Local Closed World Semantics: Keep it simple, stupid!

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Abstract. A combination of open and closed-world reasoning (usually called local closed world reasoning) is a desirable capability of knowledge representation formalisms for Semantic Web applications. However, none of the proposals made to date for extending description logics with local closed world capabilities has had any significant impact on applications. We believe that one of the key reasons for this is that current proposals fail to provide approaches which are intuitively accessible for application developers and at the same time are applicable, as extensions, to expressive description logics such as $\mathcal{SROIQ}$, which underlies the Web Ontology Language OWL.
In this paper we propose a new approach which overcomes key limitations of other major proposals made to date. It is based on an adaptation of circumscriptive description logics which, in contrast to previously reported circumscription proposals, is applicable to $\mathcal{SROIQ}$ without rendering reasoning over the resulting language undecidable.

Keywords: description logic, closed world, circumscription, decidability

1 Introduction

The semantics of the Web Ontology Language OWL [16] (which is based on the description logic $\mathcal{SROIQ}$ [17]) adheres to the Open World Assumption (OWA). This means that statements which are *not* logical consequences of a given knowledge base are not necessarily considered false. The OWA is reasonable in a World Wide Web context (and thus for Semantic Web applications), however situations naturally arise where it would be preferable to use the Closed World Assumption (CWA), that statements which are *not* logical consequences of a given knowledge base are always considered false. The CWA is applicable, e.g., when data is being retrieved from a database, or if data can otherwise be considered *complete* with respect to the application at hand (see, e.g., [14, 34]).

As a consequence, efforts have been made to combine OWA and CWA modeling for the Semantic Web (see Section 4), and knowledge representation languages which have both OWA and CWA modeling features are said to adhere to the *Local Closed World Assumption* (LCWA). Most of these combinations are derived from non-monotonic logics which have been studied in logic programming [18] or on first-order predicate logic [28, 29, 35]. Furthermore, many of them

have a *hybrid* character, meaning that they achieve the LCWA by combining, e.g. description logics with (logic programming) rules.

Of the approaches which provide a seamless (non-hybrid) integration of OWA and CWA, there are not that many, and each of them has its drawbacks. This is despite the fact that the modeling task, from the perspective of the application developer, seems rather simple: Users would want to specify, simply, that individuals in the extension of a predicate should be exactly those which are *necessarily required* to be in the extension, i.e., extensions should be *minimized*. Thus, what is needed for applications is a simple, intuitive approach to closed world modeling, which can be easily picked up by application developers.

Among the primary approaches to non-monotonic reasoning, there is exactly one approach which employs the minimization idea in a very straightforward and intuitively simple manner, namely *circumscription* [28]. However, a naive transfer of the circumscription approach to description logics, which was done in [4, 5, 15], appears to have three primary drawbacks.

1. The approach is undedicable for expressive description logics (e.g., for the description logic $\mathcal{SROIQ}$) unless awkward restrictions are put in place. More precisely, it is not possible to have non-empty TBoxes plus minimization of roles if decidability is to be retained.
2. Extensions of minimized prediates can still contain elements which are not named individuals (or pairs of such, for roles) in the knowledge base, which is not intuitive for modeling (see also [14]).
3. Complexity of the approach is very high.

The undecidability issue (point 1) hinges, in a sense, also on point 2 above. In this paper, we provide a modified approach to circumscription for description logics, which we call *grounded circumscription*, which remedies both of points 1 and 2. We are not yet addressing the complexity issue; this will be done in future work. Our idea is simple yet effective: we modify the circumscription approach from [4, 5, 15] by adding the additional requirement that extensions of minimized predicates may only contain named individuals (or pairs of such, for roles). In a sense, this can be understood as porting a desirable feature from (hybrid) MNKF description logics [9, 20, 21, 32] to the circumscription approach. In another (but related) sense, it can also be understood as employing the idea of DL-safety [33], respectively of DL-safe variables [24] or nominal schemas [22, 23].

Note that we do not claim that our approach is the only road to take—we rather view it as one step on the quest of designing suitable LCWA languages for the Semantic Web. Indeed, we mainly intend to highlight that there is a plethora of methods how to obtain local closed world versions of description logics (and thus of OWL), see e.g. [25, 26], and all of them are potential alternatives to the *big three* (circumscription [28], autoepistemic logic [29], and default logic [35]). The Semantic Web community needs a systematic investigation of options for modeling local closed world aspects, which are not ideologically bound to approaches which have been developed for different purposes in the KR community.

