Reasoning and Query Answering for Metamodeling Enabled Ontologies

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Abstract. Ontologies are expected to play an important role in many applications domains, as well as in software engineering in general. One issue is that while UML, a widely used standard for specifying and constructing the models for a software-intensive system, has a four-layer metamodeling architecture, the standard OWL Web Ontology Language does not have a layered metamodeling reasoning. Pan and Horrocks [8] have addressed this problem by introducing OWL FA, a metamodeling extension of OWL DL. However, there is currently no study and tool support for OWL FA. Another issue is there is no such query language to query metamodeling enabled ontologies yet. In this proposal, we propose *(i)* to extend an existing OWL DL reasoner to support OWL FA; *(ii)* to extend the Semantic Web standard query language SPARQL to support query answering over metamodeling enabled ontologies; *(iii)* to provide semantic approximation for OWL FA in order to obtain efficient query answering for OWL FA.

1 Introduction

Ontologies are expected to play an important role in many applications domains. One issue is that while UML, a widely used standard for specifying and constructing the models for a software-intensive system, has a four-layer metamodeling architecture, the standard Web Ontology OWL does not have a layered metamodeling architecture. Pan and Horrocks [8] have addressed this problem by introducing OWL FA, a metamodeling extension of OWL DL. However, there is currently no study and tool support for OWL FA.

Another issue is there is no such query language to query metamodeling enabled ontologies yet. Most of the existing query languages like SeRQL, SPARQL, nRQL and SPARQL-DL mainly focus on query answering in TBox/ABox/ RBox only. Query language for Semantic Web ontologies can be divided in two categories: RDF-based QLs and DL-Based QLs. RDF-based query languages such as RDQL[1], SeRQL[2] and SPARQL, are based on the notion of RDF triple patterns. DL based query languages such as DIG ASK[3] queries, nRQL[4] and SPARQL-DL[10] are based on DL model theory. DIG ASK queries are limited to atomic

[1] http://www.w3.org/Submission/RDQL/
[2] http://www.openrdf.org/doc/sesame/users/ch06.html

queries. nRQL supports only ABox queries whereas SPARQL-DL supports mixed TBox/ABox/RBox queries. SPARQL-DL is a powerful and expressive query language but SPARQL-DL does not support Meta queries.

2 Motivating example

In this section, we give an intuitive example to show why we need metamodeling enabled ontologies.

Example 1. Software Development Companies would like to improve their software development processes by using reasoning mechanisms such as inconsistency checking of models. In order to do so they need to transform the software model into OWL DL ontology, however OWL DL does not support layered metamodeling reasoning. One may argue that OWL2[7] provides simple metamodeling feature and it supported in existing DL reasoner but the semantics are based on a punning approach. The interpretation function is different based on the context, which leads to non-intuitive result. OWL FA provides more expressive power for metamodeling and semantics of OWL FA are well defined. Therefore, OWL FA is more suitable for this case.

Example 2. In this section, we illustrate an example to show why we need meta query language to query metamodeling enabled ontologies. Let `EndangeredSpecies` be meta-class; `Eagle`, `GiantPanda` and `Panda` be classes; `Ted`, `ChuangChoung`, `LinHui`, `Tewa` and `Tewee` be objects. The relationships among them are described in figure 1.

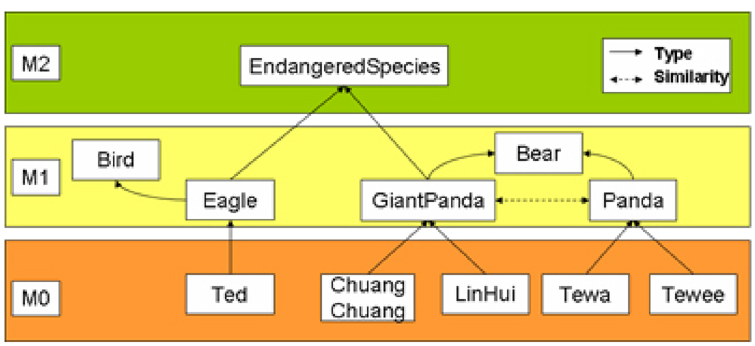

Fig. 1. EndangeredSpecies ontology

we use SPARQL query with DL-Reasoner to find all the classes that belong to the meta-class EndangeredSpecies. The SPARQL query is shown below.

```
SELECT ?x
```

```
WHERE  {
       ?x rdf:type :EndangeredSpecies .
       }
```

SPARQL will return the result set, which contains `Eagle` and `GiantPanda` . It is obvious that the result set is not complete according to the EndangeredSpecies ontology as `GiantPanda` is equivalent to `Panda`. The result set should contains `Eagle`, `GiantPanda` and `Panda`.

3 Related Work

Let us conclude this section by summarizing a small collection of the most directly related studies in this area.

