Rewriting the Description Logic $\mathcal{ALCHIQ}$ to Disjunctive Existential Rules

David Carral and Markus Krötzsch

Knowledge-Based Systems Group

TECHNISCHE UNIVERSITÄT DRESDEN

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Definition

Consider fragments $\mathcal{L}$ and $\mathcal{L}'$ of FOL. An $\mathcal{L}'$-theory $\mathcal{T}'$ is a *rewriting* of an $\mathcal{L}$-theory $\mathcal{T}$ if, for all fact sets $\mathcal{F}$ over the signature of $\mathcal{T}$, we have that $\mathcal{T} \cup \mathcal{F}$ and $\mathcal{T}' \cup \mathcal{F}$ are equisatisfiable.
If we can always compute such a rewriting, $\mathcal{L}$ is *rewritable* to $\mathcal{L}'$.

Motivation

- Theoretical: understand the expressivity of FOL fragments.
- Practical: reuse existing reasoners across FOL fragments.
  - Assume that $\mathcal{L}$ is rewritable to $\mathcal{L}'$.
  - Consider $\mathcal{T} \cup \mathcal{F}$ with $\mathcal{T}$ an $\mathcal{L}$-theory and $\mathcal{F}$ a fact set.
  - Compute an equisatisfiable theory $\mathcal{T}' \cup \mathcal{F}$ with $\mathcal{T}' \in \mathcal{L}'$.
  - Use an $\mathcal{L}'$-reasoner to decide if $\mathcal{T}' \cup \mathcal{F}$ is satisfiable.
  - The result determines whether $\mathcal{T} \cup \mathcal{F}$ is satisfiable.

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Motivation

- Theoretical: understand the expressivity of FOL fragments.
- Practical: reuse existing reasoners across FOL fragments.

Contribution

Establish that $\mathcal{ALCHIQ}$ is rewritable into rule-based languages.

The DL $\mathcal{ALCHIQ}$: Syntax and Semantics

Definition: $\mathcal{ALCHIQ}$

$A \sqcap B \sqsubseteq C$	$A(x) \wedge B(x) \rightarrow C(x)$
$A \sqsubseteq B \sqcup C$	$A(x) \rightarrow B(x) \vee C(x)$
$A \sqsubseteq \forall R.B$	$A(x) \wedge R(x,y) \rightarrow B(y)$
$A \sqsubseteq \exists R.B$	$A(x) \rightarrow \exists y.R(x,y) \wedge B(y)$
$A \sqsubseteq \leqslant 1\, R.B$	$A(x) \wedge R(x,y) \wedge B(y) \wedge R(x,z) \wedge B(z) \rightarrow y \approx z$
$R \sqcap S \sqsubseteq V$	$R(x,y) \wedge S(x,y) \rightarrow V(x,y)$
$R \sqsubseteq S \sqcup V$	$R(x,y) \rightarrow S(x,y) \vee V(x,y)$
$R^{-} \sqsubseteq S$	$R(y,x) \rightarrow S(x,y)$

In the above, A, B, and C are unary predicates (i.e., concept names) and R, S, and V are binary predicates (i.e., role names)

Definition

A *disjunctive existential rule* is a FOL formula of the form

$$\forall \vec{x}. \left(\beta[\vec{x}] \rightarrow \bigvee_{i=1}^{n} \exists \vec{y}_i . \eta_i[\vec{x}_i, \vec{y}_i] \right).$$

where $\beta[\vec{x}]$ and $\eta_i[\vec{x}_i, \vec{y}_i]$ are atom conjunctions using variables in the lists $\vec{x}_{(i)}$ and $\vec{y}_i$, such that $\vec{x}_i \subseteq \vec{x}$ and $\vec{x} \cap \vec{y}_i = \emptyset$ for all $1 \leq i \leq n$.

Definition

- Datalog$^{\vee\exists}$: all sets of disjunctive existential rules.
- *Datalog*$^{\exists}$: Datalog$^{\vee\exists}$ without disjunction.
- *Datalog*$^{\vee}$: Datalog$^{\vee\exists}$ without existential quantifiers.
- *Datalog*: Datalog$^{\vee}$ without disjunctions.

