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An ontology-based monitoring system for multi-source environmental observations

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Abstract

Multi-source observed data are generally characterized by their syntactic, structural and semantic heterogeneities. A key challenge is the semantic interoperability of these data. In this context, we propose an ontology-based system that supports environmental monitoring. Our contributions could be resumed around 1) the construction of an ontology which allows to represent the knowledge and reuse it in a real-world way, 2) the guarantee of the semantic interoperability of ontological modules since the proposed ontology is based on the upper level ontology Basic Formal Ontology (BFO) 3) the modularity of the proposed ontology in order to facilitate its reuse and evolution. The proposed ontology has been implemented and evaluated using quality metrics. We also present a real use case study that demonstrates how the proposed ontology allows implicit knowledge generation.

Keywords: Ontology; modularity; semantic heterogeneity; interoperability; environmental monitoring

1. Introduction

Environmental monitoring is a complex activity involving heterogenous observation systems such as the Copernicus programme [1] and the Sahara and Sahel Observatory (OSS) [2]. These systems generate information about observations, environmental processes, meteorological factors and events. However, they are growing ever more independent on each other and without any collaboration and interoperability between them. Consequently, generated environmental data are heterogenous. There are many different classifications of heterogeneity such as syntactic, structural and semantic heterogeneity. The latter remains one of the biggest challenges in environmental observation systems. Thus, we focus in this paper on handling the semantic heterogeneity of environmental data. Integrating

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multi-source environmental information plays an important role in environmental monitoring. It helps to understand the environmental dynamics and natural phenomena and aids in predicting disasters and environmental hazards.

In this context, ontologies have been widely used for knowledge representation and environmental data modeling, as they provide a common vocabulary for modeling a specific domain by capturing knowledge in a structured and formal way [3].The use of ontologies to represent environmental data as well as for reasoning on them has gained considerable popularity ([4] , [5], [6]). However, these approaches have largely focused on representing specific aspects of the environmental monitoring domain, they did not consider a global approach encompassing all environmental monitoring contexts (such as spatio-temporal context, sensing context, etc.).

Thus, the work presented in this paper is about developing a modular ontology that extends existing ontologies to represent the environmental monitoring domain. Our contribution deals with 1) the construction of an ontology which allows to represent the knowledge and reuse it in a real-world way, 2) the guarantee of the semantic interoperability of ontological modules since the proposed ontology is based on the upper level ontology Basic Formal Ontology (BFO) [7] and 3) on the reuse of existing ontologies and finally 4) the modularity of the proposed ontology in order to facilitate its reuse and evolution. This article is organized as follows: Section 2 presents the related work on domain ontologies developed in the field of environmental monitoring. In Section 3, we detail our proposal, namely the construction of a modular ontology for environmental monitoring. Section 4 is devoted to the ontology evaluation through two evaluation methods (quality metrics and a use case study). Finally, we conclude and evoke the perspectives of this work.

2. Related work and motivation

Several researchers were interested in the construction of ontologies for the environmental monitoring domain. Our study is focused on three ontologies: the Sensing Geographic Occurrence Ontology (SEGO) [4], the Event ABStraction ontology (EABS) [5] and the Meteorological Disaster Ontology (MDO) [6]. SEGO is a domain ontology developed to represent relations between geographic events and sensor observations. However, it requires the development of application ontologies to execute reasoning and inference processes. EABS was developed to model events inferred from observations. It is aligned to the upper level ontology Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) [8] and reuses the Semantic Sensor Network Ontology (SSNO) [9] to define concepts about sensors and observations. MDO was developed to describe the components and relationships between different parts comprising meteorological disaster system. It, therefore, represents only entities about meteorological domain.

Although they are sharing the main objective of building a domain ontology aiming at representing the semantics of the environmental monitoring domain, they differ in the way of resolving the problematic of modeling and the objectives of the developed ontology.We compare the three ontologies based on a set of criteria adopted from [10]. In this comparison, presented in table 1, we introduce four fundamental research challenges that must be consulted when developing the proposed ontology. Despite these numerous works, several limitations have been noted. None of them has applied an ontology to cover all environmental monitoring contexts. They seldom considered spatio-temporal and infrastructure factors. However, an environmental montoring system is a kind of system composed of environmental processes intrinsically tied to space, time and infrastructure factors. Related work only built ontologies

Table 1. Criteria and ontologies comparison.

