A Review of Approaches for Representing RCC8 in OWL

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ABSTRACT

This paper investigates several approaches for qualitative spatial knowledge representation on the Semantic Web, by using RCC8 relations. We discuss several issues arising when representing RCC8 in OWL DL, e.g., the lack of required features like role reflexivity, role Boolean operators, and role inclusion axioms. We conclude that, although some of these features are to be included in the new version of the OWL standard, OWL 2, this language still lacks the expressive power to support role negations, conjunctions, and disjunctions, and complex role inclusion axioms.

Categories and Subject Descriptors

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Languages, design

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1. INTRODUCTION

Nowadays, it is increasingly important to be able to represent data in a proper, meaningful way. The Semantic Web enables one to find, share, and combine information more easily. Even though one could represent and reason with many types of information, tasks related to spatial knowledge remain non-trivial. Even though spatial features can be stored in ontologies, they cannot capture the semantics of spatial relations in a reasonable manner, as relations are more complex than features. The need for spatial information modeling on the Web is stressed by the large amount of available unstructured spatial data, which is a promising resource for decision making related to various topics.

The Region Connection Calculus (RCC) [5], and in particular RCC8, is a popular method for qualitative spatial or topological representation and reasoning, and is likely to be of use on the Semantic Web as well. In this paper, we discuss several issues arising when trying to enable topological spatial reasoning on the Semantic Web using RCC8, in conjunction with Web Ontology Language (OWL).

Various versions of OWL can be considered. A commonly used OWL version is the decidable fragment OWL DL, which is based on the Description Logics (DL) language $\mathcal{SHOIN}$. Also, the specifications of OWL 2 (formerly known as OWL 1.1), an extension of OWL DL that is based on the $\mathcal{SROIQ}$ DL language, are currently beyond the working draft status [4].

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2. FROM RCC8 TO OWL

We now continue with elaborating on ways to translate the RCC8 relations to different versions of OWL.

2.1 OWL DL

Katz and Grau [3] give a translation from RCC8 into OWL DL presented in Table 1, where regions R_3, R_4, R_5, R_6, R_7, and R_8 must be non-empty. It is shown that even though OWL DL already has many of the required features to represent RCC8 relations, it still cannot represent reflexive roles. Such a role is for instance needed for specifying the connected (C) relation in RCC8 that holds as a basis for every other RCC relation.

Table 1: Translations of RCC8 to OWL DL

Relation	OWL DL
$\text{EC}(R_1, R_2)$	$\forall\text{C}.R_1 \sqsubseteq \exists\text{C}.\neg R_2; R_3 \equiv R_1 \sqcap R_2$
$\text{DC}(R_1, R_2)$	$R_1 \sqsubseteq \neg R_2$
$\text{TPP}(R_1, R_2)$	$R_1 \sqsubseteq R_2; R_4 \equiv R_1 \sqcap \exists\text{C}.\neg R_2$
$\text{TPPi}(R_1, R_2)$	$R_2 \sqsubseteq R_1; R_5 \equiv R_2 \sqcap \exists\text{C}.\neg R_1$
$\text{NTPP}(R_1, R_2)$	$R_1 \sqsubseteq \forall\text{C}.R_2$
$\text{NTPPi}(R_1, R_2)$	$R_2 \sqsubseteq \forall\text{C}.R_1$
$\text{EQ}(R_1, R_2)$	$R_1 \equiv R_2$
$\text{PO}(R_1, R_2)$	$R_6 \equiv \forall\text{C}.R_1 \sqcap \forall\text{C}.R_2;$ $R_7 \equiv R_1 \sqcap \neg R_2; R_8 \equiv \neg R_1 \sqcap R_2$

The authors stress that it is known from previous research that RCC8 can be translated into *S4*, a modal logic which is an extension of the description logic *S*, which is supported by OWL. The authors argue that the reflexive property that is supported by *S4* could be added to OWL in a future version relatively easily. As OWL 2 is based on the logic $\mathcal{SROIQ}$, which includes reflexivity, this is indeed the case.

In addition to this, we find that the approach of Katz and Grau is difficult to interpret. Also, because a TBox axiom has to be introduced for each RCC8 role association, there is an undesired explosion of TBox axioms (some of the RCC8 axioms require additional TBox axioms specifying the non-emptiness of some regions).