The paper is structured as follows. In Section 2 we introduce the semantics of grounded circumscription. In Section 3 we show that the resulting language is

decidable. In Section 4 we discuss related work, and conclude with a discussion of further work in Section 5.

2 Grounded Circumscription

We now describe a very simple way for ontology designers to model local closed world aspects in their ontologies: simply use a description logic (DL) knowledge base (KB) as usual, and augment it with *meta*-information which states that some predicates (concept names or role names) are *closed*. Semantically, those predicates are considered minimized, i.e. their extensions contain only what is absolutely required, and furthermore only contain *known* (or *named*) individuals, i.e., individuals which are explicitly mentioned in the KB. In the case of concept names, the idea of restricting their extensions only to known individuals is similar to the notion of nominal schema [23] (and thus, DL-safe rules [24, 33]) and also the notion of DBox [38], while the minimization idea is borrowed from circumscription [28], one of the primary approaches to non-monotonic reasoning.

In the earlier efforts to carry over circumscription to DLs [4, 5, 14, 15], circumscription is realized by the notion of *circumscription pattern*. A circumscription pattern consists of three disjoint sets of predicates (i.e., concept names and role names) which are called *minimized*, *fixed* and *varying* predicates, and a preference relation on interpretations. The preference relation allows us to pick *minimal* models as the *preferred* models with respect to inclusion of the extension of the minimized predicates.

Our formalism simplifies the circumscription approach by restricting our attention to models in which the extension of the minimized predicates may only contain known individuals from the KB. Moreover, we divide predicates in the KB only into two disjoint sets of minimized and non-minimized predicates.[1] The non-minimized predicates would be viewed as varying in the more general circumscription formalism mentioned above.

Let N_C, N_r, and N_I be disjoint, countably infinite sets of *concept names*, *role names*, and *individual names*, resp. Let $\mathcal{L}$ be a standard description logic whose concepts and roles are formed based on the signature that consists of N_C, N_R, and N_I, together with a set of standard DL (concept and role) constructors [2]. The only non-standard DL constructor that is needed in this paper is the role constructor *concept product*, written $C \times D$ with C, D concepts in $\mathcal{L}$, which allows a role to be constructed from the Cartesian product of two concepts [23, 37]. In addition, we define an $\mathcal{L}$-*KB* as a set of concept inclusion axioms $C \sqsubseteq D$ where $C, D \in \mathsf{N}_C$, role inclusion axioms $r \sqsubseteq s$ where $r, s \in \mathsf{N_r}$, and assertions of the form $C(a)$ and $r(a, b)$ where $C \in \mathsf{N}_C, r \in \mathsf{N}_r$ and $a, b \in \mathsf{N}_I$.

The semantics for $\mathcal{L}$ is defined in terms of *interpretations* $\mathcal{I} = (\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$ where $\Delta^{\mathcal{I}}$ is a non-empty set called the *domain* and $\cdot^{\mathcal{I}}$ is an *interpretation function*

[1] Fixed predicates can be simulated in the original circumscriptive DL approach if negation is available, i.e., for fixed class names, class negation is required, while for fixed role names, role negation is required. The latter can be added to expressive DLs without jeopardizing decidability [23, 40].

that maps each concept name to a subset of $\Delta^{\mathcal{I}}$, each role name to a subset of $\Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$ and each individual name to an element of $\Delta^{\mathcal{I}}$. An interpretation $\mathcal{I}$ is extended to complex concepts and roles in the usual way for $\mathcal{L}$, and for concept products, $(C \times D)^{\mathcal{I}} = \{(x, y) \mid x \in C^{\mathcal{I}}, y \in D^{\mathcal{I}}\}$. We say that $\mathcal{I}$ *satisfies* (*is a model of*): a concept inclusion axiom $C \sqsubseteq D$ if $C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$; a role inclusion axiom $r \sqsubseteq s$ if $r^{\mathcal{I}} \subseteq s^{\mathcal{I}}$; a concept assertion $C(a)$ if $a^{\mathcal{I}} \in C^{\mathcal{I}}$; and a role assertion $r(a, b)$ if $(a^{\mathcal{I}}, b^{\mathcal{I}}) \in r^{\mathcal{I}}$. We also say that $\mathcal{I}$ *satisfies* (*is a model of*) an $\mathcal{L}$-KB K if it satisfies every axioms in K.

