Tightly Coupled Fuzzy Description Logic Programs under the Answer Set Semantics for the Semantic Web

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ABSTRACT

We present a novel approach to fuzzy description logic programs (or simply fuzzy dl-programs) under the answer set semantics, which is a tight integration of fuzzy disjunctive logic programs under the answer set semantics with fuzzy description logics. From a different perspective, it is a generalization of tightly coupled disjunctive dl-programs by fuzzy vagueness in both the description logic and the logic program component. We show that the new formalism faithfully extends both fuzzy disjunctive logic programs and fuzzy description logics, and that under suitable assumptions, reasoning in the new formalism is decidable. We present a polynomial reduction of certain fuzzy dl-programs to tightly coupled disjunctive dl-programs, and we analyze the complexity of consistency checking and query processing for certain fuzzy dl-programs. Furthermore, we provide a special case of fuzzy dl-programs for which deciding consistency and query processing can both be done in polynomial time in the data complexity.

Keywords: Answer-set Programming; Description Logics; Fuzzy Logic

INTRODUCTION

The Semantic Web (Berners-Lee, 1999; Fensel, Wahlster, Lieberman, & Hendler, 2002) aims at an extension of the current World Wide Web by standards and technologies that help machines to understand the information on the Web so that they can support richer discovery, data integration, navigation, and automation of tasks. The main ideas behind it are to add a machine-readable meaning to Web pages, to use ontologies for a precise definition of shared terms in Web resources, to use KR technology for automated reasoning from Web resources, and to apply cooperative agent technology for processing the information of the Web.

The Semantic Web consists of several hierarchical layers, where the Ontology layer, in form of the OWL Web Ontology Language

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(Horrocks, Patel-Schneider, & van Harmelen, 2003; W3C, 2004), is currently the highest layer of sufficient maturity. OWL consists of three increasingly expressive sublanguages, namely, OWL Lite, OWL DL, and OWL Full. OWL Lite and OWL DL are essentially very expressive description logics with an RDF syntax (Horrocks et al., 2003). As shown in Horrocks and Patel-Schneider (2004), ontology entailment in OWL Lite (resp., OWL DL) reduces to knowledge base (un)satisfiability in the description logic $\mathcal{SHIF}(\mathcal{D})$ (resp., $\mathcal{SHOIN}(\mathcal{D})$). As a next step in the development of the Semantic Web, one aims especially at sophisticated representation and reasoning capabilities for the Rules, Logic, and Proof layers of the Semantic Web.

In particular, there is a large body of work on integrating rules and ontologies, which is a key requirement of the layered architecture of the Semantic Web. Significant research efforts focus on hybrid integrations of rules and ontologies, called description logic programs (or dl-programs), which are of the form $\mathcal{KB} = (\mathcal{L}, \mathcal{P})$, where $\mathcal{L}$ is a description logic knowledge base, and $\mathcal{P}$ is a finite set of rules involving either queries to $\mathcal{L}$ in a loose integration (see especially Eiter, Ianni, Lukasiewicz, Schindlauer, & Tompits, 2008; Eiter, Lukasiewicz, Schindlauer, & Tompits, 2004; Eiter, Ianni, Schindlauer, & Tompits, 2006) or concepts and roles from $\mathcal{L}$ as unary resp. binary predicates in a tight integration (see especially Lukasiewicz, 2007a; Rosati, 2006).

Other works explore formalisms for handling uncertainty and vagueness/imprecision in the Semantic Web. In particular, formalisms for dealing with uncertainty and vagueness in ontologies have been applied in ontology mapping and information retrieval. Vagueness and imprecision also abound in multimedia information processing and retrieval. Moreover, handling vagueness is an important aspect of natural language interfaces to the Web. There are several recent extensions of description logics, ontology languages, and dl-programs for the Semantic Web by probabilistic uncertainty and by fuzzy vagueness. In particular, dl-programs under probabilistic uncertainty and under fuzzy vagueness have been proposed in Lukasiewicz (2005, 2006a) and Straccia (2006c, 2006b) and Lukasiewicz (2006a), respectively.

In this article, we continue this line of research. We present tightly coupled fuzzy description logic programs (or simply fuzzy dl-programs) under the answer set semantics, which are a tight integration of fuzzy disjunctive programs under the answer set semantics with fuzzy generalizations of $\mathcal{SHIF}(\mathcal{D})$ and $\mathcal{SHOIN}(\mathcal{D})$. Even though there has been previous work on fuzzy positive dl-programs (Straccia, 2006c, 2006b) and on loosely coupled fuzzy normal dl-programs (Lukasiewicz, 2006a), to our knowledge, this is the first approach to tightly coupled fuzzy disjunctive dl-programs (with default negation in rule bodies). The main contributions of this article can be briefly summarized as follows:

- We present a novel approach to fuzzy dl-programs, which tightly integrates fuzzy disjunctive programs under the answer set semantics with fuzzy description logics. It generalizes the tightly coupled disjunctive dl-programs in Lukasiewicz (2007a) by fuzzy vagueness in both the ontological and the rule component.
- We show that the new fuzzy dl-programs have nice semantic features. In particular, all their answer sets are also minimal models, and the cautious answer set semantics faithfully extends both fuzzy disjunctive programs and fuzzy description logics. The new approach also does not need the unique name assumption.
- As an important property, in the large class of fuzzy dl-programs that are defined over a finite number of truth values, the problems of deciding consistency, cautious consequence, and brave consequence are all decidable.
- We present a polynomial reduction for certain fuzzy dl-programs to the tightly coupled disjunctive dl-programs in Lukasiewicz (2007a), and analyze the complexity of consistency checking and
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