Criterion	Definition	SEGO	EABS	MDO
Completeness	Whether the ontology covers all essential concepts in the environmental monitoring domain	Is kept enough generic	Is kept enough generic	Only meteorological domain
Modularity	Whether the ontology presents a modularization representation	NO	NO	NO
Interoperability	Whether the ontology reuses concepts or relationships from other ontologies	DOLCE	DOLCE and SSNO	NO
Reasonning	Whether the ontology can make implicit knowledge explicit through reasoning	After developing an application ontology	After developing an application ontology	YES

to solve specific problems, primarily the monitoring of a specific disaster such as meteorological disasters in MDO or to describe sensing entities like in EABS. To the best of our knowledge, there is no existing ontology based on a modular representation that enables the integration of heterogenous environmental data, spatio-temporal data and other information related to the environmental monitoring domain (such as infrastructure, and sensors). The modularity principle has become an essential field in ontology-based systems [11]. Thus, our motivation is to address these problems by building a modular domain ontology that (1) covers environmental monitoring contexts (2) reuses the upper level ontology BFO and other existing ontologies to meet the expressivity of spatio-temporal, infrastructure and sensing characteristics of an environmental monitoring system and (3) aims to ensure semantic interoperability between heterogenous data sources.

3. The proposed environmental monitoring ontology

3.1. BFO as an upper level ontology

Upper level ontologies are generic ontologies that provide abstract concepts and/or classes, which are common to all domains, used to define other ontologies. The main application of upper level ontologies is to provide semantic interoperability of ontologies across multiple domains. Among these ontologies, we quote; Suggested Upper Merged Ontology (SUMO) [12], DOLCE and BFO. SUMO is used for applications in research, linguistics and reasoning and allows to encompass scientific knowledge based on an objective reality. DOLCE is a conceptual ontology used primarily in e-learning applications and for web-based systems and services. It can contain in its field of coverage putative objects of mythology and fiction. BFO is a realistic ontology that tends to model the general characteristics of reality in the form of universals. It is developed to be used in support of domain ontologies developed for scientific application generally biomedical, biology and military. BFO organizes entities in two modules ”Continuants” and ”Occurrents”. Continuants represent entities that continue to exist over time such as forests, water, etc. Occurrents represent entities that happen and develop in time such as rain and earthquake. Accordingly, we choose BFO as a start point for our ontology building for two reasons. First, our domain of interest, the environment field, is a realistic domain. Thus, we looked up for a realist upper level ontology that represents environmental entities as they are and not representing environmental concepts and representations existing in the experts' minds. Second, the major part of existing ontologies that specialize environmental domain (such as the ENVironment Ontology (ENVO) [13]) extend BFO, which ensures the development by and for reuse and guarantees semantic interoperability of these ontologies.

3.2. Reused ontologies

To build our ontology, we reused some existing ontologies that are relevant for describing environmental monitoring domain such as ENVO, SSNO, the Common Core Ontologies (CCO) [14] and Relations Ontology (RO) [15] . We chose these ontologies for two reasons: reduce duplicate work and promote interoperability between ontologies.

ENVO is an environment ontology which delineates the environmental domain as a whole, and also includes other fields such as biomedicine, ecology, food, habitats and socioeconomic development. ENVO uses the upper level ontology BFO to define the top classes. It defines occurrences (environmental processes) and continuants (environmental materials, qualities and functions) relevant to environmental domain.

SSNO aims to provide a structured vocabulary of terms for the description of sensing information. It has a standard value and it is integrated in many projects and ontologies based on sensor networks. Although SSNO uses a subset of DOLCE as top classes, its terms are reused to be manually integrated under appropriate BFO classes.

CCO are a collection of ten mid-level ontologies interoperable that extend BFO. These modules deal with information content entities (eg. information artifact module), spatial information (eg. geospatial module), temporal information (eg. temporal module). In the design of our ontology, we reuse and further extend their structure to identify and organize the entities in an is-a class hierarchy.

RO presents a collection of OWL2 relations intended to be shared among various ontologies to define the semantics of the relationships between classes. It incorporates a set of upper-level relations such as ”part of” and ”has input”.

