  rdfs:label "Character string"^^xsd:string ;
  owl:equivalentClass xsd:string .
```

```
basic:Number
  a rdfs:Datatype ;
  rdfs:label "Number"^^xsd:string ;
  owl:equivalentClass
    [ a rdfs:Datatype ;
      owl:unionOf (xsd:double xsd:float xsd:decimal) ] .
```

```

basic:Measure
  a owl:Class ;
  rdfs:label "Measure"@en , "Mesure"@fr ;
  rdfs:subClassOf
    [ a owl:Restriction ;
      owl:cardinality "1"^^xsd:nonNegativeInteger ;
      owl:onProperty basic:value ] ;
  rdfs:subClassOf
    [ a owl:Restriction ;
      owl:cardinality "1"^^xsd:nonNegativeInteger ;
      owl:onProperty basic:uom ] .

```

4.2 Dependencies

O&M has formal dependencies on classes from ISO 19107, 19108, 19109, 19115 and 19123, as well as transitive dependencies on a number of other standards. The GFM from ISO 19109 is implemented primarily in two classes: `gf:AnyFeature` and `gf:PropertyType`. `AnyFeature` is defined as follows:

```

gf:AnyFeature
  a owl:Class ;
  rdfs:label "Geographic feature"^^xsd:string ;
  rdfs:subClassOf h2o:FeatureType ;
  h2o:isAbstract "true"^^xsd:boolean ;
  owl:disjointWith gf:PropertyType , tm:Object , gm:Object ;
  owl:equivalentClass h2o:FeatureType ;
  skos:notation "GFI_Feature"^^h2o:ISOClassName .

```

The sub-class, equivalent class, and disjoint properties here provide the essential characteristics of ‘feature’ in the OGC/ISO context, and the GFM ‘upper ontology’.

The class hierarchy from the spatial schema defined in ISO 19107 follows the UML. For example, the class of spatial points is defined:

```

gm:Point
  a owl:Class ;
  rdfs:label "Spatial point"^^xsd:string ;
  rdfs:subClassOf gm:Primitive ;
  rdfs:subClassOf
    [ a owl:Restriction ;
      owl:cardinality "1"^^xsd:nonNegativeInteger ;
      owl:onProperty gm:position ] ;
  skos:notation "GM_Point"^^h2o:ISOClassName .

```

In ISO 19107 the geometry and topology classes are specified primarily in terms of the operations that software implementations must support. Hence, at this time there has been no attempt to implement any more than the subsumption hierarchy in OWL.

We have developed partial OWL implementations of the other packages in a similar vein, sufficient to support the dependencies of O&M. At this time full implementations of the class models are only provided for O&M [4] and metadata [25].

4.3 Rules for an ontology matching strict UML pattern

The ontologies for observations and sampling features that strictly match the UML assumptions are denoted:

```
http://def.seegrid.csiro.au/isotc211/u/iso19156/2011/observation
http://def.seegrid.csiro.au/isotc211/u/iso19156/2011/sampling
```

The RDF namespaces for the elements in the ontologies append # to these names:

```
@prefix om: <http://def.seegrid.csiro.au/isotc211/u/iso19156/2011/observation#> .
@prefix sam: <http://def.seegrid.csiro.au/isotc211/u/iso19156/2011/sampling#> .
```

These URIs match the pattern defined in ISO 19150-2, except that here the path `http://def.seegrid.csiro.au/isotc211/u/` (`/u/` for UML) substitutes for the domain `http://def.isotc211.org/` so that we can actually publish the test ontologies.

The following specific rules are applied to generate the strict OWL model:

- class name includes the bi-alpha prefix from the UML model where it exists
- e.g. `om:OM_Observationproperty` name includes the class name in order to disambiguate it from properties with the same name on other classes
e.g. `om:OM_Observation.result`
- property domain is the class on which it is found in the UML model
- property range is the target class or type from the UML model
- property cardinality is specified in OWL restrictions providing both ends of the interval, except if the upper limit is 'unbounded', for which there is no explicit representation in OWL.

Developing an OWL representation from the UML following this rule is predictable. For example, the following is the strict OWL representation of the UML model for spatial sampling features shown in Fig 1.:

```
sam:SF_SpatialSamplingFeature
  a owl:Class ;
  rdfs:label "Spatial sampling feature"@en ;
  rdfs:subClassOf h2o:FeatureType , sam:SF_SamplingFeature ;
  rdfs:subClassOf
  [ a owl:Restriction ;
    owl:cardinality "1"^^xsd:nonNegativeInteger ;
    owl:onProperty sam:SF_SpatialSamplingFeature.shape ] ;
  rdfs:subClassOf
  [ a owl:Restriction ;
```

```

owl:minCardinality "0"^^xsd:nonNegativeInteger ;
owl:onProperty sam:SF_SpatialSamplingFeature.positionalAccuracy ] ;
rdfs:subClassOf
[ a owl:Restriction ;
owl:maxCardinality "2"^^xsd:nonNegativeInteger ;
owl:onProperty sam:SF_SpatialSamplingFeature.positionalAccuracy ] ;
rdfs:subClassOf
[ a owl:Restriction ;
owl:minCardinality "0"^^xsd:nonNegativeInteger ;
owl:onProperty sam:SF_SpatialSamplingFeature.hostedProcedure ] ;
skos:notation "SF_SpatialSamplingFeature"^^h2o:ISOCClassName .

```

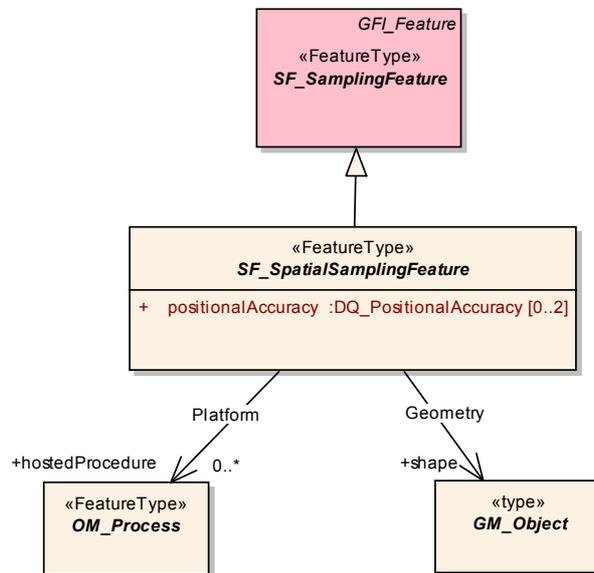


Fig. 1. UML class model for spatial sampling features from O&M [4]

However, the ontology resulting from these strict rules contains features that would be considered unusual to users familiar with more conventionally designed ontologies. Most immediately striking are the compound URIs for properties, which contain multiple punctuation elements. For example, the observation result property is defined

```

om:OM_Observation.result
a owl:ObjectProperty ;
rdfs:domain om:OM_Observation ;
rdfs:label "Result"@en .

```

The appearance of a very specific domain reduces the potential re-use of properties.

4.4 Rules for an open world ontology

The ontologies for observations and sampling features that follow the UML model with relaxed assumptions are denoted:

```
http://def.seegrid.csiro.au/isotc211/iso19156/2011/observation
http://def.seegrid.csiro.au/isotc211/iso19156/2011/sampling
```

The following specific rules are applied to generate the OWL model:

- a) class name omits the bi-alpha prefix from the UML model
e.g. `om:Observation`
- b) property name is scoped to the ontology
e.g. `om:result`
- c) property domain is one of `gf:AnyFeature` or `owl:Thing`, depending on whether or not it is a feature property range is the target class or type from the UML model (no change)
- d) property cardinality is specified in OWL restrictions, but relies on RDF defaults whenever possible.

Under this rule properties are more general and re-usable:

```
om:result
  a owl:ObjectProperty ;
  rdfs:domain gf:AnyFeature ;
  rdfs:label "Result"@en .
```

However, the relaxed rule requires interpretation where properties with the same local name are associated with more than one class in a package, but with differing target classes or types. For example, the attribute name appears multiple times in the ISO 19115 Metadata model (which is an important dependency of O&M), with both the type `CharacterString` and more specific types. This is resolved by defining one generic property and two specific properties with qualified names as follows:

```
md:name
  a owl:DatatypeProperty ;
  rdfs:domain owl:Thing ;
  rdfs:label "name"^^xsd:string ;
  rdfs:range basic:CharacterString .
```