The non-monotonic feature of the formalism is given by restricting models of an $\mathcal{L}$-KB such that the extension of closed predicates may only contain individuals (or pairs of them) which are explicitly occurring in the KB, plus a minimization of the extensions of these predicates. We define a function Ind that maps each $\mathcal{L}$-KB to the set of individual names it contains, i.e., given an $\mathcal{L}$-KB K, $\mathsf{Ind}(K) = \{b \in \mathsf{N}_I \mid b \text{ occurs in } K\}$. Among all possible models of K that are obtained by the aforementioned restriction to $\mathsf{Ind}(K)$, we then select a model that is minimal w.r.t. concept inclusion or role inclusion.

Definition 1. *A* GC-$\mathcal{L}$-knowledge base *(KB)—GC stands for* grounded circumscription*—is a pair (K, M) where K is an $\mathcal{L}$-KB and $M \subseteq \{A \in \mathsf{N}_C \mid A \text{ occurs in } K\} \cup \{r \in \mathsf{N}_r \mid r \text{ occurs in } K\}$. For every concept name and role name $W \in M$, we say that W is* closed with respect to K. *For any two models $\mathcal{I}$ and $\mathcal{J}$ of K, we furthermore say that $\mathcal{I}$ is* smaller than $\mathcal{J}$ w.r.t. M, *written $\mathcal{I} \prec_M \mathcal{J}$, iff all of the following hold: (i) $\Delta^{\mathcal{I}} = \Delta^{\mathcal{J}}$ and $a^{\mathcal{I}} = a^{\mathcal{J}}$ for every $a^{\mathcal{I}} \in \Delta^{\mathcal{J}}$; (ii) $W^{\mathcal{I}} \subseteq W^{\mathcal{J}}$ for every $W \in M$; and (iii) there exists a $W \in M$ such that $W^{\mathcal{I}} \subset W^{\mathcal{J}}$*

We now define models of GC-$\mathcal{L}$-KBs as follows.

Definition 2. *An interpretation $\mathcal{I}$ is a* GC-model *of a GC-$\mathcal{L}$-KB (K, M) if all of the following hold: (i) $\mathcal{I}$ is a model of K; (ii) for each concept name $A \in M$, $A^{\mathcal{I}} \subseteq \{b^{\mathcal{I}} \mid b \in \mathsf{Ind}(K)\}$; (iii) for each role name $r \in M$, $r^{\mathcal{I}} \subseteq \{b^{\mathcal{I}} \mid b \in \mathsf{Ind}(K)\} \times \{b^{\mathcal{I}} \mid b \in \mathsf{Ind}(K)\}$; and (iv) $\mathcal{I}$ is minimal w.r.t. M, i.e., there is no model $\mathcal{J}$ of K such that $\mathcal{J} \prec_M \mathcal{I}$.*

The notion of logical consequence is defined as usual: An axiom α is a logical consequence (a *GC-inference*) of a given GC-$\mathcal{L}$-KB (K, M) if and only if α is true in all GC-models of (K, B).

Our formalism here is inspired by one of the approaches described by Makinson in [26], namely restricting the set of valuations to get more logical consequences than what we can get as classical consequences. Intuitively, this approach is a simpler version of the circumscription formalism for DLs as presented in [5, 15] in the sense that concept names and role names are either varying or minimized, i.e., no predicate is considered fixed. Indeed, every GC-model of a KB is also a circumscriptive model,[2] hence every circumscriptive inference is also a valid GC-inference.

[2] This can be seen, e.g., by a straightforward proof by contradiction.

To give an example, consider the knowledge base K consisting of the axioms

$$\texttt{hasAuthor}(\texttt{paper1}, \texttt{author1}) \qquad \texttt{hasAuthor}(\texttt{paper1}, \texttt{author2})$$
$$\texttt{hasAuthor}(\texttt{paper2}, \texttt{author3}) \qquad \top \sqsubseteq \forall \texttt{hasAuthor}.\texttt{Author}.$$

Then $(\leq 2\ \texttt{hasAuthor}.\texttt{Author})(\texttt{paper1})$ is not a logical consequence of K under the classical description logic semantics. However, if we assume that we have complete information on authorships relevant to the application under consideration, then it would be reasonable to *close* parts of the knowledge base in the sense of the LCWA. In the original approach to circumscriptive DLs, we could close the class name `Author`, but to no avail. But if we close `hasAuthor`, we obtain $(\leq 2\ \texttt{hasAuthor}.\texttt{Author})(\texttt{paper1})$ as a logical consequence. However, closure of roles in the original circumscriptive DL approach leads to undecidability [5]. The GC-semantics, in contrast, is decidable even under role closure (see Section 3 below), and also yields the desired inferences.

