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DISSERTATION AND HABILITATION ABSTRACTS

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Abstract

The present paper is a summary of a habilitation (*Habilitation à Diriger des Recherches*, in French), which has been perused and evaluated by a committee composed by the following members: Franz Baader, Stéphane Demri, Hans van Ditmarsch, Sébastien Konieczny, Pierre Marquis, Marie-Laure Mugnier, Odile Papini and Leon van der Torre. It was defended on 26 November 2019 at Université d'Artois in Lens, France.

Keywords Knowledge representation and reasoning · Formal ontologies · Description logic · Defeasible reasoning · Preferential semantics · Rationality

1 Introduction

Description logics (DLs) are a family of logic-based knowledge representation formalisms with useful computational properties and a variety of applications across several disciplines. In particular, DLs are well-suited for representing and reasoning about terminological knowledge and therefore they stand as the formal foundations of ontologies.

Since their inception in the early '80s, there has been a sustained research focus on DLs. Indeed, many extensions and fragments of the basic description languages have been investigated and powerful DL-based algorithms exist for performing a variety of reasoning tasks over ontologies. Examples of these are the extraction of information implicitly contained in the specification of a given domain of application and the pinpointing of logical errors therein.

The success of description logics as formal languages for representing ontologies is evidenced by the decision by the World Wide Web Consortium to base the Web Ontology Language OWL (https://www.w3.org/OWL) on a description logic. This has resulted in an increasing number of ontologies being represented in OWL and its variants.

Notwithstanding the good trade-off between expressive power and computational complexity that they enjoy, DLs remain fundamentally classical formalisms inasmuch as they are good at formalising how to reason under ideal circumstances, e.g. the type of unquestionable reasoning we perform when doing classical metamathematics. Nevertheless, it is equally important to be able to reason when these ideal circumstances are not met, in human quotidian as well as formal abstract contexts. This involves, for example, the presence of conflicting information and the supposition of certain facts as provisional (and therefore revisable), among many others. Situations such as these are often encountered in human everyday reasoning and therefore they also show up in the knowledge about the domains one is likely to represent through ontologies. On the other hand, it is widely acknowledged that classical reasoning is unsuitable to cope with such issues. Certain principles, properties or idiosyncrasies of classical logic—which, by the way, DLs inherit—make perfect sense in an ideal setting, but they are hard to justify or to accommodate to everyday-life situations, as the following example from the access-control domain shows:

Assume we know that employees have access to classified documents, that interns are also considered as employees, and that John has access to classified info. Represented as classical statements, the addition of the information that interns do not have access to classified documents leads to the undesirable consequence that interns do not exist since, being employees, they have to have access to documents that are classified, contradicting the explicit statement that they do not have such access. Of course, the intention here is not

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to state that employees necessarily have access to classified information, but rather the defeasible knowledge that they usually do, leaving open the possibility that there may be exceptions (such as interns). Unfortunately, it turns out that classical representational formalisms such as DLs do not allow for handling defeasibility.

Another important issue at stake when reasoning with ontologies is the inability of the underlying reasoning mechanism to (i) under lack of information, venture beyond the knowledge base and still draw tentative relevant conclusions, and (ii) upon incoming information, overrule, i.e., ‘forget’, some of the conclusions that used to be sanctioned, if needed. For instance, in the example above, a sensible conclusion to draw would be that John is an employee. This should be retracted upon learning that he does not work for any company. To use a technical term commonly adopted in the literature, there is a need for the underlying reasoning mechanism to behave in a non-monotonic way.

In this regard, endowing DLs and their associated reasoning services with the ability to cope with defeasibility is a natural step in their development. Even if some of the issues related to uncertainty in reasoning have been studied using probabilistic approaches and statistical methods, their qualitative computational nature remains a large avenue for exploration. Indeed, the past 30 years have witnessed many attempts to introduce defeasible reasoning capabilities in Description Logics. These range from preferential approaches [6, 13, 15, 16, 19] to circumscription-based ones [3, 4, 20], amongst others [1, 14, 17, 18, 21]. These and other recent developments in the field show that DLs still allow for meaningful, decidable extensions, as new knowledge representation requirements are identified, motivated by philosophical as well as practical needs.

2 Introducing Defeasibility in DL Ontologies

In a sense, class subsumption (alias concept inclusion) of the form $C \sqsubseteq D$ is the main notion in DL ontologies. Given its implication-like intuition, subsumption lends itself naturally to defeasibility. A defeasible concept inclusion (DCI) of the form $C \sqsubset\!\!\sim D$ is read as “usually, an instance of the class C is also an instance of the class D”. An example of DCI is $\mathsf{Employee} \sqsubset\!\!\sim \exists\mathsf{hasAcc.Classified}$ (usually, employees have access to classified documents).