```
md:ApplicationSchema.name
  a owl:ObjectProperty ;
  rdfs:domain md:ApplicationSchemaInformation ;
  rdfs:label "Application schema.name"^^xsd:string ;
  rdfs:range ci:Citation .
```

```
md:Medium.name
  a owl:ObjectProperty ;
  rdfs:domain md:Medium ;
```

```
    rdfs:label "Medium.name"^^xsd:string ;
    rdfs:range md:MediumNameCode .
```

However, there are very few property name clashes in the ISO model, so in practice this is a minor annoyance (which nevertheless prevents an automated conversion). Much more significant in terms of the ontology is the choice of strict or lax property domains, which effectively either prevents or enables reuse of properties outside the context of the original class.

4.5 General Feature Model

Several considerations in the revision of ISO 19109 (publication scheduled for 2014) have emerged from the development of ISO 19150-2. Key modifications to the meta-model are (i) relaxation of the requirement that property types are bound to feature types, (ii) addition of the requirement that property names are used consistently within an application schema, not just a class. These changes mean that properties are scoped to the UML package or OWL ontology (RDF namespace), which is more consistent with the expectations of the semantic web community.

5 Comparison with SSN ontology

5.1 Expressivity

The expressivity of the O&M and SSN ontologies for describing simple observations is compared in the listings below, which are based on an example from the OGC repository (<http://schemas.opengis.net/om/2.0/examples/measurement2.xml>). The 'open-world' form of the O&M ontology is used in the examples, though in the instance view this only affects the class and property names and the structure is otherwise the same.

O&M ontology:

```
p1:obsTest1
  rdf:type om:Measurement ;
  rdfs:comment "Observation test instance: fruit mass"^^xsd:string ;
  rdfs:label "Observation test 1"^^xsd:string ;
  om:featureOfInterest
    <http://wfs.example.org?request=getFeature&featureid=fruit37f> ;
  om:observedProperty <http://sweet.jpl.nasa.gov/2.0/phys.owl#Mass> ;
  om:phenomenonTime p1:ot1t ;
  om:procedure p1:Sscales1 ;
  om:result
  [ rdf:type basic:Measure ;
    basic:uom <http://www.opengis.net/def/uom/UCUM/0/kg> ;
    basic:value "0.28"^^basic:Number
```

```

] ;
om:resultTime p1:ot1t ;
om:parameter
[ rdf:type om:NamedValue ;
  om:name <http://sweet.jpl.nasa.gov/2.0/physThermo.owl#Temperature> ;
  om:value
  [ rdf:type basic:Measure ;
    basic:uom <http://www.opengis.net/def/uom/UCUM/0/Cel> ;
    basic:value "22.3"^^basic:Number
  ]
] .

```

```

p1:Sscales1
  rdf:type om:Process ;
  rdfs:label "Salter scales"^^xsd:string .

```

```

p1:ot1t
  rdf:type tm:Instant ;
  tm:dateTimePosition "2005-01-11T16:22:25.00"^^xsd:dateTime .

```

SSN ontology:

```

p1:obsTest1
  rdf:type ssn:Observation ;
  rdfs:label "Observation test 1"^^xsd:string ;
  rdfs:comment "Observation test instance: fruit mass"^^xsd:string ;
  ssn:featureOfInterest
    <http://wfs.example.org?request=getFeature&featureid=fruit37f> ;
  ssn:observedProperty <http://qudt.org/vocab/quantity#Mass> ;
  ssn:observationSamplingTime p1:ot1t ;
  ssn:observedBy p1:Sscales1 ;
  ssn:observationResult
  [ rdf:type ssn:SensorOutput ;
    ssn:hasValue
    [ rdf:type DUL:Amount , ssn:ObservationValue ;
      DUL:hasDataValue "0.28"^^xsd:float ;
      DUL:isClassifiedBy <http://qudt.org/vocab/unit#Kilogram> ] ;
    ssn:isProducedBy p1:Sscales1 ] ;
  ssn:observationResultTime p1:ot1t ;
  DUL:hasSetting p1:tempObsTest1 .

```

```

p1:tempObsTest1
  a ssn:Observation ;
  rdfs:comment "Observation of temperature context for measurement of fruit
mass"^^xsd:string ;

```