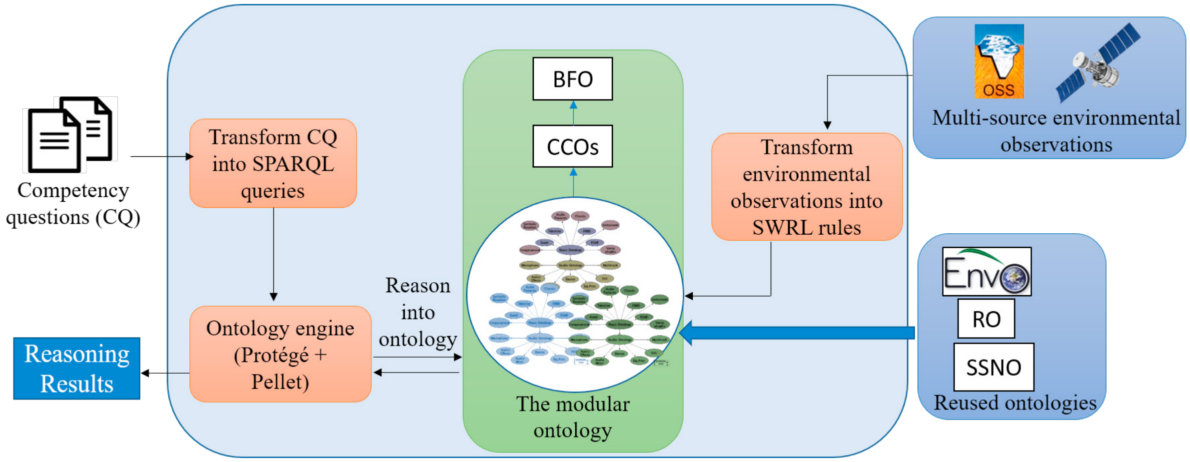

Fig. 1. The ontology-based monitoring system for multi-source environmental observations

3.3. Overview of our ontology

In this work, we adopt the Agile methodology for developing Ontology Modules (AOM) [16] since it is an agile and iterative methodology that allows the incremental development of our ontology and its extension with eventual new modules. The key steps in a single iteration include define competency questions (CQ) which represent the formulation of ontology requirements as questions, build semi-formal module, formalize module, evaluate module, merge module with other ontological modules.This methodology enables the development of the ontological modules in an incremental and iterative way. Our ontology-based system is illustrated in Fig.1. Based on the developed ontology, the ontology-based system process can be executed as follows: defining competency questions, transformating them into SPARQL queries, reasoning into ontology and presenting reasoning results. The proposed ontology is composed of a set of modules covering the subdomains of environmental monitoring. It consists of 8 main modules:

- the disaster module(M_{o_1}): which contains entities about natural and manmade disasters.
- the environmental process module (M_{o_2}): which contains climatological, hydrological, geographical and other processes. This module reuses classes from ENVO.
- the environmental material module (M_{o_3}): which contains entities such water, soil. This module also reuses classes from ENVO.
- the sensor and sensing module (M_{o_4}): which contains entities about sensing. Some of the SSNO terms are reused and redefined in our ontology, since SSNO is based on DOLCE upper level ontology.
- the observation and measurement module (M_{o_5}): which contains entities about measurements and observations.
- the geospatial module (M_{o_6}): which contains environmental features (eg. forest) and entities about locations.
- the temporal module (M_{o_7}): which contains temporal entities.
- and the infrastructure module (M_{o_8}) which contains entities such as bridge and dam.

Each module is referenced by a main class called ”pivotal class” (CP_M) and linked to other classes by a hierarchical ”subClassOf” or non-hierarchical relations.

Definition 1. *Formally, we can define our ontology as a 3-tuple*

$$O = < C_o, R_o, A_o > \quad (1)$$

where
(i) C_o *is a set of classes,*
(ii)$R_o \subset C_o \, x \, C_o$ *is a set of relations; with*
$R_o = R_{inter} \cup R_{intra}$

