LiFR: A Lightweight Fuzzy DL Reasoner

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Abstract. In this paper we present LiFR, a lightweight DL reasoner capable of performing in resource-constrained devices, that implements a fuzzy extension of Description Logic Programs. Preliminary evaluation against two existing fuzzy DL reasoners and within a real-world use case has shown promising results.

1 Introduction

Managing vague and imprecise knowledge is a common requirement in many real-world application domains. For this purpose, several fuzzy DLs extensions to classical DLs [1] have been proposed [9,10] and alongside, a number of reasoners for very expressive fuzzy DLs have been implemented, including FiRE[1] [13], FuzzyDL[2] [4] and DeLorean [3]). Furthermore, a number of optimisation techniques have been proposed recently for improving reasoning efficiency for very expressive fuzzy DLs [5,12]. However, many applications require less expressive DLs and would benefit from trading the full expressivity of the language for reasoning efficiency. For instance in location- and context-aware applications that run in resource-constrained devices, like smartphones, tablets, set-top boxes etc., computational efficiency and scalability would enable decision-making to take place either on the server-side or on the end-device, thereby also enhancing privacy preservation.

To this scope, this paper presents LiFR (Sect. 2), a lightweight fuzzy DL reasoner that supports a subset of fuzzy Description Logics Programs (*f-DLP*) [15]. Section 3 discusses preliminary evaluation results, while future directions are given in Sect. 4.

2 LiFR Semantics, Syntax and Reasoning Services

LiFR[3] is a lightweight fuzzy DL reasoner that supports *f-DLP*. It extends Pocket KRHyper [6], a (crisp) first order model generator for last-generation mobile

[1] http://www.image.ece.ntua.gr/~nsimou/FiRE/
[2] http://nemis.isti.cnr.it/~straccia/software/fuzzyDL/fuzzyDL.html
[3] Maintained at http://mklab.iti.gr/project/lifr

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devices that performs DL reasoning by translating DL axioms to first order clauses and by using the hyper-tableaux calculus [2]. Fuzzy DLs extend classical DLs by interpreting concepts and roles as fuzzy sets of individuals and binary relations respectively. The crisp set operations intersection, union and implication, are extended to fuzzy sets and performed by t-norm, t-conorm and implication functions respectively [7], providing corresponding semantics.

LiFR implements the operators of Zadeh fuzzy logic (Table 1), namely the minimum t-norm, the maximum t-conorm and the Kleene-Dienes implication ($\Rightarrow_{KD}$), and provides in addition support for weighted concept modifiers as introduced in [4]. Currently fuzzy assertions are restricted to concepts only and role assertions are treated as crisp with an imposed membership degree of $\geq$1.0. Its syntax (Table 2) is a variant of the Knowledge Representation System Specification (KRSS) proposal [11], rendering it significantly more lightweight compared to other specifications (e.g. RDF/XML serialisation), thus enhancing the capability of performing in resource-constrained devices.

Table 1. LiFR semantics.

Syntax	Semantics
C $\sqsubseteq$ D	C$^I(x) \Rightarrow_{KD} D^I(x)$
C $\sqcap$ D	min(C$^I(x)$, D$^I(x)$)
C $\sqcup$ D	max(C$^I(x)$, D$^I(x)$)
$\exists$ R.C	$\sup_{y \in \Delta^I} \{min(R^I(x,y), C^I(y))\}$
$\forall$ R.D	$\inf_{y \in \Delta^I} \{R^I(x,y) \Rightarrow_{KD} C^I(y)\}$
w $\cdot$ C	C$^I(x)$ $\cdot$w
$\langle \alpha : C \geq d \rangle$	C$^I(\alpha^I)$ $\geq$d
$\langle \alpha, \beta \rangle$:R	R^I $(\alpha^I, \beta^I) \geq 1.0$

Table 2. LiFR syntax.

DL syntax	LiFR syntax
$\top$	TOP
$\perp$	BOTTOM
$C \sqsubseteq D$	(IMPLIES C D)
$C \equiv D$	(EQUIVALENT C D)
$C \sqcap D$	(AND C D)
$C \sqcup D$	(OR C D)
$C \sqcap D \sqsubseteq \perp$	(DISJOINT C D)
$\exists R.C$	(SOME R C)
$\forall R.D$	(ALL R C)
$w \cdot C$	(WEIGHT C w)
$S \sqsubseteq R$	(ROLE R :PARENT S)
$R^- \equiv S$	(ROLE R :INVERSE S)
R^+	(ROLE R :TRANSITIVE)
$\langle \alpha : C \geq d \rangle$	(INSTANCE a C $\geq$ d)
$\langle \alpha, b : R \rangle$	(RELATED a b R)