```

rdfs:label "Temperature Observation test 1"^^xsd:string ;
ssn:featureOfInterest
  p1:fruit37f ;
ssn:observationResult
  [ a ssn:SensorOutput ;
    ssn:hasValue
      [ a DUL:Amount , ssn:ObservationValue ;
        DUL:hasDataValue "22.3"^^xsd:float ;
        DUL:isClassifiedBy unit:DegreeCelsius
      ] ;
    ssn:isProducedBy p1:Thermometer1
  ] ;
ssn:observationResultTime
  p1:ot1t ;
ssn:observationSamplingTime
  p1:ot1t ;
ssn:observedBy p1:Thermometer1 ;
ssn:observedProperty
  <http://qudt.org/vocab/quantity#ThermodynamicTemperature> ;
DUL:isSettingFor p1:obsTest1 .

p1:Sscales1
  rdf:type ssn:SensingDevice ;
  rdfs:label "Salter scales"^^xsd:string .

p1:Thermometer1
  a ssn:SensingDevice ;
  rdfs:label "Alcohol in glass thermometer"^^xsd:string .

p1:ot1t
  rdf:type DUL:Amount ;
  DUL:hasDataValue "2005-01-11T16:22:25.00"^^xsd:dateTime .

```

Both capture the information in a similar way. However, the SSN ontology is more flexible and less prescriptive, with multiple alternatives for capturing some information. For example, here we use `DUL:Amount` for the result value, as this provides a slot for recording a unit of measure in the instance. This may be contrasted with other SSN applications that use a specific type with a locally defined property already bound to a unit of measure value, thus moving the scale factor up a meta-level [28]. Note also that in the SSN example we captured the event-specific parameter (in this case the environmental temperature at the time of the sensing event) as a second observation related to the primary observation using `DUL:isSettingFor`. This corresponds to using the O&M 2.0 `ObservationContext` association, rather than the lightweight parameter property.

5.2 Sampling Features

O&M [2, 3, 4] includes an explicit model for cross-domain feature types used for sampling. Individuals of these classes have a specific relationship to the domain feature(s) of ultimate interest. There are types for spatial sampling and for specimens used for *ex situ* observations. These classes are not implemented in the SSN ontology, but are provided in the O&M ontologies described here. The OWL implementation of `SF_SamplingFeature` is listed in section 4.3 above, and an example of an individual `Specimen` is given below (here using the ‘open-world’ form):