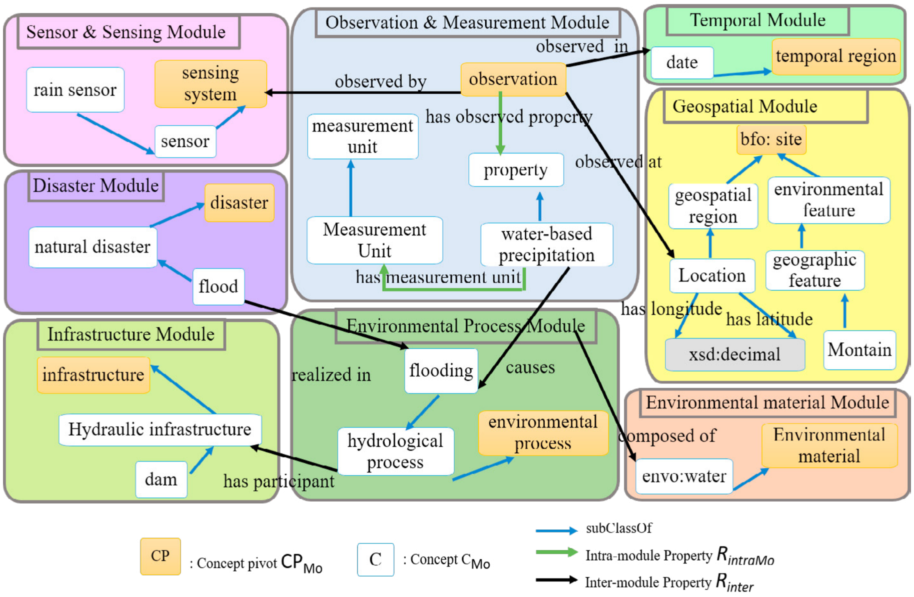

Fig. 2. View of the environmental monitoring ontology modules.

R_{inter} : the inter-modules relations.
R_{intra} : the intra-modules relations.
(iii) A_o is a set of axioms.

Definition 2. *Additionally, an ontological module, denoted as M_o can be represented as*

$$M_o = < CP_{M_o}, C_{M_o}, R_{M_o}, A_{M_o} > \quad \in O \tag{2}$$

Where,
(i) $CP_{M_o} \in C_{M_o}$: is the pivotal class of the module,
(ii) $C_{M_o} \subset C_o$: represents the set of the classes of the module,
(iii) $RM_o \subset C_{M_o}\ x\ C_{M_o}$: is the set of the relationships among ontological module classes,
$R_{M_o} = R_{intraSubClass} \cup R_{intraSemantic} \subset R_o$
$R_{intraSubClass}$: the hierarchical intra-relations.
$R_{intraSemantic}$: the non-hierarchical intra-relations.
(iv) $A_{M_o} \subset A_o$: is the set of axioms which refer to assertions and rules in a logical form.

Based on this definition, the ”environmental process” module, for example, can be described as follows:
CP_{M_o} = ”Environmental process”.
$C_{M_o} \supset$ {”oceanographical process”, ”geographical process”, ”climatological process”, ”hydrological process”, ”precipitation”, ”earth trembling”.}
$R_{intraSemantic} \supset$ { caused by(earth trembling, seism wave), preceded by (ashfall process, volcanic eruption)}
$R_{intraSubClass} \supset$ {SubClassOf (hydrological process, environmental process)},
$A_{M_o} \supset$ {”Rain which precipitation rate between 1.0mm/h and 4.0mm/h, are moderate rain.” }
The ontological modules are not independent. They have inter-module connectors R_{inter} that are defined by relationships between two classes belonging each to a different module. These relations translate a hierarchical structure $R_{interSubClass}$ (subClassOf relation) or a semantic relation $R_{interSemantic}$ (relations other than subClassOf, like ”realized in” and ”observed at”).
The diagram in fig. 2 provides an overview of the ontology modules and some intra and inter-relationships.

4. Implementation and evaluation

In order to show that our proposal can have a great interest and can contribute to improve the performance of the retrieval task, we integrated our proposal in a query reformulation process. To evaluate our system, we conducted a series of experiments that we will discuss in the following subsections.

4.1. Implementation

The proposed ontology was developed using the Protégé[1] 5.2.0 ontology editor, an open source platform that provides the user with a set of tools for modeling ontologies and ensuring more expressiveness with the OWL-DL. We also used the Semantic Web Rule Language (SWRL) [17] to express ontology rules.