2.2 OWL 2

Grütter and Bauer-Messmer [1, 2] discuss a way to implement the RCC8 relations within OWL 2. They identify some problems that arise when translating RCC8 to OWL 2. First of all, by using the approach from the previous section, the regions in the calculus are sets in the abstract object domain, represented by the TBox in OWL, which is at schema level. Hence, regions are not in a concrete domain, i.e., the OWL ABox. OWL 2 does not allow classes to be individuals at the same time. The punning mechanism of OWL 2 does not address this problem, as this allows the same name to be used for classes and individuals, which do not represent the same entity. This prevents RCC8 from being used with domain ontologies, as these require the regions to be represented as individuals [1, 3]. Furthermore, OWL 2 lacks the support for complex role inclusion axioms of the form $S \circ T \sqsubseteq R_1 \sqcup \ldots \sqcup R_n$, required for RCC composition tables.

To cope with these problems, the authors of [1, 2] propose to extend OWL with RCC-specific relations at the architecture level of the knowledge representation system and not at the level of the formalisms. This information cannot be captured in the TBox or ABox, and thus the authors propose a hybrid approach, i.e., the introduction of an *RCCBox*, similar to the RBox (role box) in $\mathcal{SROIQ}$, in which the RCC relations and composition tables are specified.

Also, Grütter and Bauer-Messmer note that this hybrid approach does not work well with OWL DL, because OWL DL – as opposed to OWL 2 – does not support role negation at ABox level, and thus is unable to check whether two regions are connected or not, unless all connected relations have been explicitly defined. However, to explicitly define all the combinations of two disconnected regions would be impossible with a large number of regions. When implementing the approach in OWL 2, it becomes possible to check whether any of the other 7 RCC8 relations hold, and if not, to then automatically state that the disconnected relation takes place between the two regions. This approximation results from working with the open world assumption.

2.3 Beyond OWL 2

Although OWL 2 supports reflexivity, it still lacks some necessary features for implementing the RCC8 relations, as neither role negations, nor role conjunctions and disjunctions are supported. Also, one is not able to represent complex role inclusion axioms using OWL 2. For instance, if we translate the non-tangential proper part (NTPP) relation to DL, we obtain $\mathrm{NTPP} = \mathrm{PP} \sqcap \neg(\mathrm{EC} \circ \mathrm{EC})$, where PP refers to the proper part relation and EC refers to the externally connected relationship; this is an expression that is currently not supported by OWL.

This complex spatial relationship demonstrates the need for both negation and conjunction in OWL at TBox level, as well as the need for composition in the right hand side (e.g., the equivalents given by the composition tables or RCC8 relation definitions are in fact double inclusions between the left hand sides and the right hand sides). Furthermore, for expressing RCC8 relations like NTPP, we also need role conjunctions that contain role composition, i.e., there is a need for support of complex role inclusion axioms in OWL 2 in order to be able to fully express RCC8 relations. Finally, the shortcomings of OWL 2 are not only limited to the RCC8 relations, but can also be found in the associated compositions of RCC relation definitions. As stated earlier in Sect. 2.1, OWL 2 lacks the support for complex role inclusion axioms that use disjunctions, which are needed for creating the composition tables used for RCC relations.

3. CONCLUSIONS

We have discussed several issues encountered when representing RCC8 in OWL by reviewing different approaches to implementing RCC8 relations in OWL. OWL DL, based on the DL language $\mathcal{SHOIN}$, lacks required features such as role reflexivity, role Boolean operators, and role inclusion axioms, and therefore is not suitable for implementing RCC8 relations. Some of these features are included in OWL 2 (based on $\mathcal{SROIQ}$), but this does not satisfy all our needs, as it would still not support role negations at TBox level, conjunctions, and disjunctions at an abstract level, as well as complex role inclusion axioms.

Since OWL 2 does not satisfy all the requirements for spatial reasoning, it is also worthwhile to consider extending it with role Boolean operators and more complex role inclusion axioms for better spatial representations and reasoning, while maintaining decidability. Also, we would like to investigate how one can represent more powerful spatial knowledge representation formalisms like RCC15 and 9-Intersection on the Semantic Web.

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