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Optimising fuzzy description logic reasoners with general concept inclusion absorption [☆]

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Abstract

General Concept Inclusion (GCI) absorption algorithms have shown to play an important role in classical Description Logic (DL) reasoners. They allow to transform GCIs into simpler forms to which we may apply specialised inference rules, returning important performance gains. In this work, we develop the first absorption algorithm for fuzzy DLs, implement it in the *fuzzyDL* reasoner and evaluate it extensively over both classical and fuzzy ontologies. The results show that our algorithm improves the performance of the reasoner significantly.

Keywords: Fuzzy description logics; Fuzzy ontologies; Fuzzy logic; Logic for the semantic web; Optimization

1. Introduction

Description Logics (DLs for short) [1] is a well-known family of logics for representing structured knowledge. In the last two decades, DLs have gained even more popularity due to their application in the context of the *Semantic Web* [2]. Indeed, the current standard language for specifying ontologies is the Web Ontology Language (OWL 2) [3], which is based on the DL $\mathcal{SROIQ}(\mathbf{D})$ [4].

Fuzzy DLs have been proposed as an extension to classical DLs with the aim of dealing with *fuzzy, vague*, and *imprecise* concepts. In these logics, the axioms may not be bivalent, but instead can be satisfied with a certain degree of truth (typically, a truth value in [0, 1]). Since the first work of J. Yen in 1991 [5], an important number of works can be found in the literature (good surveys on *fuzzy DLs* can be found in [6,7]).

However, little effort has been paid so far to the study and implementation of optimization techniques, which is essential to reason with real-world scenarios in practice. Up to now, we are only aware of two works [8,9], but neither of them considers reasoning with a general TBox.

☆ This paper is a revised and extended version of "General Concept Inclusion Absorptions for Fuzzy Description Logics: A First Step", published in the Proceedings of the 26th International Workshop on Description Logics (DL 2013).

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In classical DLs, a TBox contains *General Concept Inclusion* axioms (GCIs) of the form

$$C \sqsubseteq D,$$

intuitively encoding that an instance of class C is also an instance of class D. *GCI absorption* is a technique that allows to transform GCIs into simpler forms to which we may apply then specialised inference rules: the so-called *lazy unfolding rules* [1,10–16]. The basic principle in absorption is to avoid the *internalisation* of GCIs, which is the naive way to reason with these axioms. For example, the GCI

$$A \sqcap C \sqsubseteq D \tag{1}$$

is usually internalised into the canonical form

$$\top \sqsubseteq \neg A \sqcup \neg C \sqcup D.$$

The original GCI encodes the idea that an instance of both classes A and C is also an instance of class D, while the canonical form encodes that any object is either not an instance of A, or not an instance of C, or an instance of D. The consequence of this transformation is that the inference rule handling GCIs will be applied to *every* object that occurs during the reasoning process. If A is an atomic concept, it is a smarter option to rewrite Eq. (1) as

$$A \sqsubseteq \neg C \sqcup D.$$

The subsequent idea behind the latter axiom is that an instance of class A is either not an instance of class C or an instance of class D. The consequence of this transformation is that the inference rule for such axiom applies (among other conditions) *only if* an object has been inferred as being an instance of concept A. This implies a reduction of the number of applications of the axiom and hence of the reasoning time.

While absorption algorithms have experimentally shown to provide a very important performance gain for classical DLs reasoners, no such algorithms have been investigated so far in the context of fuzzy DLs. It is expected that absorption would provide a reduction in the reasoning time within fuzzy DLs.

Another benefit of absorption for fuzzy DLs is the possibility of transforming a non-acyclic ontology [17] into an acyclic one. This is important from a computational point of view since reasoning problems are in general undecidable in the presence of GCIs for several fuzzy DLs [18,19,21] (for instance in Łukasiewicz and Product $\mathcal{ALC}$), but are decidable if the TBox is acyclic [18,20]. That is, in some cases it may be possible to transform a non-acyclic fuzzy ontology (for which reasoning problems are not guaranteed to be decidable) into an equivalent acyclic one (and thus for which reasoning problems are guaranteed to be decidable).

It is also worth to note that the absorption method holds for the case of a finite linearly-ordered truth space as well (for which the decidability of the satisfiability problem is always guaranteed). Therefore, the absorptions can be beneficial for finitely valued DLs as well [22,23].

The aim of this paper is to propose the first absorption algorithm for fuzzy DLs. This algorithm is implemented in the *fuzzyDL* reasoner[1] [24] and evaluated over several existing ontologies. Our results show that our algorithm significantly improves the performance of the reasoner.

The rest of this paper is organised as follows. Section 2 recalls some preliminaries on fuzzy logic and fuzzy DLs. Section 3 presents our GCI absorption algorithm. Next, Section 4 discusses an experimental evaluation of the algorithm. Finally, Section 5 sets out some conclusions and ideas for future research.

2. Fuzzy DLs basics

In this section we recap some basic definitions needed during the rest of the paper. We refer the reader to [6,7] for a more in depth presentation.

[1] http://www.straccia.info/software/fuzzyDL/fuzzyDL.html.