Our starting point in the study of defeasibility in DL ontologies was an investigation of the properties that $\sqsubset\!\!\sim$ ought to satisfy in order to be deemed as an appropriate form of defeasible subsumption. In that respect, we have put forward a set of syntactic properties (sometimes also referred to as postulates) that are DL versions of properties commonly accepted in the non-monotonic reasoning literature. The important point here is that such properties are explainable to and understandable by human users and capture in a formal and unambiguous way the expected behaviour of $\sqsubset\!\!\sim$.

The semantic constructions providing an unambiguous meaning to $\sqsubset\!\!\sim$ are based on the idea that objects of the domain of interpretation can be ordered according to their degree of normality or typicality. Given that, we enrich standard DL interpretations with an ordering $\prec$ on the elements of the domain. An enriched interpretation satisfies a DCI $C \sqsubset\!\!\sim D$ if the elements in the interpretation of C that are minimal w.r.t. $\prec$ are also in the interpretation of D, i.e., if the most normal Cs are also Ds.

Our first technical contribution includes representation results linking our semantic constructions to the above mentioned set of properties considered. These results show that our proposal provides an appropriate and intuitive semantics for the notion of defeasible subsumption encapsulated by $\sqsubset\!\!\sim$.

We then turn to the problem of defeasible reasoning at the level of entailment. We start by analysing two basic forms of logical consequence in the context of defeasible DLs and show their unsuitability in a general non-monotonic setting. We then provide a definition of a form of defeasible entailment that is suitable and present an algorithm for the computation of the rational closure [13] of a defeasible ontology. Importantly, the algorithm relies completely on classical DL entailment and shows that the computational complexity of reasoning over basic defeasible ontologies is no worse than that of reasoning in the underlying classical DL $\mathcal{ALC}$.

3 Typicality for Classes and Relationships

Of particular interest in a non-monotonic context is the ability to express and reason about a notion of typicality (or normality, or expectations). And, as already argued in the propositional case [5], being able to do so explicitly in the language brings in many advantages from the standpoint of knowledge representation. In a DL setting, this need is mainly felt when checking whether a given individual is a typical instance of a class or whether a pair of individuals is a typical instance of a given role, or some combination involving both.

It turns out that the aforementioned issue has only partially been addressed in the literature on non-monotonic reasoning in that explicit notions of typicality for concepts have been introduced [2, 15], but of which the use in logical statements has to adhere to certain syntactic constraints. To the best of our knowledge, a framework for full-fledged typicality in concepts and, important, also in roles has not been developed before.

With this motivation in mind, we introduced a logic allowing for the representation of and reasoning about both typical class-membership and typical instances of a relation [22]. We do so by enriching the description logic $\mathcal{ALCH}$

with a *typicality operator* •, applicable to both concepts and roles, and of which the intuition is to capture the most typical instances of a class or a relation. As an example, the concept description $\bullet\mathsf{Employee} \sqcap \exists\bullet\mathsf{hasAcc}.\neg\bullet\mathsf{Classified}$ describes the class of individuals who are typical employees having a typical access to an atypical classified document.

We have defined a semantics for our enriched language in terms of structures allowing not only for objects of the domain to be ordered according to their degree of typicality but also for pairs of objects to be comparable in such a way. Given that, the extension of the concept $\bullet C$ in such interpretations is given by the minimal objects in the interpretation of C, and that of the role $\bullet r$ corresponds to the minimal pairs taking part in the binary relation associated with r. One of the consequences of the new semantic definitions is that every DCI of the form $C \mathrel{\underset{\sim}{\sqsubset}} D$ can be reduced to a •-based classical subsumption of the form $\bullet C \sqsubseteq D$.

The main technical contribution in this thread of investigation is the definition of a tableau-based algorithm for checking consistency of knowledge-bases specified in our typicality-based DL. In particular, we show that the algorithm always terminates and that it is sound and complete w.r.t. our proposed semantics.

4 Defeasible Class Constructs and Context

Given the special status of subsumption in DLs in particular and the historical importance of entailment in logic in general, the bulk of the effort in formalising defeasibility has quite naturally been put in the definition of accounts of defeasible subsumption and in the characterisation of notions of defeasible entailment relations. Therefore, in a sense, there has been too much focus on defeasibility of 'implication-like' statements, whereas other facets of defeasibility, possibly at the object level, have somewhat been neglected by the defeasible reasoning community. As it turns out, there are contexts where the ability to express nuances of defeasibility other than that of conditionals is desirable [7, 10, 11].

