Enhancing Context Knowledge Repositories with Justifiable Exceptions
(Extended Abstract)*

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Abstract
The Contextualized Knowledge Repository (CKR) framework was conceived as a logic-based approach for representing context dependent knowledge, which is a well-known area of study in AI. The framework has a two-layer structure with a global context that contains context-independent knowledge and meta-information about the contexts, and a set of local contexts with specific knowledge bases. In many practical cases, it is desirable that inherited global knowledge can be “overridden” at the local level. In order to address this need, we present an extension of CKR with global defeasible axioms: these axioms locally apply to (tuples of) individuals unless an exception for overriding exists; such an exception, however, requires a justification that is provable from the knowledge base. We formalize this intuition and study its semantic and computational properties. Furthermore, we present a translation of extended CKRs to datalog programs under the answer set (i.e., stable) semantics and we present an implementation prototype. Our work adds to the body of results on using deductive database technology in these areas, and provides an expressive formalism for exception handling by overriding.

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 [1993], Lenat [1998], and Giunchiglia et al. [2001; 1994]. In the era of the Semantic Web (SW), the representation of context dependent knowledge has been recognized as an extremely relevant issue, due to the need for equipping data sets with meta-data in order to enable users and applications to interpret the data contents in the right context. This interest has led to a number of logic based proposals, e.g. [Brewka and Eiter, 2007; Khriyenko and Terziyan, 2006; Klarman, 2013; Serafini and Homola, 2012; Straccia et al., 2010]. In this paper, we extend the Contextualized Knowledge Repository (CKR) framework [Serafini and Homola, 2012; Bozzato et al., 2012; 2013] in its latest formulation in [Bozzato and Serafini, 2013], with a new form of non-monotonic reasoning based on justification.

2 CKR Knowledge Bases
A CKR knowledge base is a two-layer structure: the upper layer consists of a global context, while the lower layer consists of a set of local contexts.

For example, a CKR for a touristic recommendation system in the Trentino region is depicted in Figure 1: it is composed of a global context that describes all locations, venues and events that are available in the region, and of a set of local contexts each of which describes the details of an event (e.g. a football match), a local market, or the profile, interests and plans of a single user (e.g. a certain tourist).

The global context of a CKR contains knowledge of two kinds: (i) a context-independent kernel of facts and axioms about the domain of discourse (or global object knowledge), and (ii) meta-knowledge specifying the properties and struc-

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tural relationships of contexts, which may be arranged in a con-
text hierarchy. As regards (i), the truth of the pieces of knowl-
edge in the kernel is assumed to be indisputable; for instance, the
fact isLocatedIn(CastelloDelBuonconsiglio, Trento) or City(Rovereto). This knowledge is accessible by all local
contexts. As regards the meta-knowledge in (ii), given that
events are viewed as contexts, we may e.g. assert that sports
events are events (SportsEvent ⊆ Event), that the football
match event is a sports event (SportsEvent(fbmatch)) and that
the football match and local market events are low-priced
events (CheapEvent(fbmatch), CheapEvent(market)). An
axiom Event ∈ 3mod[m_event] may express that each event
is associated with axioms of a knowledge module m_event
for events. Knowledge modules are pieces of (object level)
information that can be associated either to single context or
contexts classes.

Local contexts, on the other hand, contain knowledge
that holds under specific circumstances or assumptions and
thus they represent different partial and views of the do-
main in perspective. In our example, local axioms may
represent knowledge that is valid during a certain event
(e.g. HomeTeam(trento) in the event fbmatch) or in the
local preferences of a certain user (e.g. CulturalEvent ⊆
InterestingEvent in the knowledge of tourist01). Knowledge
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.

3 Motivation and Aim

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 \( \theta \) that “by default, all cheap events are interesting”
(i.e. CheapEvent ⊆ InterestingEvent), but then override this
implication for particular kind of events in the context of a
specific participant: for instance, tourist01 can state to not be
interested in the football match, independently of its price
by locally asserting \( \neg \text{InterestingEvent(fbmatch)} \). 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.

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 (e.g. since InterestingEvent(market) is
not locally contradicted, we want that this conclusion of
the global defeasible axiom holds locally);

2. overriding should be supported by clear evidence, in terms
of facts that lead to a contradiction (e.g. in our example, the
local assertion \( \neg \text{InterestingEvent(fbmatch)} \));

3. reasoning with exceptions should be realized using de-
ductive database technology, in particular SQL and dat-
alogue, that has been fostered for CKRs [Bozzato and Ser-
afini, 2013] in line with work around Description Logics
[Motik et al., 2005; Calvanese et al., 2007; Krötzsch, 2010;
Krötzsch et al., 2010; Kontchakov et al., 2010; Eiter et al.,
2012; Ahmetaj et al., 2016].