4.2. Quality metrics evaluation

Various approaches have been proposed in the literature for ontology evaluation, targeting a number of different criteria and metrics ([18] and [19]). In this work, the following criteria are chosen to evaluate the proposed ontology:

- Coherence (Consistency) (C1): refers to the fact that the ontology must not include any contradictions neither incoherencies. This property was checked through Pellet[2], which is an OWL2 reasoner, used in Protégé, that supports SWRL rules.
- Interoperability (C2): represents how the ontology is aligned to upper level or other ontologies. The consistent use of an upper level ontology and existing ontologies such as ENVO, CCO is a major step towards enabling the achievement of interoperability among ontologies.
- Extensibility (C3): defines the capability of the ontology to be easily extended by other ontologies. Our ontology has been designed, by the use of the BFO upper level ontology and the reuse of existing ontologies, with the capability to be interoperable with other ontologies. Also, since our proposal is modular, new modules and ontologies can be easily integrated.
- Completeness (C4): measures if the domain of interest is appropriately covered by the ontology. Completeness also covers the granularity and richness of the ontology. Base metrics (which comprise classes, properties and axioms numbers) and schema metrics which address the design of the ontology such as inheritance and relationship richness and axiom/class and class/relation ratios, were chosen to measure the completeness of each module. The evaluation of the global ontology completeness was done by the use case study.
  Let C_{M_o} be the set of classes in a module, H_{M_o} the set of hierarchical relations, P_{M_o} the set of non-hierarchical relations and A_{M_o} the set of axioms in a module.

  Inheritance richness (IR) metric : describes the distribution of information across different levels of the ontology. It indicates how well knowledge is grouped into different categories.

  Definition 3. *The IR is defined as :*

  $$IR(M_o) = \frac{|H_{M_o}|}{|C_{M_o}|} \tag{3}$$

  Relationship richness (RR): describes the diversity of relations types in the ontology.

  Definition 4. *It is represented as:*

  $$RR(M_o) = \frac{|P_{M_o}|}{|H_{M_o}| + |P_{M_o}|} \tag{4}$$

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[1] https://protege.stanford.edu/
[2] https://www.w3.org/2001/sw/wiki/Pellet

Axiom/class ratio (ACR) : describes the ratio between axioms and classes. It is calculated as the average amount of axioms per class.

Definition 5. *The axiom/class ratio is defined by:*

$$ACR(M_o) = \frac{|A_{M_o}|}{|C_{M_o}|} \tag{5}$$

- Clarity (C5): measures how effectively the ontology communicates the intended meaning of the defined terms. This criterion can be measured by the method class/relation ratio from [18].
  Class/relation ratio (CRR) : describes the ratio between classes and relations (properties).

Definition 6. *The class/relation ratio is defined by:*

$$CRR(M_o) = \frac{|C_{M_o}|}{|H_{M_o}| + |P_{M_o}|} \tag{6}$$

- Modularity (C6): defines the degree to which the ontology is composed of modules such that a change to one module has minimal impact on other modules. A cohesion and two coupling metrics are used to measure modularity [20]. In fact, cohesion refers to the degree to which the elements in a module belong together. It is obtained by computing the number of relation between different classes in a module.

Definition 7. *The cohesion of a module is defined by:*

$$coh(M_o) = \begin{cases} \sum\limits_{c_i \in M_o} \sum\limits_{c_j \in M_o} \dfrac{sr(c_i, c_j)}{\frac{|M_o|(|M_o|-1)}{2}} & if|M_o| > 1 \\ 1 & otherwise \end{cases} \tag{7}$$

where $sr(c_i, c_j)$ is the relation function and M_o is the module.

Coupling refers to the number of disconnected classes. We use two metrics to evaluate coupling:

Definition 8. *Number of separated hierarchical relations(NSHR):*

$$NSHR(M_o) = \sum_{c_i \in M_o} \sum_{c_j \in M_o} nshr(c_i, c_j), \tag{8}$$

as $c_i \in M_o$ and $c_j \in O - M_o$.O is the global module, M_o is the module and - is the difference operation. $nshr(c_i, c_j)$ is the number of hierarchical relations between the c_i and c_j classes.

Definition 9. *Number of separated non-hierarchical relations (NSNR):*

$$NSNR(M_o) = \sum_{c_i \in M_o} \sum_{c_j \in M_o} nsnr(c_i, c_j), \tag{9}$$

as $c_i \in M_o$ and $c_j \in O - M_o$. O is the global module, M_o is the module and - is the difference operation. $nsnr(c_i, c_j)$ is the number of non-hierarchical relations between the c_i and c_j classes.