In that respect, we have investigated a notion of defeasibility that is complementary to defeasible subsumption, namely that of relativised role defeasibility. Our motivation stems essentially from the observation that a given relationship holding between some objects may be deemed more normal than between others and that this may be the case irrespective of whether the relevant objects are typical in one way or another. Such an observation can then be used to determine the relevance of certain relationships when evaluating role-based concept constructs.

Indeed, classical value restrictions of the form $\forall r.C$ constrain objects (in its interpretation) to those that are related by r only to objects in C. This requirement can be (and, in practice, often is) too strong. For instance, consider the concept $\forall\mathsf{worksFor}.\mathsf{Company}$. An individual who works for a company but is also a freelancer after hours would not belong to this class, even though we may want to include such an individual when referring to workers whose 'normal' working relationship is with companies. The typicality operators sketched in Sect. 3 above constitute a first-step in this direction. Nevertheless, it is not hard to see that the concepts $\bullet\forall\mathsf{worksFor}.\mathsf{Company}$, $\forall\mathsf{worksFor}.\bullet\mathsf{Company}$, and $\forall\bullet\mathsf{worksFor}.\mathsf{Company}$ mean something quite different from the intuition we want to convey here.

In order to single out cases such as the aforementioned one, while still being able to draw conclusions on what is typically the case about an individual's relationship, we have made a case for defeasible value restrictions of the form $\tilde{\forall} r.C$ [8]. Intuitively, $\tilde{\forall}\mathsf{worksFor}.\mathsf{Company}$ should cater for the example above.

The semantics of the enriched language draws on that for typicality of roles sketched in Sect. 3. A concept of the form $\tilde{\forall} r.C$ is then interpreted as the class of all objects whose most normal r-links are with objects in the interpretation of C.

We then move on by introducing contextual defeasible subsumptions of the form $C \mathrel{\underset{\sim}{\sqsubset}}_r D$, in which the role name r serves as a primitive notion of context. This simple addition to the expressivity of the language suddenly allows for a more fine-grained formalisation of domains in which typicality (and atypicality) depends on a particular context. We show that contextual defeasible subsumption can be given an elegant semantics in terms of multiple orderings on objects induced from those on the respective roles [12].

The main technical contribution of this thread of investigation is two-fold: first, we have defined a tableau-based algorithm for checking consistency of contextual defeasible knowledge bases, a central piece in the definition of other forms of contextual defeasible reasoning over ontologies; second, we provide a semantic construction for contextual rational closure as well as a method for its computation, with a correspondence result linking the two.

5 Defeasible $\mathcal{SROIQ}$

Finally, we investigate the foundations of highly-expressive defeasible description logics. We do so by introducing several defeasible-reasoning constructs into $\mathcal{SROIQ}$, the most expressive DL that is still decidable and the one on which the Web Ontology Language OWL is based.

We start by enriching $\mathcal{SROIQ}$ with non-monotonic concept constructors in the concept language and defeasible statements at the knowledge-base level, along the lines of those described in the previous sections. We also introduce the notion of defeasible role inclusion of the form $r \mathrel{\underset{\sim}{\sqsubset}} s$, a natural counterpart of our DCIs and to date never explored in the literature. Furthermore, we investigate defeasibility of role assertions, a feature of expressive DLs allowing for the specification of role properties such as functionality, transitivity, disjointness and many others that are useful from a knowledge representation perspective.

As it turns out, our preference-based semantic constructions are fruitful in providing an appropriate semantics for the resulting defeasible DL $d\mathcal{SROIQ}$ [9]. We show that reasoning over $d\mathcal{SROIQ}$ ontologies can be done via a translation of entailment to concept satisfiability relative to a subset of the defeasible knowledge base. We then define a tableau-based proof method for deciding on consistency of $d\mathcal{SROIQ}$-concepts w.r.t. our preferential semantics.

6 Concluding Remarks

We have addressed the problem of modelling and reasoning in the presence of defeasibility in ontologies, and emphasised how fruitful the preferential approach can be when applied to rich logical languages. The several DL-based formalisms that we have designed enjoy the following features: They are simple and intuitive; they all have a neat syntax and a clean semantics; they are amenable to implementation; they are all decidable, and they do not add to the computational complexity of the classical description language they build on. The innovation of the research endeavour here summarised relies mostly in the investigation of nuances of reasoning hitherto largely unexplored by the community and in the quest for a comprehensive framework for multifarious defeasible reasoning in DL ontologies.

