

A pattern-based ontology for the Internet of Things

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Abstract. The Internet of Things (IoT) is about inter-networking real word objects in order to foster data exchange and communication among things. In this work we present the IoT Application Profile (IoT-AP) ontology with a particular focus on the pattern-based design methodology used for modelling the ontology.

Keywords: internet of things, ontology design patterns, ontology re-use

1 Introduction

In recent years a lot of research has been carried out for realising a novel paradigm known as the Internet of Things (IoT). Basically, the IoT is about inter-networking real word objects (i.e. things), such as vehicles, roads, buildings, etc. The inter-networking is realised by providing those things with sensors, actuators, and network connectivity for enabling data production and exchange. Nevertheless, the enhancement of real word objects with intelligent behaviours is still challenging. In this paper we present an ontology, named the IoT Application Profile (IoT-AP) ontology, for representing and modelling the knowledge within the domain of the Internet of Things. The focus of the paper is mainly on the Ontology Design Patterns re-used for modelling the ontologies and on the design methodology. The ontology is part of a wider ontology network, which has been designed in the context of a project founded by the Italian Government aimed at providing a big data framework for dealing with the Open Data coming from the Italian Public Administration (PA). The rest of the paper is organised as follows. Section 2 presents the related work, Section 3 presents the IoT-AP ontology, Section 4 presents a usage scenario. Finally, Section 5 presents the conclusions and future work.

2 Related Work

The main considerable effort to offer a comprehensive ontology for the IoT is the Semantic Sensor Network ontology⁴ [2] (SSN), which is currently a W3C

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⁴ <https://www.w3.org/TR/vocab-ssn/>

candidate recommendation. SSN is built on top of the the SOSA ontology⁵ and describes sensors and their observations, the involved procedures, the studied features of interest, the samples used to do so, and the observed properties, as well as actuators. More recently, the IoT-Lite ontology⁶, a W3C member submission, is aimed at instantiating and extending the SSN ontology by introducing three distinct concepts belonging to the IoT domain, i.e. objects, systems or resources and services. Our solutions is inspired by the IoT and SSN ontologies. However, we cannot directly re-use those ontologies as (i) both are still unstable being not W3C recommendations yet, (ii) we have a soft requirement that encourages us to design self-contained ontologies in order to avoid dependencies with external ontologies that might evolve separately, thus, introducing inconsistencies.

3 Ontology overview

In next sub-sections we present the design methodology used and the resulting IoT-AP ontology.

3.1 Design Methodology

IoT-AP is designed by following best design practices and pattern-based ontology engineering aimed at extensively re-using Ontology Design Patterns (ODPs) [3] for modelling ontologies. The design methodology that we followed is based on an extension [6] of the eXtreme Design [1], an agile design methodology developed in the context of the NeON project⁷. Such an extension mainly focuses on providing ontology engineer with clear strategies for ontology re-use. According to the guidelines provided by [6], we adopted the *indirect re-use*. This means that ODPs are used as templates. At the same time, the ontology guarantees interoperability by keeping the appropriate alignments with the external ODPs, and provides extensions that satisfy more specific requirements.

3.2 IoT-AP ontology

Table 1 reports the competency questions used at design time for modelling the IoT-AP ontology. Figure 1 shows the core classes and properties of the IoT-AP ontology by using the Graffoo notation.

The IoT-AP ontology is designed around the class **Observation**, which is declared as subclass of `dul:Event` and is modelled by re-using the time indexed situation⁸ Ontology Design Pattern (ODP) and the Observation⁹ ODP. In fact, an observation represents the situation carried out by a sensor of estimating or

⁵ https://www.w3.org/2015/spatial/wiki/SOSA_Ontology

⁶ <https://www.w3.org/Submission/2015/SUBM-iot-lite-20151126/>

⁷ <http://www.neon-project.org/nw/>.

⁸ <http://ontologydesignpatterns.org/wiki/Submissions:TimeIndexedSituation>

⁹ <http://ontologydesignpatterns.org/wiki/Submissions:Observation>

Table 1. Competency questions used for modelling the ontology.

ID	Competency question
CQ1	What is the sensor that makes an observation?
CQ2	What is the object (i.e. the feature of interest) associated with an observation?
CQ3	When is a certain observation made?
CQ4	What is the value of an observation?
CQ5	What is the observation parameter of an observation?
CQ6	What is the quality of an observation?

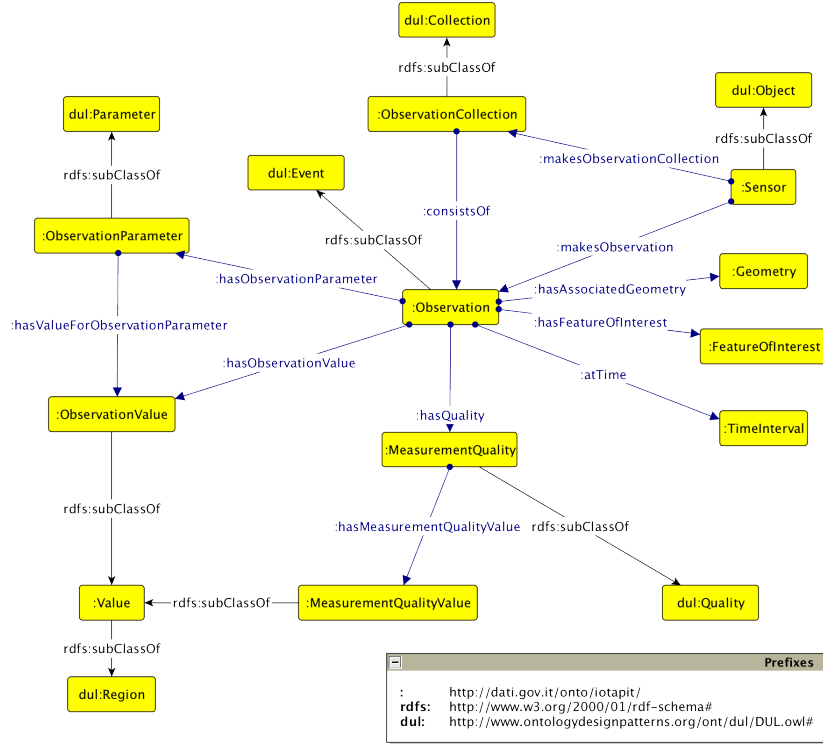


Fig. 1. Core classes of the IoT-Ont.