Given a fuzzy DL knowledge base Σ, LiFR currently supports the following reasoning services: (i) *satisfiability checking*, i.e. whether there exists a fuzzy interpretation I that satisfies all axioms in Σ, (ii) *fuzzy entailment*, i.e. whether every model of Σ satisfies τ, where τ is an axiom of the form $C(\alpha) \geq d$, (iii) *concept subsumption*, i.e. whether every model of Σ satisfies $C^I(x) \leq D^I(x)$ $\forall x \in \Delta^I$, and (iv) *greatest lower bound* (GLB), defined as the sup$\{ \alpha : \Sigma \models \langle \tau \geq \alpha \rangle \}$ where τ is an axiom of the form $C(\alpha) \geq d$. GLB is one of the most important and interesting reasoning services in fuzzy DLs, as it enables to determine which is the greatest degree that Σ entails an individual α to participate in a concept C. Extending Pocket KRHyper, LiFR's default reasoning service consists in the generation of all models that satisfy the input fuzzy knowledge base, thereby providing native support for the computation of the *global GLB*, i.e. the GLB for all combinations of individuals and concepts.

3 Evaluation

LiFR's performance was evaluated against fuzzyDL and FiRE on several sets of randomly generated assertions using the LinkedTV User Model Ontology (LUMO)[4][14], as demonstrated in Table 3[5].

Table 3. Time performance and memory consumption of LiFR, FiRE and FuzzyDL on *global GLB* calculation.

Individuals	Time (ms)			Memory (MB)		
	LiFR	*FuzzyDL*	*FiRE*	*LiFR*	*FuzzyDL*	*FiRE*
20	189	38458	47538	10.00	59.07	67.95
50	192	169875	318228	92.42	181.19	252.80
100	332	596292	665721	137.28	206.36	274.27
250	923	4955568	3137765	169.26	268.23	386.82
500	2015	23239036	6316162	191.64	294.75	474.02
1000	4208	>12 h	12260563	239.93	N/A	515.12

LiFR's reasoning services are currently employed within the LinkedTV EU project[6], primarily for personalized content and concept filtering and for mappings retrieval among ontologies, while supplementary it is used in several tasks, such as topic detection within content and user preferences. To this scope, as part of an evaluation experiment, it was called to label a dataset of 970 media content items with topics from the reference LUMO ontology, ranked by the membership degree of each topic belonging to a media item.

The content items were annotated with ∼500–2500 DBPedia [8] entities (individuals) along with their types (concepts) from the DBpedia ontology. In most cases these types represented agents, events, locations and objects, of which existing counterparts in LUMO are related to certain topics by axioms of the sort $Type \sqsubseteq \forall has(Sub)Topic.Topic$, where $Type$ is the concept in the annotation and $Topic$ is subsumed by the $Topics$ concept/category of LUMO. The process involved running three distinct reasoning services per content item: (1)*entailment* based on the LUMO mappings[7] TBox, in order to map DBPedia types

[4] http://data.linkedtv.eu/ontologies/lumo/: 804 atomic concepts, 6 roles, >200 complex concepts.

[5] Due to time restrictions, FuzzyDL was terminated for the 1000 instances case after it exceeded 12 h of processing without rendering results.

[6] http://www.linkedtv.eu/

[7] http://data.linkedtv.eu/ontologies/lumo_mappings/: 1309 concepts.

to LUMO concepts; (2) *global GLB* calculation within the LUMO TBox, based on the assertions retrieved in the previous step as the ABox per content item (main task); (3) Iterative *subsumption* check for each of the predicates in the produced model against the LUMO *Topics* concept, to retrieve from the entirety of the predicates in the produced model, the ones that are subsumed by *Topics*, thus are actually topics. The time performance of LiFR for this experiment is portrayed in Fig. 1.

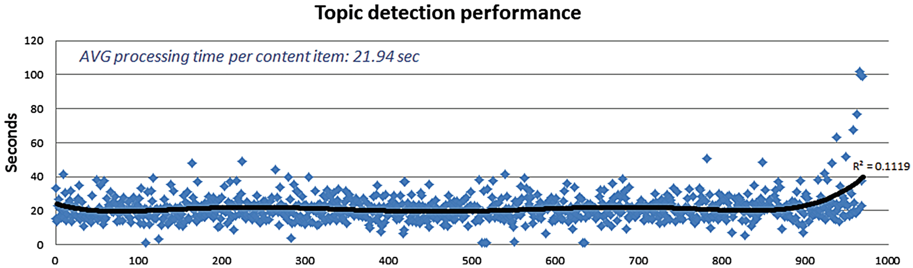

Fig. 1. LiFR's time performance for topic detection. Points denote each content item's processing time. The line shows the polynomial trendline (order of 6) of the data points.

4 Conclusions and Future Work

In this paper, we presented LiFR, a lightweight fuzzy DL reasoner that implements a fuzzy extension of DLP. A preliminary evaluation shows that LiFR is capable of performing in limited-resource devices. In future work, we plan to extend LiFR to support the OWL 2 RL profile and develop a benchmark for a more detailed evaluation and comparison with other fuzzy DLs reasoners.

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