In our work, we refer to OntoMetrics[3], a web-based tool for ontology evaluation, that calculates, validates and displays statics about a given ontology. OntoMetrics was used to measure base and schema metrics to evaluate the criteria C4 and C5. Then, we calculate the value of modularity metrics based on the equations 7-9 to evaluate the criterion C6. We applicate this evaluation for the eight modules of our ontology. The results are summarized in Tab.2.

Table 2. Quality metrics.

M_o	Base metrics			Schema metrics				Modularity metrics		
	classes	properties	axioms	$IR(M_o)$	$RR(M_o)$	$ACR(M_o)$	$CRR(M_o)$	$coh(M_o)$	$NSHR(M_o)$	$NSNR(M_o)$
M_{o_1}	82	1	782	0.979	0.021	4.542	1	0.07	0	4
M_{o_2}	161	3	1083	1.031	0.122	3.205	0.852	0.025	0	5
M_{o_3}	53	6	800	1	0.159	4.264	0.841	0.04	0	1
M_{o_4}	29	5	680	1.115	0.147	3.923	0.765	0.08	1	0
M_{o_5}	77	9	742	1.023	0.167	3.795	0.815	0.08	0	1
M_{o_6}	291	21	2216	1.045	0.093	7.615	0.869	0.008	0	0
M_{o_7}	12	4	223	0.917	0.3125	2.583	0.75	0.18	0	0
M_{o_8}	2	4	223	0.93	0.125	2.2	0.9375	0.02	1	1

Analyzing table 2, we can deduce the following points:

- M_{o_1} has the lowest RR and M_{o_7} has the highest one. In fact, an ontology that has low value of RR, may have only inheritance relationships. That is the case of M_{o_1} since it includes only the set of disasters organized in a hierarchical way. Consequently, it conveys less information than M_{o_7} which contains a diverse set of relationships (eg. ”interval during” and ”has ending instant”).
- IR values are comprised between 0.9 and 1.1 which represent high values. Indeed, Ontological modules with high IR are called horizontal ontologies since classes have a large number of direct subclasses. This indicates that our modules represent a wide range of knowledge with a low level of detail. Accordingly, they are more open to evolve and to be specified. This evolution corresponds to our objective to enrich the ontology with details in other development iterations.
- By comparing the cohesion values (coh(M_o)), we found that the modules M_{o_4}, M_{o_5} and M_{o_7} have the highest cohesion values, due to the strong relatedness of different classes of each module. For instance, the observation and measurement module M_{o_5} deals with the classes of observed properties. This module modelizes relations between observation events, measured properties and measurement units. All of these classes and how they are related are the essence of the higher cohesion in the ontological module.
- Comparing the values of the two-coupling metrics (NSHR and NSNR), we note that the NSNR values of the modules M_{o_1} and M_{o_2} are higher than other modules, due to having more disconnected non-hierarchical relations. As a whole, the coupling between the modules is weak. Each ontological module is loosely coupled with other modules. Consequently, the modules of the proposed ontology are sufficiently independent and easier to understand, modify and reuse.
  We conclude that the principle : a good modular ontology design implies low coupling high cohesion, is considering in the proposed ontology.

4.3. Use case study

In order to evaluate the competency (ie. completeness) of the proposed ontology, a series of semantic querying and reasoning based on CQ was designed. These questions are formulated in natural language to describe the ontology requirements. Then, they are formalized in a query language such as SPARQL[4](cf. fig.1). Their answers allow to

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[3] https://ontometrics.informatik.uni-rostock.de/

[4] http://www.w3.org/TR/rdf-sparql-query/

check if the ontology meets the requirements stated. A good ontology has to provide the correct answers to these questions with the help of reasoners.

The ontology is evaluated by a use case that demonstrates making implicit knowledge explicit. This is done by inferring the implicit relationships defined in the semantic model. Some inferences require additional reasoning beyond that supported by the standard reasoning with OWL-DL semantics. Therefore, we use SWRL to define rules that cannot be defined with OWL2. These rules follow the syntax form: antecedent ⇒ consequent. The following table (cf. Tab.3) shows examples of SWRL rules.