To this end, we introduce defeasible axioms inspired by the
approach of inheritance logic programs in [Buccafurri et al.,
1999] and extend the datalog representation of CKR semantics
in [Bozzato and Serafini, 2013]. In inheritance logic programs
the idea is that special rules recognize exceptional facts at the
department 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 formu-
lated in the Description Logics SROIQ, which in essence
underlies OWL-RL [Motik et al., 2009], with defeasible ax-
ioms into datalog programs under the answer set semantics
[Gelfond and Lifschitz, 1991]. Specifically, instance checking
over a CKR reduces this way to (cautious) inference from an-
swer set programs which thus can be exploited to implement
query answering for CKR with defeasibility.

4 Main Contributions

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

CKR extension with defeasible global axioms. We present
a new syntax and semantics of an extension of CKR for de-
feasible axioms \( D(\alpha) \) in the global context (in our example above, \( \alpha = \text{CheapEvent} \subseteq \text{InterestingEvent} \)). Notably, this allows us
to introduce for the first time a notion of non-monotonicity
across contexts in CKR. Intuitively, a global defeasible axiom
\( D(\alpha) \) means that, at the level of instantiations for individuals,
the axiom \( \alpha \) is inherited by local contexts unless it gener-
ates a contradiction in the local context knowledge base. The
model based semantics of CKR needs thus to be extended
in order to reason with exceptions for such axioms. Axiom
instances \( \alpha(e) \) representing local exceptions are called clash-
ing assumptions: in the evaluation of \( \alpha \) at a local context, its
instantiation with \( e \) is not considered (i.e. \( \alpha \) is “overridden”
for \( e \)). In our example, we could have \( e = fbmatch \) for \( \alpha \) at
the context tourist01. However, such assumptions of exceptions
must be justified: the instance of \( \alpha \) for \( e \) must be provably
unsatisfiable at the local context, given the contents of the
context local knowledge base. This is ensured if (atomic)
assertions can be derived locally which entail this unsatisfiability:
we call such assertions clashing sets. In our example, \( S = \{ \text{CheapEvent(fbmatch)}, \neg \text{InterestingEvent(fbmatch)} \} \)
would be such a clashing set. As such, CKR interpretations are thus
extended with a set of the local clashing assumptions $\text{CAS}$ and called $\text{CAS}$-interpretations. Intuitively, $\text{CAS}$-interpretations interpret local axioms by disregarding exceptional instances contained in $\text{CAS}$. Then, $\text{CKR}$ models can be defined as those $\text{CAS}$-models that are justified, i.e., provide a reason for the presence of each clashing assumption in $\text{CAS}$ by verifying some corresponding local clashing set (in our example, the set $S$ above). As it turns out justified $\text{CAS}$-models involve minimal sets of clashing assumptions; that is, exceptions are used, in the spirit of Occam’s razor, as little as necessary.

**Reasoning.** We characterize reasoning in $\text{CKR}$ with defeasible axioms, where we consider entailment of axioms and conjunctive queries (CQs) for a specific context or all contexts of a $\text{CKR}$. More in detail, we derive semantic characterizations of justified clashing assumptions in terms of least models via fixpoint-constructions. Armed with them, we study the computational complexity of major reasoning tasks. In particular, we show that justified $\text{CAS}$- and $\text{CKR}$-model checking are feasible in polynomial time. On the other hand, satisfiability is NP-complete in general (and NP-hardness holds even if the contextual structure is fixed). Under data complexity, entailment of axioms is coNP-complete while answering conjunctive queries is $\Pi^p_2$-complete, with lower complexity for restricted inputs: in particular, CQ answering is tractable in the case of acyclic CQs over $\text{CKR}$s that contain no defeasible axioms.

**Datalog translation.** We extend the datalog translation for $\text{CKR}$s based on $\text{SROIQ-RL}$ from [Bozzato and Serafini, 2013] with rules for the translation of defeasible axioms and for considering local exceptions in the propagation of such knowledge. We express non-monotonicity using answer set semantics, such that instance checking over a $\text{CKR}$ with defeasible axioms reduces to cautious inference from all answer set of the translation, and likewise conjunctive query answering. In particular, we note that the proposed translation (based on positive datalog programs) is non-trivial and checking the derivability of negative knowledge in clashing sets (as $\neg \text{InterestingEvent(fbmatch)}$ in our example) needs special attention (in particular, the presence of negative disjunctive information), as a naive extension of a materialization calculus to negative literals fails. To overcome this problem, we develop a translation in which derivation of negative knowledge is accomplished by encoding proofs by contradiction, using a special set of “test” rules in the translation. In our example, to check whether $\neg \text{InterestingEvent(fbmatch)}$ is derivable, we add $\text{InterestingEvent(fbmatch)}$ hypothetically to the knowledge base and test whether a contradiction would be derivable. We show that the proposed translation provides a sound and complete materialization calculus for instance checking and conjunctive query answering on $\text{CKR}$s formulated in $\text{SROIQ-RL}$ (i.e., in OWL-RL). We briefly discuss the possibility of a more direct encoding where the test mechanism can be omitted by assuming a suitable notion of justification safeness.