Are there inferences which hold with respect to the GC-semantics but not with respect to the original circumscriptive DL approach? There are, but it seems difficult to find a *convincing* example which might indicate practical relevance. If this is indeed the case, then we could argue that the original circumscriptive approach is too sceptical with respect to application requirements, in addition to the decidability issue already noted.

The following is an *academic* example, adapted from [15], which shows the different inferencing capabilities of the GC-semantics versus the original circumscriptive DL semantics. Consider the knowledge base K_1 consisting of the following axioms, where `EndangeredSpecies` is a minimized class name.

$$\texttt{Bear}(\texttt{polarBear})$$
$$\exists \texttt{isHabitatFor}.(\texttt{Bear} \sqcap \texttt{EndangeredSpecies})(\texttt{arcticSea})$$

In the original circumscriptive DL approach, there is a model in which the extensions of both `Bear` and `EndangeredSpecies` share a common element distinct from `polarBear`, hence it cannot be concluded that `polarBear` is an `EndangeredSpecies`. Under the GC-semantics, however, this can be concluded. This is due to the fact that there are no individuals other than `polarBear` in the knowledge base. Indeed, if we assume that there is another individual, say, `blueWhale`, then the conclusion no longer holds even under the GC-semantics.

Is the conclusion under the GC-semantics desirable, that `polarBear` is an `EndangeredSpecies`? We believe so, because we are essentially restricting our world to one individual. I.e., if we would like to reject the conclusion, we should rather question the adequacy of our modeling, than of the semantics. However, this discussion seems to be quite academic, since the situation above is not that of a realistic knowledge base, where we could reasonably assume the presence of other individuals, such as `blueWhale`, such that the arguable inference no longer holds even with respect to the GC-semantics.[3] And indeed it should not hold

[3] The situation might be different with respect to knowledge bases *under development*, but this would rather be an interface issue.

in this case under an intuitive reading of the knowledge base: If there is also a second individual `blueWhale`, then we have no reason to assume that it must be `polarBear` which is an `EndangeredSpecies` (unless, of course, we also state that `blueWhale` must not be a `Bear`).

3 Decidability Considerations

As noted earlier, circumscription in many expressive DLs is undecidable [5]. Undecidability even extends to the basic DL $\mathcal{ALC}$ when non-empty TBoxes are considered and roles are allowed as minimized predicates. Such a bleak outlook would greatly discourage useful application of circumscription, despite the fact that there is a clear need of such a formalism to model LCWA.

Our formalism aims to fill this gap by offering a simpler approach to circumscription in DLs that is decidable provided that the underlying DL is also decidable. The decidability result is obtained due to the imposed restriction of minimized predicates to known individuals in the KB as specified in Definition 2. Let $\mathcal{L}$ be any standard DL. We consider the following reasoning task of *GC-KB satisfiability*: "given a GC-$\mathcal{L}$-KB (K, M), does (K, M) have a GC-model?" and show in the following that this is decidable. Note that other basic reasoning tasks can usually be reduced to this task [5, 15].

Assume that $\mathcal{L}$ is any (standard) DL, e.g., $\mathcal{ALCOB}(\times)$, featuring nominals, concept disjunction, concept products and role disjunctions.[4] We show that GC-KB satisfiability in $\mathcal{L}$ is decidable if satisfiability in $\mathcal{L}$ is decidable.