```
<http://handle.net/10273/IGSN.SIOabc123>
  a    sam:Specimen ;
  rdfs:comment "A specimen encoded using the RDF representation of the O&M Sampling
Feature model"^^xsd:string ;
  rdfs:label "SIO specimen abc123"^^xsd:string ;
  sam:currentLocation <http://example.org/various/Warehouse3/shelf9/box67> ;
  sam:materialClass p1:rock ;
  sam:preparationStep
    [ a    sam:PreparationStep ;
      sam:processOperator p1:JohnDoe ;
      sam:processingDetails <http://example.org/various/sf-process/jk1987> ;
      sam:time <http://handle.net/10273/IGSN.SIOabc123/tim2> ] ;
  sam:sampledFeature p1:midAtlanticRidge ;
  sam:samplingFeatureComplex
    [ a    sam:SamplingFeatureComplex ;
      sam:relatedSamplingFeature <igsn:SIOxyz456> ;
      sam:role p1:parent ] ;
  sam:samplingLocation
    p1:loc123 ;
  sam:samplingMethod <http://ldeo.columbia.edu/sampling/ghostbuster> ;
  sam:samplingTime
    [ a    tm:Instant ;
      tm:dateTimePosition "2013-06-12T09:25:00.00+11:00"^^xsd:dateTime ] ;
  sam:size
    [ a    basic:Weight ;
      basic:uom <http://www.opengis.net/def/uom/UCUM/0/kg> ;
      basic:value "0.46"^^basic:Number ] ;
  sam:specimenType p1:splitCore .
```

5.3 SensorML

Conversely, we have not developed an OWL implementation of SensorML. This is because (i) the only published version of SensorML is 1.0 [7], which is linked to version 1.0 of O&M 1.0 [1], while the O&M ontology described here is based on version 2.0 [3, 4]; (ii) the UML model provided in SensorML 1.0 represents XML Schema

implementation details rather than a conceptual model, and furthermore is informative not normative. SensorML 2.0 is approaching completion, at which time OWL versions may be developed following the same process described here.

5.4 Observed property

The `observedProperty` property is unusual as it relates to properties of the *type* or *class* of the feature-of-interest. Thus its value should strictly be a classifier or type, rather than an instance. While the semantics appear correct, this property crosses meta-levels and is thus in conflict with both UML and OWL meta-models, and requires workarounds in both representations.

5.5 Temporal properties

The SSN ontology is based on O&M 1.0 [1]. The treatment of time properties associated with observations was refined in O&M 2.0 [3, 4], and is reflected in the O&M ontologies presented here. In particular, the property `samplingTime` from O&M 1.0 does not appear as an observation property in O&M 2.0, because the time of sampling was judged to be better associated with sampling features. A new property `phenomenonTime` is used to indicate the time that the result applies to the feature of interest, which may be different from a sampling time (e.g. in the cases of forecasts where the `phenomenonTime` is in the future, or estimates of values of historical or geological properties where the `phenomenonTime` is the past even if physical sampling was contemporary). This refinement clarifies the relationship of the temporal properties to the respective classes: `resultTime` (which remains the same) is intrinsic to the act of observation, while `phenomenonTime` describes a relationship between the observation result and the feature of interest (“it had this value at that time”). An additional property `validTime` was also introduced to indicate the time period during which the data provider recommends the result may be safely used.

5.6 Ontology alignment

Probably the most significant consequence of the alignment of the SSN ontology to DUL is that `Observation` is classified as a subclass of `DUL:Situation`, which is a subclass of `DUL:SocialObject`, and thus disjoint to `DUL:Event`. The rationale for this is sound: observations can reasonably be interpreted as essentially social artefacts. However, under the clarification of the temporal properties in O&M 2.0, discussed above, observations are essentially events. The inconsistency may therefore be because SSN was based on O&M 1.0. Nevertheless, in the SSN report [11] the authors clearly felt some explanation was required, and suggested that an observation resource may strictly be seen as a record of a sensing event, though under that interpretation `Observation` could have been made a subclass of `DUL:InformationObject`, rather than either of these sibling classes. The argument could also be compensating for limitations in DOLCE: surely some social objects are also events?

6 Future work

The next phase of the project will be to develop mappings to the SSN ontology, and other observation ontologies, and analysis the semantic implications. Since the principal resources in both O&M and SSN ontologies are OWL classes, the RDFS `equivalentClass` and OWL `subclassOf` relations should be used for mapping where possible. Other vocabularies, such as SKOS [29] mapping relations, and PROV-O [30] relations provide richer sets of relations, but scoped to individuals rather than classes, so care must be taken if DL-conformance is required, else OWL2 punning must be used.

Table 7.1 in the SSN report [11] provides mappings from SSN to O&M [3,4], SensorML [7] and VIM [31]. These are described using SKOS `closeMatch`, `exactMatch` and `narrowerMatch`, and recorded in text within `dc:source` properties, using informal identifiers for concepts from O&M, SensorML and VIM. The ontologies presented here provide URIs for all the concepts in O&M, so the mappings can now be done formally. Mappings may be persisted in separate graphs or linksets [32] that will import the O&M and SSN ontologies.

7 Summary & conclusions

We have developed OWL representations of the OGC observations and measurements information model. The ontologies are literal conversions of the original UML models, following UML \rightarrow OWL conversion rules proposed for ISO 19150-2, and are aligned only to the (meta-)models from the OGC/ISO suite on which O&M depends. The O&M ontology is consistent with OWL-DL. It provides

1. an RDF encoding for sensor data. This could be used as an alternative transfer model for SWE services such as SOS, immediately compatible with semantic web technologies with their capacity for abstraction, categorization and reasoning
2. an OWL representation reflecting the original design of O&M models. This enables analysis and description of the relationships between OGC SWE and SSN in a framework where both source and target of assertions are OWL classes and properties.

The O&M ontologies are as expressive as the SSN ontology for describing observations. Two flavours of the O&M ontology have been prepared: one which replicates the frame-based assumptions of UML using OWL2 mechanics; the other being a more conventional ‘open-world’ ontology. The latter is probably preferable as it does not inherit constraints from the UML meta-model that are incidental to the key semantics, but it requires judgement and interpretation in a small number of places to resolve clashes in property naming.

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