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Personal View:

Local closed world reasoning: a personal view on current status and trends

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1 Introduction

In computer science and artificial intelligence, an ontology is a model of (some aspect of) the world that introduces the vocabulary of a particular domain, and specifies the meaning (semantics) of terms. Today's ontologies are based on the description logics (DLs). With the help of DL reasoners, implicit knowledge can be inferred from explicit knowledge in an ontology. Different from the relational database or logic programming, ontologies impose the open world assumption (OWA) instead of the closed world assumption (CWA). In CWA, a proposition will be regarded as false, if there is no evidence for it being true. While in OWA, a proposition will be regarded as false if and only if there is clear evidence for it being false. These two assumptions seem to contradict with each other. However, in real world applications, it is usually desired to combine OWA and CWA. For example, a restaurant should not close the class 'Vegetarian Customer' because whether a new customer is vegetarian or not is unknown to the restaurant unless explicitly asserted by the customer. Nevertheless, it can close the class 'Vegetarian Food Menu' because it has the complete knowledge about its own menus. This raises the challenge of doing local closed world reasoning (LCWR) with ontologies. In the following sections of this extended abstract, we review the state of the art regarding this topic. We also propose several emerging topics in this research area and discuss possible technical directions.

2 State of the art

LCWR has attracted many research attentions recently. We just mention a few proposals here.

Seylan *et al.* (2009) proposed the DBox approach to accommodate a database component in an ontology. A DBox consists of atomic class or property assertion axioms such as "Pepper Salad is Vegetarian Food". The extensions of predicates (classes and properties) that appear in DBox are bounded by the DBox, which means that besides their DBox instances they do not have any other instance. The predicates that do not appear in DBox remain open. However, the DBox has a limitation; i.e., inference regarding DBox predicates is prohibited in a sense that no new instance can be inferred.

Motik and Rosati (2010) adopted the epistemic operators used in MKNF (minimal knowledge and negation as failure) to model LCWR. This approach introduces a new operator called the K operator to indicate the things that we know in a knowledge base. For example, the class 'Koala' includes all the Koalas while the class 'K Koala' contains only the known Koalas in the knowledge base. Another new operator, not, is introduced to model NAF (negation as failure). Different from set complement, not is concerned only with the known facts; thus, a class 'not Koala' is equivalent to the complement of 'K Koala'. Therefore, a class can be closed by using the K and not operators on it. The limitation of this approach is that the introduction of two new operators can substantially increase the reasoning complexity.

Ren *et al*. (2010) proposed an NBox (short for NAF box) approach to explicitly deal with the closure of a particular vocabulary of an ontology. Different from the DBox, an NBox is a set of predicates. In reasoning, these predicates will be treated as closed in a sense that their extensions are equivalent to the set of their inferable instances. The other predicates will remain open. It has been shown that LCWR with NBox can be reduced to incremental reasoning: First reasoning without the NBox is performed to retrieve the instances for all the NBox predicates. Then the ontology is extended with the axioms defining NBox predicates with the sets of their inferred instances. On top of that, LCWR can be performed. The benefit is that inference of new instances of closed predicates can be realized. This reasoning procedure has been implemented in the TrOWL infrastructure (http://TrOWL.eu), which also allows users to specify the NBox before or during reasoning with annotation properties. As we can see, NBox LCWR requires support to enumerations (sets) in the ontology language. How it can be realized in a language that does not support enumeration remains an open issue.

Besides the above approaches, there are also many other related works such as grounded circumscription (Sengupta *et al*., 2011) and integrity constraints (Motik *et al*., 2009). Due to the limited space of this extended abstract we cannot elaborate more details but refer our readers to these papers.

3 Emerging topics

LCWR with ontologies have opened a new horizon for ontology applications:

1. Combining ontologies with relational databases. The inter-operability between relation databases and DL-based ontologies is one of the most interesting topics in ontology applications, especially for industrial audience. LCWR bridges one of the biggest gaps between legacy relational database systems and ontology based systems. With LCWR supported by reasoners, users can specify the closure of certain classes/properties so that the semantics of their database remains the same when they are combined with ontologies.

2. Ontology-based recommendation systems. Due to the semantics of the OWA, anything derived by legacy reasoning technologies must be absolutely true facts. Possible (i.e., not definite) solutions cannot be derived by reasoning because they are not logical implications of the ontology. With LCWR, a user can close the class of definitely wrong answers, and then its complement becomes the set of possible answers. Such a pattern can be widely applied in recommendation services, such as system configuration and repairing, diagnosis and matchmaking, etc.

3. Non-monotonic ontology reasoning. Classical ontology reasoning is monotonic in a sense that adding new knowledge into an ontology will not retract existing conclusions. However, with LCWR, non-monotonic reasoning is realized. It will be a very interesting research topic to investigate the relationship between LCWR and other non-monotonic reasoning services, and to develop theories that can provide a unified explanation for these services.

To sum up, a range of new applications can be incubated by the utilization of LCWR technologies, and the research work on these topics will have significant industrial and academic impacts.

4 Discussions

In the above section, we have pointed out several interesting topics for LCWR applications. To facilitate the wide acceptance of LCWR, ontology system developers and researchers will have to address different technical issues. For developers, it is crucial to know the pros and cons and tool support of each different LCWR solution and identify their own requirements, so that they can find out which solution is most suitable and available for them. For researchers it will be important to investigate the connections between different LCWR solutions and discover the possibility of using them complementarily to overcome the limitations of each other. Furthermore, new technologies should be developed with the collaboration of both communities to improve the user-friendliness of LCWR. Particularly, because LCWR is non-monotonic, it will be very important to help users understand how the ontology and reasoning results will be changed if they decide to close or open certain predicates. These are all future directions we will be looking into.

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