calculating a value of an attribute of a feature of interest at a specific time. Additionally, an observation can be associated with an instance of the class **Geometry**, which identifies a location as a point, line, polygon, etc., and is expressed by using coordinates in some coordinate reference system. This class **Sensor** is declared as subclass of **dul:Object** and represents a sensor. A sensor is a device whose purpose is to detect and respond to events or changes in its environment. The detected information can be used and disseminated for successive elaborations. Individuals of the class **Sensor** are associated with individuals of the class **Observation** by means of the object property **makesObservation**. An observation can be associated with an **ObservationParameter** by means of the object property **hasObservationParameter**. The class **ObservationParameter** repre-

sents a property or a characteristic of a feature of interest under observation. For instance, if we say that the temperature of the kitchen is 28 degrees celsius, the observed parameter is the temperature. Additionally, an `Observation` can be associated with a `MeasurementQuality`. The class `MeasurementQuality` is declared as subclass of `dul:Quality` and expresses quality parameters or measurement capabilities of an observation. Examples include latency, accuracy, repeatability, etc. We re-used the Region ODP¹⁰ to represent and reason on values of attributes of `MeasurementQuality` and `Observation`. Hence, the object property `hasObservationValue` links individuals of the class `Observation` to individuals of the class `ObservationValue` and the object property `hasMeasurementQualityValue` links individuals of the class `MeasurementQualityValue`. The classes `ObservationValue` and `MeasurementQualityValue` represent values for observations and measurement quality, respectively. Additionally, both classes are declared as subclasses of `Value`, which, in turn, is subclass of `dul:Region`. Collections of observations made by a sensor can be represented by instantiating the class `ObservationCollection`. The conceptualisation around `ObservationCollection` is obtained by re-using the `Collection`¹¹ ODP. Hence, `ObservationCollection` is subclass of `dul:Collection` and is associated with the class `Observation` by means of the object property `consistOf`. The IoT-AP ontology is aligned with DOLCE Ultra-Light and the Semantic Sensor Network (SSN) ontology. The alignments with these two ontologies are kept in a separate OWL file. Both the core IoT-AP ontology and the OWL file with the alignments are available online¹². The HTML documentation is available via LOD¹³.

4 Usage scenario

The following RDF triples, serialised as TURTLE, provide a usage example of the IoT-AP ontology. These triples come from real traffic data provided us by an organisation part of the Italian Public Administration.

```

:sensor a iotap:Sensor;
  iotap:makesObservation :observation .

:observation a iotap:Observation;
  iotap:hasFeatureOfInterest :a1_Calenzano-SestoFiorentino;
  iotap:atTime :observation_time;
  iotap:hasObservationParameter :average_speed;
  iotap:hasObservationValue :average_speed_value .

:a1_Calenzano-SestoFiorentino a iotap:FeatureOfInterest;
  rdfs:label "A1 road segment between Calenzano and Sesto Fiorentino".

:observation_time a iotap:TimeInterval;
  iotap:startTime "2017-07-27T23:12:00+02:00"^^xsd:dateTime;
  iotap:endTime "2017-07-28T01:54:00+02:00"^^xsd:dateTime .

```

¹⁰ <http://ontologydesignpatterns.org/wiki/Submissions:Region>

¹¹ <http://ontologydesignpatterns.org/wiki/Submissions:Collection>

¹² IoT-AP: <http://stlab.istc.cnr.it/IoT-AP/IoT-AP.rdf> - alignments: <http://stlab.istc.cnr.it/IoT-AP/IoT-AP-aligns.rdf>

¹³ <https://goo.gl/MFggc4>

```

:average_speed a iotap:ObservationParameter;
  rdfs:label "Average speed" .

:average_speed_value a iotap:ObservationValue;
  value "65";
  iotap:hasMeasurementUnit :kilometres_per_hour .

:kilometres_per_hour a iotap:MeasurementUnit;
  rdfs:label "Kilometres per hour" .

```

The individual `:sensor` represents the sensor who makes the observation identified by the individual `:observation`. This observation is about the average speed observed by the sensor during the time interval identified by `:observation.time` on the road segment of the A1 motorway between the cities of Calenzano and Sesto Fiorentino (i.e. the feature of interest identified by the individual `:a1_Calenzano-SestoFiorentino`). The value associated with the observation (i.e. the individual `:average_speed.value`) allows to say that the observed average speed is 65 Km/h.

5 Conclusion and future work

This paper proposes an ontology for the Internet of Things, namely the IoT-AP ontology. The focus of the paper is on the pattern-based design methodology used for modelling such an ontology. The design of the ontology is part of a project with the Italian Government aimed at implementing a big data framework for dealing with a variety of data sources including Open Data. As future work we are planning to assess the quality of the ontology by using real data coming from the big data framework as Linked Open Data and to analyse the ontology in the context of the wider ontology network we are designing.

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