Model Transformation in Description Logics

Motivation and Approach

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Abstract

In the field of knowledge representation and reasoning, description logics are commonly used to design knowledge bases and to reason about this knowledge. Various algorithms have been introduced to solve common reasoning problems, some of which compute models of the knowledge bases. There are, however, reasoning services that require models to admit certain properties not taken into consideration by these algorithms. This, for instance, is the case for explaining reasoning results using models. Consequently, our research goal is to identify desired model properties and to define appropriate model transformations as well as to investigate the computational complexity of these transformations.

Keywords

Description Logic, Model Transformation, Explainable AI

1. Introduction

Knowledge representation and reasoning (KRR) is a well-established branch of artificial intelligence (AI) that is concerned with modeling information as logical statements in knowledge bases in order to apply reasoning algorithms. A commonly used family of knowledge representation languages is description logics (DLs), which usually are decidable fragments of first-order logic (FOL) and closely related to modal logics [1]. Models of DL knowledge bases can be regarded as edge and vertex-labeled, directed graph structures. DLs are frequently used in practice to formalize domain specific knowledge as they, for instance, constitute the foundation for W3C standardized ontologies in the OWL 2 standard.

One main advantage of DLs is that they provide formally defined and well-investigated reasoning problems. DL reasoners decide many reasoning problems, such as satisfiability, by computing a model of the knowledge base under consideration. Usually, the respective reasoning procedures are implemented in highly optimized reasoning algorithms [2]. However, DL reasoner systems usually compute models according to their optimization criteria and do not take other factors, such as comprehensibility, into account. In fact, reasoning results can be hard to comprehend for users of DL systems as DL knowledge bases can easily grow very large and complex. This is the reason for an ongoing active development of various syntactic and semantic approaches for explaining logic-based AI reasoning.

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Consequently, this project is concerned with the transformation of models of DL knowledge bases such that the resulting model satisfies additional properties, which depend on the use case. More precisely, we identify desired properties of models to, for instance, serve as explanation, and define according model transformations as well as investigate their computational complexity.

2. Motivation

A main motivation for the manipulation of models of DL knowledge bases is, as mentioned before, explanation of reasoning results. Some reasoning results computed by DL systems can be far from obvious due to a number of reasons, e.g. because of the size and complexity of the respective knowledge base or because of a lack of familiarity with the logical syntax and deduction steps. There are, in principle, two ways of explaining reasoning results of DL systems for users. First, the reasoning result should be deducible in a logical calculus in case of positive entailment. This approach seems natural for positive entailments but less striking for explaining negative entailments. We take the path of explaining reasoning results semantically, which is the second way of explaining. This means we provide suitable models as prototypical examples to users in order to explain positive reasoning results, and we present suitable counter examples in case of negative reasoning results.

DL reasoner systems are optimized in terms of efficient computation of reasoning results. Hence, the computed models can appear artificial and counter-intuitive to users of DL systems. In order to make the reasoning result based on the computation of a model more comprehensible, the model can be transformed into another model of the DL knowledge base that admits additional properties, which shall foster human understanding of the reasoning result under consideration. For instance, possibly small models could ease comprehension since they do not contain redundancies. To identify interesting properties and discuss their meaning for improving model based explanations is part of this project. Besides, a mere visualization of the knowledge base by a well-shaped model can already help users to understand their knowledge base without having to read all its logical formulae, which already requires a certain level of expertise. Of course, one can transform models for various purposes other than to improve explainability. The need for transforming models becomes evident whenever a use case requires the model of the knowledge base to satisfy an additional property that is not expressible in the respective DL. For instance, the well-investigated DL $\mathcal{ALC}$, and hence any less expressive DL, admits the tree model property, intuitively meaning that no $\mathcal{ALC}$ knowledge base (without constants) can enforce its models to be tree-shaped or prevent them from being tree-shaped because tree-shapedness is not expressible in $\mathcal{ALC}$. Hence, if the knowledge base is meant to model tree-shaped structures, such as pedigrees, transforming models into tree-shape while simultaneously maintaining their model property w.r.t. the given knowledge base can be useful.