Reasoning for Metamodeling Enabled Ontologies Motik[6] addressed the decidability in OWL-Full to obtain metamodeling capability by applying the semantics of HiLog which allows us to axiomatize the logical interaction between concepts and their metaconcepts. Giacoma et al.[1] proposed the `HiDL-Lite` language, which adds one layer on top of the DL-Lite$_{\mathcal{R}}$ language. This supports meta-classes and meta-properties and presents the query answering algorithm by trimming down `HiDL-Lite` syntax to DL-Lite$_{\mathcal{R}}$ syntax with the intention of using the existing DL-Lite reasoner. Finally, OWL2[7] provides simple metamodeling feature and is supported in existing DL reasoner but semantics are based on a punning approach. OWL FA provides more expressive power for metamodeling and semantics of OWL FA are well defined.

Query Answering for Metamodeling Enabled Ontologies In terms of syntax, SPARQL query can support meta queries in OWL FA ontologies since SPARQL is based on graph matching and its semantics is derived from RDF semantics. However, it is obvious that the result set is not complete because a result set from a SPARQL query can contain answers which match the target graph only. SPARQL-DL has more expressive power than SPARQL, which allows mixed TBox/ABox/RBox queries. In addition, SPARQL-DL has well-formed semantic based on OWL DL. However, SPARQL-DL does not support meta query as it is mainly focusing on OWL DL and some syntax of OWL FA is not recognised by DL reasoner.

Approximation The approximation has been identified as a potential way to reduce the complexity of reasoning over OWL DL ontologies. Approximation techniques can divide into categories. First, syntactic approximation is the approach to covert complex syntax into simple syntax, which can be computed in polynomial time. However, syntactic approximation approaches can introduce unsound answers. The existing approach on syntactic approximation can be found at [11, 5, 2]. Second, semantic approximation is the approach that allows ontologies to be converted into a less expressible and more tractable language. This approach guarantees soundness and completeness for all queries with non-distinguished variables. By using this technique to reduce the complexity of query answering, we can perform conjunctive queries against large knowledge bases. For more detail refer to [9].

4 Proposed Approach

In this section, we describe our approach for support reasoning and query answering for metamodeling enabled ontologies.

Reasoning for Metamodeling Enabled Ontologies An OWL FA ontology $\mathcal{O}$ can be divided into a set of sub-ontologies $\mathcal{O}_1, \ldots, \mathcal{O}_k$. In the sub-ontology $\mathcal{O}_{i+1}$ ($1 \leq$ i $\leq$ k), (meta-) objects are resources in layer (i-1), while (meta-) classes and properties are resources in layer i. An OWL DL ontology can be regarded as a special form of an OWL FA ontology that only have the sub-ontology $\mathcal{O}_1$. In an OWL FA knowledge base $\mathcal{O} = \langle \mathcal{O}_1, \ldots, \mathcal{O}_k \rangle$, it is obvious that each $\mathcal{O}$ is a $\mathcal{SHOIN}$(D) knowledge base. Note that classes and property names in $\mathcal{O}_i$ are treated as individual names in $\mathcal{O}_{i+1}$. Therefore, individual equalities explicitly asserted and implicitly entailed by number restrictions in $\mathcal{O}_{i+1}$ can act as class and property equality axioms in $\mathcal{O}_i$. For that reason, we are able to transform OWL FA ontology into collection of OWL DL ontologies then we can use existing OWL DL reasoner to perform a reasoning tasks. Nevertheless, this cannot be done easily. We need to maintain the relationshiop between OWL DL ontologies according OWL FA semantics.

Query Answering for Metamodeling Enabled Ontologies Most studies about query languages in Section 3 mainly focus on query answering in TBox/ABox/RBox only. In our approach, we would like to extend the Semantic Web standard query language SPARQL to support mixed Meta/TBox/ABox/RBox queries. It will be able to query over n levels of the metamodeling ontology with a single query based on the semantics of OWL FA.

Approximation for OWL FA The complexity of query answering for OWL FA is equivalent to OWL DL. Since, from one layer to the next layer of OWL FA ontology is equivalent to $\mathcal{SHOIN}$(D) knowledge base. Then, we would like to provide semantic approximation for OWL FA. If we could approximate OWL FA to less expensive languages, then we could enjoy query answering within `LOGSPACE` rather than `NExptime`.

5 Conclusion and Work Plan

This proposal propose to support reasoning and query with metamodeling enabled ontologies. Specially, we have discussed how metamodeling enabled ontologies are needed though practical examples and we have shown how to achieve our goal. In the first step, we will implement the wrapper to transform OWL FA ontology into collection of OWL DL ontologies. So far we have defined the algorithm for the wrapper but we need to test our algorithm. Afterward, we can perform the reasoning tasks and query answering with OWL FA and finally, We would like to apply an approximation technique for OWL FA then we could enjoy query answering within `LOGSPACE`. This approach can be done after we get an OWL FA reasoner.

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