**Datalog translation prototype $\text{CKRew}$.** We have developed a prototype implementation, called $\text{CKRew}$ ($\text{CKR}$ datalog Rewriter) that compiles a $\text{CKR}$ (represented in terms of OWL-RL RDF files) to a datalog program following the presented translation. We present the prototype and we study its behavior with respect to different sizes of the input $\text{CKR}$ and percentage of defeasible axioms. In particular, the experiments confirm that scalability of the approach is influenced by the percentage of defeasible axioms in the initial $\text{CKR}$ and the number of their exceptional instances. The prototype and test sets are freely distributed for use, replication of experiments and possible comparison with other similar implementations: the prototype and test sets used in the experiments are online available at http://ckrew.fbk.eu/.

## 5 Context and Related Work

The contributions of this work are interesting in general for the area of (logic based) Knowledge Representation: our solution proposes an expressive means for combining reasoning with structured Description Logics knowledge bases (viz. contextualized Semantic Web knowledge bases) with a notion of axiom overriding. As such, our work can be compared not only with respect to approaches to incorporate defeasibility in contextualized logics (e.g. [Bikakis and Antoniou, 2010]), but also to solutions for introducing non-monotonic reasoning in Description Logics (e.g., [Giordano et al., 2013; Bonatti et al., 2015]). In our work we provide an extended comparison of our approach with some of the major non-monotonic formalisms for description logics and contextual knowledge representation, highlighting commonalities and differences. In particular, our work differs from these formalisms with respect to some relevant aspects:

- our approach allows to reason with non-monotonic features in modular knowledge bases under an expressive language corresponding to a standard ontology language (cf. [Bikakis and Antoniou, 2010]);
- in case of conflicts across possible overridings, it does not request or elicit a preference on possible interpretations, but it presents—in line with the ASP paradigm—alternatives as different models, thus allowing to “reason by cases” on the conflicting solutions: in particular, reasoning by cases in the well-known Nixon Diamond scenario can be properly handled (cf. [Bikakis and Antoniou, 2010; Bonatti et al., 2015]);
- the definition of model is not defined by minimization, but through the idea of justification of exceptions which is based on semantic consequence (cf. for example [Giordano et al., 2013]). In particular, no “normal” members of a concept are defined, but instead single or tuples of individuals are regarded as “exceptional” with respect to defeasible axioms: this allows us to deal with inheritance of properties at the level of instances (cf. [Bonatti et al., 2015]);
- we provide a translation to datalog that is a direct extension of the materialization calculus approach proposed for the monotonic case in [Bozzato and Serafini, 2013] and shows how modular knowledge can be encoded for non-monotonic reasoning using existing tools.

## 6 Summary and Conclusion

In conclusion, our work contributes to the body of work extending formalisms based on description logics, where the
use of database technology such as datalog have an important role in ongoing improvements that can be exploited by the resulting reasoning systems.

As for future work, it is possible to explore new solutions both in the computational and modelling directions.

Regarding computation, in order to increase the practical applicability of the defeasible CKRs to larger sets of data, the current translation and its implementation need optimization: some possibilities are represented by the study of alternative datalog translations limiting the need for materialization or the use of different reasoning approaches. One possible direction is to limit the use proofs by contradiction for negative knowledge in clashing sets to CKRs that are not “safe” with respect to a direct reasoning about negative facts; preliminary results identify some syntactic classes of “justification safe” knowledge bases.

On the modeling side, an interesting direction is to allow defeasible axioms across local contexts, possibly along an explicit hierarchical relation between contexts (as by the coverage relation in [Serafini and Homola, 2012]). Allowing local defeasible axioms also opens the discussion on how defeasible knowledge import across contexts should be defined, thus allowing a notion of “defeasible propagation” of knowledge across local contexts. Another direction would be to allow local inconsistencies in contexts, similarly to defeasible MCS [Bikakis and Antoniou, 2010].

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References