Let (K, M) be a GC-$\mathcal{L}$-KB. We assume that $M = M_A \cup M_r$ where $M_A = \{A_1, \ldots, A_n\}$ is the set of minimized concept names and $M_r = \{r_1, \ldots, r_m\}$ is the set of minimized role names. Now define a family of $(n + m)$-tuples as

$$\mathcal{G}_{(K,M)} = \{(X_1, \ldots, X_n, Y_1, \ldots, Y_m) \mid X_i \subseteq \mathsf{Ind}(K), Y_j \subseteq \mathsf{Ind}(K) \times \mathsf{Ind}(K)\}$$

with $1 \leq i \leq n, 1 \leq j \leq m$. Note that there are

$$\left(2^{|\mathsf{Ind}(K)|}\right)^n \cdot \left(2^{\mathsf{Ind}(K)^2}\right)^m = 2^{n \cdot |\mathsf{Ind}(K)| + m \cdot |\mathsf{Ind}(K)|^2} \tag{1}$$

of such tuples; in particular note that $\mathcal{G}_{(K,M)}$ is a finite set.

Now, given (K, M) and some $G = (X_1, \ldots, X_n, Y_1, \ldots, Y_m) \in \mathcal{G}_{(K,M)}$, let K_G be the $\mathcal{L}$-KB consisting of all axioms in K together with all of the following axioms, where the A_i and r_j are all the predicates in M—note that we require role disjunction and concept products for this.

$$A_i \equiv \bigsqcup \{a\} \quad \text{for every } a \in X_i \text{ and } i = 1, \ldots, n$$
$$r_j \equiv \bigsqcup (\{a\} \times \{b\}) \quad \text{for every pair } (a, b) \in Y_j \text{ and } j = 1, \ldots, m$$

Then the following result clearly holds.

[4] For concept products, see [23]—they can be eliminated if role constructors are available. For role disjunctions, see [40], where it is shown, amongst other things, that $\mathcal{ALCQIOB}$ is decidable.

Lemma 1. *Let (K, M) be a GC-$\mathcal{L}$-KB. If (K, M) has a GC-model $\mathcal{I}$, then there exists $G \in \mathcal{G}_{(K,M)}$ such that K_G has a (classical) model $\mathcal{J}$ which coincides with $\mathcal{I}$ on all minimized predicates. Likewise, if there exists $G \in \mathcal{G}_{(K,M)}$ such that K_G has a (classical) model $\mathcal{J}$, then (K, M) has a GC-model $\mathcal{I}$ which coincides with $\mathcal{J}$ on all minimized predicates.*

Observe that class disjunction, nominals, concept products, and role disjunction are needed to obtain Lemma 1. From [40] we know that adding role disjunction to $\mathcal{ALCQIO}$ retains decidability. Now consider the set

$$\mathcal{G}'_{(K,M)} = \{G \in \mathcal{G}_{(K,M)} \mid K_G \text{ has a (classical) model}\},$$

and note that this set is finite and computable in finite time since $\mathcal{G}_{(K,M)}$ is finite and $\mathcal{L}$ is decidable. Furthermore, consider $\mathcal{G}'_{(K,M)}$ to be ordered by the pointwise ordering $\prec$ induced by $\subseteq$. Note that the pointwise ordering of the finite set $\mathcal{G}'_{(K,M)}$ is also computable in finite time.

Lemma 2. *Let (K, M) be a GC-$\mathcal{L}$-KB and let*

$$\mathcal{G}''_{(K,M)} = \{G \in \mathcal{G}'_{(K,M)} \mid G \text{ is minimal in } (\mathcal{G}'_{(K,M)}, \prec)\}.$$

Then (K, M) has a GC-model if and only if $\mathcal{G}''_{(K,M)}$ is non-empty.

Proof. This follows immediately from Lemma 1 together with the following observation: Whenever K has two GC models $\mathcal{I}$ and $\mathcal{J}$ such that $\mathcal{I}$ is smaller than $\mathcal{J}$, then there exist $G_\mathcal{I}, G_\mathcal{J} \in \mathcal{G}'_{(K,M)}$ with $G_\mathcal{I} \prec G_\mathcal{J}$ such that $K_{G_\mathcal{I}}$ and $K_{G_\mathcal{J}}$ have (classical) models $\mathcal{I}'$ and J', respectively, which coincide with $\mathcal{I}$, respectively, $\mathcal{J}$, on the minimized predicates.

Theorem 1. *GC-KB-satisfiability is decidable.*

Proof. This follows from Lemma 2 since the set $\mathcal{G}''_{(K,M)}$, for any given GC-KB (K, M), can be computed in finite time, i.e., it can be decided in finite time whether $\mathcal{G}''_{(K,M)}$ is empty.