3. Research Goal

In short, the general goal of this project is to define, investigate, and provide instances of a model transformation framework for specifying mappings over models of DL knowledge bases such that the images satisfy additional constraints while maintaining their model property.

In this framework, the desired property is a parameter, as is the respective knowledge base. This framework can then be used to define and discuss concrete instances of it as well as to classify model transformations w.r.t. the parameters of the framework.

This implies two aspects. First, the search for properties and use cases in which model transformations are useful. For these cases, we define appropriate transformations and prove their soundness. Second, the investigation of such framework w.r.t. general aspects, such as the computational complexity of model transformations given a certain logical language in which the desired model property is formalized. Such a language could be monadic second-order logic (MSO), or any other language that is more expressive than the DL in use.

The ideal of this research line would then be to construct an automated service for model transformations with user definable properties.

4. Related Work

Explainabilty of logic-based AI reasoning is an active research area with various approaches, see e.g. [3, 4]. On the syntax side, one approach computes a minimal set of logical statements from the knowledge base that produces the entailment to be explained. These sets are called justifications and were intensively investigated in recent years [5]. Another syntax-based approach is to provide comprehensible proofs [6]. However, these approaches require, as mentioned earlier, a certain level of expertise from the user.

On the semantic side, there is previous work on making entailments more intelligible by revealing only parts of the respective model in a user interactive fashion [7]. Other approaches suggest visualizations of DL concepts by models, where information that is irrelevant to the user is filtered [8]. In addition, there is previous work on computing minimal models for FOL [9]. Nonetheless, to the best of our knowledge, there is little research about transforming DL models respecting user definable properties.

5. Approach and Results to Date

Since DL models can be regarded as edge and vertex-labeled graphs, the initial formalism of choice is MSO graph transductions [10], which is a powerful tool to specify maps over graph structures using MSO formulae with free variables. Since many DLs admit the finite model property, decidability of these MSO formulae is noncritical. The definition of our model transformation framework is, however, not limited to MSO graph transductions. A well known alternative are, for instance, Graph Rewriting Systems [11].

In [12], we present a model transformation framework as described in Section 3 and define the basic decision problem of a *successful transformation*, meaning that a model transformation as an instance of the framework is called *successful* if and only if the image of the model transformation is indeed a model of the respective knowledge base that satisfies the additionally desired property. As an example instance of this framework, we construct a family of transformations for the DL $\mathcal{ALC}$ for obtaining finite tree-like models. We call the transformations *ℓ-unraveling*, where ℓ is an integer determining the depth of the unraveling, and prove that they are model-preserving by showing that any model and the transformations of it are bisimilar.

We provide another use case of model transformations in [13, 14, 15], where models are transformed in order to explain non-entailment for the DL $\mathcal{EL}$. The objective is to reduce counter examples for the non-entailment in question to a relevant minimum. Lastly, in a use case that does not have explanation as focus, we apply the model transformation techniques in [16] for repairing $\mathcal{EL}$ knowledge bases using methods from formal concept analysis [17].

6. Future Work

The first line of research is the extension of the catalogue of interesting properties for models that foster human understanding of knowledge bases and reasoning results. To support users of DL systems, findings from cognition theory are to be taken into consideration. Furthermore, user studies can be conducted to empirically verify the suitability of potentially interesting model properties.

The second direction of research is dedicated to the further investigation of the model transformation framework introduced in [12]. An open question in this context is if there can be an automated reasoning service that allows a user to specify a desired property for a model of a given knowledge base and deduces the MSO formulae that define the MSO transduction needed to transform the respective model. Future work can also consider model transformations with constants to incorporate reasoning services using named elements — foremost query answering over TBox and ABox. Since there are multiple formalisms to define model transformations, it appears also reasonable to compare these formalisms with respect to their suitability for the overall task by, for instance, investigating their expressive power.

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