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Enhancing context knowledge repositories with justifiable exceptions ☆

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ABSTRACT

Dealing with context dependent knowledge is a well-known area of study that roots in John McCarthy's seminal work. More recently, the Contextualized Knowledge Repository (CKR) framework has been conceived as a logic-based approach in which knowledge bases have a two layered structure, modeled by a global context and a set of local contexts. The global context not only contains the meta-knowledge defining the properties of local contexts, but also holds the global (context independent) object knowledge that is shared by all of the local contexts. In many practical cases, however, it is desirable to leave the possibility to "override" the global object knowledge at the local level: in other words, it is interesting to recognize the pieces of knowledge that can admit exceptional instances in the local contexts that do not need to satisfy the general axiom. To address this need, we present in this paper an extension of CKR in which defeasible axioms can be included in the global context. The latter are verified in the local contexts only for the instances for which no exception to overriding exists, where exceptions require a justification in terms of facts that are provable from the knowledge base. We formally define this semantics and study some semantic and computational properties, where we characterize the complexity of the major reasoning tasks, among them satisfiability testing, instance checking, and conjunctive query answering. Furthermore, we present a translation of extended CKRs with knowledge bases in the Description Logic $\mathcal{SROIQ}$-RL under the novel semantics to datalog programs under the stable model (answer set) semantics. We also present an implementation prototype and examine its scalability with respect to the size of the input CKR and the amount (level) of defeasibility in experiments. Finally, we compare our representation approach with some major formalisms for expressing defeasible knowledge in Description Logics and contextual knowledge representation. Our work adds to the body of results on using deductive database technology such as SQL and datalog in these areas, and provides an expressive formalism (in terms of intrinsic complexity) for exception handling by overriding.

☆ Part of this work has been previously presented in preliminary form in [1–3].

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1. Introduction

In the field of Knowledge Representation and Reasoning, the problem of dealing with context dependent knowledge is a well-known area of study. Initial proposals for a formal definition of contextual knowledge and reasoning date back to the works of McCarthy [4], Lenat [5], and Giunchiglia et al. [6,7]. In the era of the Semantic Web (SW), representation of context dependent knowledge has been recognized as an extremely relevant issue, due to the necessity to qualify each data set with meta-data to allow users and applications to interpret the data set contents in the right context. This interest has led to a number of logic based proposals, e.g. [8–15]. In the current article we will extend one of the current formalisms, the *Contextualized Knowledge Repository (CKR) framework* [12,16,17], with its latest formulation in [1], with a new form of non monotonic reasoning based on justification.

A CKR knowledge base is a two-layer structure: the higher level consists of a global context; the lower level consists of a set of local contexts. For example, a CKR for a touristic recommendation system in the Trentino region,[1] is composed of a global context that describes all the locations, the venues and the events that are available in the region, and by a set of local contexts each of which describes the details of an event or the profile, interests and plans of a single user. The global context contains two types of knowledge: the former is composed by a context independent kernel of facts about the domain of discourse. The truth of these pieces of knowledge is assumed to be immutable; for instance, the fact that *Castello del Buonconsiglio* is located in *Trento*. This knowledge is accessible by all the local contexts. The second type of knowledge contained in the global context, is *meta-knowledge* specifying the properties of local contexts. Local contexts, on the other hand, contain knowledge that holds under specific circumstances or assumptions (e.g. during a certain period of time, or when a certain event occurs) and thus they represent different partial and perspective views of the domain. Knowledge in different contexts is not completely independent, as the global context independent knowledge is propagated from the global to the local contexts and it is used to constrain local knowledge in different contexts.

In many practical cases, however, it is desirable to leave the possibility to "override" the global object knowledge at the local level, by allowing axioms to admit *exceptions* in their local instantiations. For example, in the above scenario of the event recommendation system, we might want to assert at the global level that *"by default, all of the cheap events are interesting"*, but then override this implication for particular kind of events in the context of a specific participant. (e.g., a user might not be interested in sport events independently of their price). We might also want to express defeasibility on the propagation of information: for instance, in a CKR representing an organization, we might want to express that *"by default, all the employees of a year will be employees in the next year"* and override the axiom in the context of a specific year for employees that finished their working contract.[2] In other words, we want to allow certain global axioms to be *defeasible*, so that they admit exceptional instances in local contexts, while holding in the general case: this clearly requires to add a notion of *non-monotonicity* across the global and the local parts of a CKR.

The aim of this work is thus to extend the CKR framework in order to support the form of defeasibility for global object knowledge as described above, under some desiderata: (1) defeasibility should be used parsimoniously, in the sense that information is inherited as much as possible, such that the information loss in conclusions at the local level is as little as necessary; (2) overriding should be supported by clear evidence, in terms of facts that lead to a contradiction; and (3) reasoning with exceptions should be realized using deductive database technology, in particular SQL and datalog, that has been fostered for CKRs [1] in line with work around Description Logics [18–24].

To this end, we introduce defeasible axioms guided by the approach of inheritance logic programs in [25], extending the datalog representation of CKR semantics in [1]. In inheritance logic programs the idea is that special rules recognize exceptional facts at the local level and others propagate global facts only if they are not proved to be overridden at the local level, which happens if the opposite is derived; in the same vein, we consider instances of axioms that might be overridden at the local level. On the basis of this semantics, we develop a translation for CKRs on $\mathcal{SROIQ}$-RL (i.e. OWL-RL [26]) with defeasible axioms into datalog programs. Specifically, instance checking over a CKR reduces this way to (cautious) inference from such programs under the answer set semantics [27] (also known as stable model semantics [28]), which thus can be used to implement query answering for CKR with defeasibility.

The main contributions of this paper are briefly summarized as follows:

(1) We present a new syntax and semantics of an extension of CKR for *defeasible axioms* $\mathrm{D}(\alpha)$ in the global context. Notably, this allow us to introduce for the first time a notion of non-monotonicity across contexts in CKR (Section 3). Intuitively, a global defeasible axiom $\mathrm{D}(\alpha)$ means that, at the level of instantiations for individuals, α is inherited by local contexts unless it generates a contradiction in the local context knowledge base. Model based semantics of CKR needs thus to be extended in order to reason with exceptions for such axioms. Axiom instances $\alpha(\mathbf{e})$ representing local exceptions are called *clashing assumptions*: in the evaluation of α at a local context, its instantiation with $\mathbf{e}$ is not considered (i.e. α is "overridden" for $\mathbf{e}$). However, such assumptions of exceptions must be justified: the instance of α for $\mathbf{e}$ must be provable to be unsatisfiable at the local context. This is ensured if (atomic) assertions can be derived which prove this unsatisfiability; we call

[1] Cf. Examples 4 and 5 in Section 3.
[2] Cf. Example 6 in Section 3.