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References

1. Baader F, Hollunder B. How to prefer more specific defaults in terminological default logic. In: Bajcsy R, editor. Proceedings of the 13th international joint conference on artificial intelligence (IJCAI). USA: Morgan Kaufmann Publishers; 1993. pp 669–675
2. Bonatti P, Faella M, Petrova IM, Sauro L (2015) A new semantics for overriding in description logics. Artif Intell 222:1–48
3. Bonatti P, Faella M, Sauro L (2011) Defeasible inclusions in low-complexity DLs. J Artif Intell Res 42:719–764
4. Bonatti P, Lutz C, Wolter F (2009) The complexity of circumscription in description logic. J Artif Intell Res 35:717–773
5. Booth R, Meyer T, Varzinczak I. A propositional typicality logic for extending rational consequence. In: Fermé EL, Gabbay DM, Simari GR, editors, Trends in belief revision and argumentation dynamics. vol 48 of Studies in logic–Logic and cognitive systems. King's College Publications; 2013. pp 123–154.
6. Britz K, Meyer T, Varzinczak I. Semantic foundation for preferential description logics. In: Wang D, Reynolds M, editors. Proceedings of the 24th Australasian joint conference on artificial intelligence, number 7106 in LNAI. Berlin: Springer; 2011. pp 491–500.
7. Britz K, Varzinczak I (2013) Defeasible modalities. In: Proceedings of the 14th conference on theoretical aspects of rationality and knowledge (TARK). pp 49–60
8. Britz K, Varzinczak I. Introducing role defeasibility in description logics. In: Michael L, Kakas AC, editors. Proceedings of the 15th European conference on logics in artificial intelligence (JELIA), number 10021 in LNCS. Berlin: Springer; 2016. pp 174–189.
9. Britz K, Varzinczak I. Toward defeasible *SROIQ*. In: Proceedings of the 30th international workshop on description logics; 2017.
10. Britz K, Varzinczak I (2018) From KLM-style conditionals to defeasible modalities, and back. J Appl Non-Classical Logics (JANCL) 28(1):92–121
11. Britz K, Varzinczak I (2018) Preferential accessibility and preferred worlds. J Logic Lang Inf (JoLLI) 27(2):133–155
12. Britz K, Varzinczak K. Rationality and context in defeasible subsumption. In: Ferrarotti F, Woltran S, editors. Proceedings of the 10th international symposium on foundations of information and knowledge systems (FoIKS), number 10833 in LNCS. Berlin: Springer; 2018. pp 114–132.
13. Casini G, Straccia U. Rational closure for defeasible description logics. In: Janhunen T, Niemelä I, editors. In: Proceedings of the 12th European conference on logics in artificial intelligence (JELIA), number 6341 in LNCS. Berlin: Springer-Verlag; 2010. pp 77–90.
14. Donini FM, Nardi D, Rosati R (2002) Description logics of minimal knowledge and negation as failure. ACM Trans Comput Logic 3(2):177–225
15. Giordano L, Gliozzi V, Olivetti N, Pozzato GL (2007) Preferential description logics. In N. Dershowitz and A. Voronkov, editors, *Logic for Programming, Artificial Intelligence, and Reasoning (LPAR)*, number 4790 in LNAI, pages 257–272. Springer
16. Giordano L, Gliozzi V, Olivetti N, Pozzato GL (2013) A non-monotonic description logic for reasoning about typicality. Artif Intell 195:165–202
17. Heymans S, Vermeir D (2002) A defeasible ontology language. In: Meersman R, Tari Z, editors, CoopIS/DOA/ODBASE, number 2519 in LNCS. Berlin: Springer; 2002. pp 1033–1046.
18. Padgham L, Zhang T. A terminological logic with defaults: a definition and an application. In: Bajcsy R, editor, Proceedings of the 13th international joint conference on artificial intelligence (IJCAI). Morgan Kaufmann Publishers; 1993. pp 662–668.
19. Quantz J, Royer V. A preference semantics for defaults in terminological logics. In: Proceedings of the 3rd International conference on principles of knowledge representation and reasoning (KR). 1992. pp 294–305.
20. Sengupta K, Alfa Krisnadhi A, Hitzler P. Local closed world semantics: grounded circumscription for OWL. In: Aroyo L, Welty C, Alani H, Taylor J, Bernstein A, Kagal L, Noy N, Blomqvist E, editors. Proceedings of the 10th international semantic web conference (ISWC), number 7031 in LNCS. Berlin: Springer; 2011. pp 617–632.
21. Straccia U (1993) Default inheritance reasoning in hybrid KL-ONE-style logics. In R. Bajcsy, editor, *Proceedings of the 13th International Joint Conference on Artificial Intelligence (IJCAI)*, pages 676–681. Morgan Kaufmann Publishers
22. Varzinczak IJ (2018) A note on a description logic of concept and role typicality for defeasible reasoning over ontologies. Logica Universalis 12(3–4):297–325