Some remarks on complexity are as follows. Assume that the problem of deciding KB satisfiability in $\mathcal{L}$ is in the complexity class C. Observe from equation (1) that there are exponentially many possible choices of the $(n+m)$-tuples in $\mathcal{G}_{(K,M)}$ (in the size of the input knowledge base). Computation of $\mathcal{G}'_{(K,M)}$ is thus in $\textsc{Exp}^{\text{C}}$, and subsequent computation of $\mathcal{G}''_{(K,M)}$ is also in Exp. We thus obtain the following upper bound.

Proposition 1. *GC-KB satisfiability is in $\textsc{Exp}^{C}$, where C is the complexity class of the DL under consideration.*

Observe that the decidability proof gives rise to a straightforward implementation procedure, however this is certainly not a smart algorithm. As future work, it should be possible to adjust the tableaux algorithm from [15], which may also give rise to a sharpening of the upper bound on complexity.

4 Related Work

In this paper we have presented a new approach to DL reasoning under the Local Closed World Assumption (LCWA). There are several approaches described in the literature for LCWA which combine the OWA and CWA semantics, and in the following we briefly discuss some of the most important proposals.

Autoepistemic Logic [29, 30] is an approach followed by a number of authors. The semantics of autoepistemic logic have been defined using an autoepistemic operator **K** [7, 8] and has been studied for $\mathcal{ALC}$ and also for more expressive DLs. [7, 9] further provide an epistemic operator **A** related to negation-as-failure which allows for the modeling of default rules and integrity constraints.

Circumscription [28] is another approach taken to develop LCWA extentions of DLs [5, 14, 15]. [5] evaluates the complexities of reasoning problems in variations of DLs with circumscription. [14] provides examples to stress the importance of LCWA to provide an intuitive notion of matchmaking of resources in the context of Semantic Web Services. [15] provides an algorithmization for circumscriptive $\mathcal{ALCO}$ by introducing a preferential tableaux calculus, based on previous work on circumscription [4]. [19] proves a method to eliminate fixed predicates in circumscription patterns by adding negation of fixed predicates to the minimized set of predicates.

Some significant proposals involve the use of hybrid MKNF knowledge bases [32] which are based on an adaptation of the Stable Model Semantics [12] to knowledge bases consisting of ontology axioms and rules, thereby combining both open world and closed world semantics. A variant of this approach using the well-founded semantics, i.e., with a lower complexity, has also be presented [20, 21], and algorithms and implementations have been developed [1, 13].

[10] takes a hybrid approach to combine ontologies and rules by keeping the semantics of both parts separate, but also at the same time allowing for building rules on top of ontologies and vice versa with some limitations, again following the Stable Model Semantics. [11] provides a related well-founded semantics.

Some of the work related to LCWA also involves the use of integrity constraints (ICs) and of the Unique Name Assumption (UNA). An approach extending OWL ontologies to add ICs such that it adds non-montonicity to the DL is [31]. [39] provides semantics for OWL axioms to allow for IC and UNA to achieve local closed world reasoning.

In [38], the notion of *DBox* is introduced. A DBox consists of a set of (atomic) assertions such that the extension of a DBox predicate under any interpretation is exactly as defined by this set of assertions. In a sense, grounded circumscription encompasses this expressive feature but goes beyond it, while, as expected, loosing some of the desirable features of the more specialized DBox approach.

There are a number of other approaches which have been attempted in the past, but without follow-up work, e.g. [3, 6, 27, 36]. For some further pointers to the literature, please refer to [22].

5 Conclusion and Outlook

We have provided a new approach for incorporating the LCWA into description logics. Our approach, grounded circumscription, is a variant of circumscriptive description logics which avoids two major issues of the original approach: Extensions of minimized predicates can only contain named individuals, and we retain decidability even for very expressive description logics while we can allow for the minimization of roles.

A primary theoretical task is to investigate the complexity of our approach, but it can be expected that it is not going to be worse than the previous circumscription proposal. In fact, lower complexities should result in some cases, which may yield to tractable or data-tractable fragments.

Likewise, it should be possible to adapt the tableaux algorithm for circumscriptive description logics from [15] to our setting, and there may even be more efficient procedures.

From a more general perspective, it should be worthwhile to investigate further alternatives for incorporating closed world modeling into description logics. Preferably, one would like to obtain a language which is intuitively very simple, appeals to ontology engineers, and is computationally effective. Whether such a language exists, however, is an open question.

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