Chapter 101
A Review of Answering Queries Over Ontologies Based on Databases

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ABSTRACT

Ontologies, as a standard (W3C recommendation) for representing knowledge in the Semantic Web, have been employed in many application domains. Currently, real ontologies tend to become very large to huge. Thus, one problem is considered that has arisen from practical needs: namely, efficient querying of ontologies. To this end, there are today many proposals for answering queries over ontologies, and until now the literature on querying of ontologies has been flourishing. In particular, on the basis of the efficient and mature techniques of databases, which are useful for querying ontologies. To investigate querying of ontologies and more importantly identifying the direction of querying of ontologies based on databases, in this chapter, we aim at providing a brief review of answering queries over ontologies based on databases. Some query techniques, their classifications and the directions for future research, are introduced. Other query formalisms over ontologies that are not related to databases are not covered here.

INTRODUCTION

The integration of databases and ontology-based systems became an important research problem for the Semantic Web and database communities. On one hand, the databases may be enriched by an ontological theory that enforces expressive constraints over the databases. Such constraints go far beyond traditional integrity constraints and can be used to enable complex reasoning tasks over the database instances

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(Gottlob, Orsi, & Pieris, 2011). On the other hand, the database research community has successfully developed a wide theory corpus and a mature and efficient technology to deal with large and persistent amounts of information. In this case, some mature database techniques (e.g., data management, maintenance, and query) may be employed to handle some issues of ontologies, such as storage and query of ontologies. To investigate these issues and more importantly serve as helping non-experts grasp the main ideas and results of querying ontologies with databases and identifying the direction of querying ontologies for the Semantic Web study, in this chapter, we aim at providing a review of answering queries over ontologies with databases.

In particular, one of the main tasks in databases and ontologies remains that of query answering. It is well-known that query is one of the things that make databases so powerful, and the related techniques of database queries have been investigated for many years. Also, querying is the fundamental mechanism for extracting information from a knowledge base. In the Semantic Web, the ontology layer is highly important, and has led to a vast corpus of literature. The ontology can provide a high-level conceptual view of the data repository, and specify implicit concepts and roles that extend the vocabulary of the database with terms that are relevant for specific applications (Ortiz & Simkus, 2012). When clients access the application ontology, the ontology can be exploited to access the data and to answer queries taking into account the knowledge that is implicit in the ontology. To this end, reasoning is of paramount importance when querying the implicit knowledge in the ontology. As we have known, description logics (DLs for short) (Baader, Calvanese, & McGuinness, 2003), as the logic foundation of the World Wide Web Consortium (W3C) recommendation Web Ontology Language (OWL), have a long tradition in knowledge representation and reasoning and play a central role in ontology reasoning. In these contexts, many works concerning query answering in ontologies refer in fact to DLs, which led to wide studies of answering queries over DL knowledge bases (KBs). Considering the different expressivity of the DLs and the trade-off between the expressivity of DLs and the complexity of their querying and reasoning problems, many query works focus on several different families of DLs, to name a few, the lightweight DLs of the DL-Lite (Calvanese et al., 2013, 2007) and $\mathscr{EL}$ (Baader, Brandt, & Lutz, 2005) families, and the families of expressive DLs (Ortiz, 2010). The references (Ortiz & Simkus, 2012) and (Ortiz, 2013) survey some query answering techniques for both lightweight and expressive DLs, and give an overview of the computational complexity landscape.

Being similar to the DLs, the basic query to be posed to ontologies or knowledge bases is instance checking, which determines whether a given individual is always an instance of a certain concept (i.e., whether this instance relationship is implied by the description of the individual and the definition of the concept). However, recently, the widening range of applications has led to extensive studies of answering queries over ontologies that require, beyond simple instance checking, to join pieces of information in finding the answer. In particular, a very well known query form is *Conjunctive Queries* (*CQs*), which originated from research in relational databases (Chandra & Merlin, 1977). Moreover, disjunctions of these queries are known as *Unions of Conjunctive Queries (UCQs)*, and are also popular. These languages have been widely studied in the area of databases, and, more recently, there has been increasing interest in the problem of querying ontologies. Driven by this need, the problems related to the CQs and UCQs for ontologies have been studied in the literature (Lutz, Toman, & Wolter, 2009; Calvanese et al., 2006, 2013; Orsi & Pieris, 2011; Gottlob, Orsi, & Pieris, 2011; Ortiz, 2013; Lutz, 2008; Ortiz & Simkus, 2012; Baader et al., 2005). Moreover, as we have known, in the context of the Semantic Web, much information may be represented by the data format RDF and its vocabulary description language RDF Schema. The main query languages adopted in Semantic Web consist of D2RQ, R2RML, RDQL, RQL, SeRQL,

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