Rewritings of DL-Type Logics to Rule Languages

[Hustadt et al., 2007]	$\mathcal{ALCHIQ}$	Datalog$^\vee$	exp.	†
[Eiter et al., 2012]	Horn-$\mathcal{SHIQ}$	Datalog	exp.	†
[Rudolph et al., 2012]	$\mathcal{SHIQ}b_s$	Datalog$^\vee$	exp.	†
[Bienvenu et al., 2014]	$\mathcal{SHI}$	Datalog$^\vee$	exp.	†
[Carral et al., 2018]	Horn-$\mathcal{ALCHOIQ}$	Datalog	exp.	†
[Carral et al., 2019b]	Horn-$\mathcal{SHIQ}$	Datalog	exp.	†
[Ortiz et al., 2010]	Horn-$\mathcal{ALCHOIQ}$	Datalog	poly.	
[Ahmetaj et al., 2016]	$\mathcal{ALCHIO}$	Datalog$^\vee$	poly.	
[Krötzsch, 2011]	$\mathcal{EL}^{++}$	Datalog	poly.	†
[Carral et al., 2019a]	Horn-$\mathcal{ALC}$	Datalog$^\exists$	poly.	†

†: rules of bounded size that does not depend on input

Remark

All rewriting techniques for expressive DLs produce rule sets of exponential size or rules of unbounded arity.

Theorem 1

$\mathcal{ALCHIQ}$ is poly-time rewritable into terminating Datalog$^{\vee\exists}$ rules **of bounded size**.

Definition: Terminating Datalog$^{\vee\exists}$

Language of all sets $\mathcal{R}$ of disjunctive existential rules that terminate with respect to the Datalog-first restricted chase.

Theorem 2

$\mathcal{ALCHIQ}$ is poly-time rewritable to Datalog$^{\vee}$ rules (of unbounded size).

Simplified Theorem

$\mathcal{ALC}$ is poly-time rewritable into terminating Datalog$^{\vee\exists}$ rules of bounded size.

Definition: $\mathcal{ALC}$

$A \sqcap B \sqsubseteq C$	$A(x) \wedge B(x) \rightarrow C(x)$
$A \sqsubseteq B \sqcup C$	$A(x) \rightarrow B(x) \vee C(x)$
$A \sqsubseteq \forall R.B$	$A(x) \wedge R(x, y) \rightarrow B(y)$
$A \sqsubseteq \exists R.B$	$A(x) \rightarrow \exists y.R(x, y) \wedge B(y)$

In the above, A, B, and C are unary predicates (i.e., concept names) and R is a binary predicate (i.e., role name)

Definition: $\mathcal{ALC}$ Rewritings

Consider a theory $\mathcal{T}$ of $\mathcal{ALC}$ axioms and a sequence $A_1, \ldots, A_n$ containing all of the classes in $\mathcal{T}$. Then, the following set of Datalog$^{\vee\exists}$ rules is a terminating rewriting for $\mathcal{T}$:

$$\{A(x) \wedge B(x) \to C(x) \mid A \sqcap B \sqsubseteq C \in \mathcal{T}\} \cup \{A(x) \to B(x) \vee C(x) \mid A \sqsubseteq B \sqcup C \in \mathcal{T}\} \cup$$
$$\{A(x) \wedge R(x,y) \to B(y) \mid A \sqsubseteq \forall R.B \in \mathcal{T}\} \cup$$
$$\{A(x) \to \exists y.R(x,y) \wedge B(y) \wedge Succ(x,y) \mid A \sqsubseteq \exists R.B \in \mathcal{T}\} \cup$$

$$\{\ \to A(x) \vee A^{\neg}(x), A(x) \wedge A^{\neg}(x) \to \bot \mid A \in \textbf{Classes}(\mathcal{T})\} \cup$$
$$\{A_1(x) \wedge A_1(z) \to SameClasses_1(x,z), A_1^{\neg}(x) \wedge A_1^{\neg}(z) \to SameClasses_1(x,z)\} \cup$$
$$\{SameClasses_{i-1}(x,z) \wedge A_i(x) \wedge A_i(z) \to SameClasses_i(x,z),$$
$$SameClasses_{i-1}(x,z) \wedge A_i^{\neg}(x) \wedge A_i^{\neg}(z) \to SameClasses_i(x,z) \mid 2 \leq i \leq n\} \cup$$
$$\{SameClasses_n(x,y) \to SameType(x,y)\} \cup$$

$$\{SameType(x,z) \wedge Succ(x,y) \wedge R(x,y) \to Succ(z,y) \wedge R(z,y) \mid R \in \textbf{Roles}(\mathcal{T})\}$$

Thank you for your attention!

Link to the paper:
iccl.inf.tu-dresden.de/web/Inproceedings3244/en

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