Table 3. SWRL rules examples.

	SWRL rule
(R1)	*rain(?r), precipitation(?p), has_precipitation_value(?r, ?p), swrlb:greaterThan(?p, 0.25), swrlb:lessThan(?p, 1) ⇒ light_rain(?r)*
(R2)	*rain(?r), precipitation(?p), has_precipitation_value(?r, ?p), swrlb:greaterThan(?p, 1), swrlb:lessThan(?p, 4) ⇒ moderate_rain(?r)*
(R3)	*rain(?r), precipitation(?p), has_precipitation_value(?r, ?p), swrlb:greaterThan(?p, 4), swrlb:lessThan(?p, 16) ⇒ heavy_rain(?r)*
(R4)	*rain(?r), precipitation(?p), has_precipitation_value(?r, ?p), swrlb:greaterThan(?p, 16), swrlb:lessThan(?p, 50) ⇒ very_heavy_rain(?r)*

For instance, R4 can be used to describe a rain as a ”very heavy rain” in case that the antecedent conditions, ”precipitation detection” and ”the value of the measurement is between 16 and 50”, are satisfied. In our implementation, we define the rules manually by considering rain categories. Defining a mechanism that can automatically extract rules from data, is a future work.

The ontology is evaluated by inferring rainfall category from precipitation data supplied by the OSS, our project partner. We used precipitation data during the period 2010-2017 in Africa. First, we instantiate our ontology with climatological data. Then, we choose a set of CQ and translate them into SPARQL queries. They work fine with our ontology and correct result can be queried. Based on the SWRL rules, we can infer rain types. Two examples of competency questions and their results are presented by table 4. The prefixes we used are:
PREFIX ns:<http://www.ontologylibrary.mil/Common Core/Mid/MyOntology#>
PREFIX rdf:<http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl:<http://www.w3.org/2002/07/owl#>
PREFIX rdfs:<http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd:<http://www.w3.org/2001/XMLSchema#>
At the start of the evaluation process, we input precipitation values as instance of the ”precipitation” class, we still do not know if the values respect which rain type. Once the reasoning process is started, these SWRL rules are applied upon the proposed ontology. According to the precipitation rate, rain should be classified as an instance of one of these classes ”very heavy rain”, ”heavy rain”, ”moderate rain” or ”light rain”.

Table 4. Competency questions and obtained results.

Competency question	SPARQL query	Results
Is there a rain qualified as a very_heavy_rain?	SELECT ?subject WHERE { ?subject a ns:very_heavy_rain }	39.5 mm
What are the values of a rain properties (unit, location, date, etc.)?	SELECT ?subject ?property ?value WHERE { ?subject a ns:precipitation. ?subject ?property ?object. ?object :hasValue ?value }	39.5 mm, has measurement unit, Millimeter 39.5 mm, observed in, 20170801 39.5 mm, observed at, Niamey

The second query results showed in table 4 represent 3 records of all the results the reasoner generates. This query retrieve precipitation values and their observing information, for example, location and time. To analyze and gain understanding of environmental processes occurrences, one should identify spatio-temporal and related information.

After the inference reasoner gave reasonably complete and coherent answers to the competency questions, we can conclude that the proposed ontology satisfies the completeness criterion.

5. Summary and future works

In this paper, we presented a domain ontology for environmental monitoring. The contributions of our approach are (1) the use of an upper level ontology BFO to support interoperability, (2) the reuse of existing ontologies to reduce duplicated work (3) and the modularity of the ontology which allows its reuse and extensibility. The proposed modular ontology has three main objectives: 1) to ensure the semantic interoperability between heterogenous sources, 2) to integrate and/or annotate data from multiple sources and 3) to link data together in order to build a global interactive network that permits to better understand environmental dynamics and natural phenomena. We are currently working on the further development of an automatic method for the population of the ontology with specific instances. Next, we plan to use the developed ontology for an ontology-based data integration approach in order to integrate multi-source environmental data. Environmental monitoring process may require data from multiple sources. For such needs, multiple sources must be integrated. This integration will be based on the developed ontology. Finally, we plan to apply the ontology for other applications such as the prediction of natural disasters.

Availability. The proposed ontology is available at: `https://github.com/MEMOntology/memon` and the modules are described in a complete view at: `https://sites.google.com/view/memon/accueil`

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