Evaluating the Generality of Disjunctive Model Faithful Acyclicity on OWL ontologies

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Disjunctive Existential Rules

$$\forall \vec{x} \forall \vec{y}. Body(\vec{x}, \vec{y}) \rightarrow \bigvee_{i=1}^{n} \exists \vec{z}_i . Head^i(\vec{x}_i, \vec{z}_i)$$

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- $Body$ and $Head^i$: conjunctions of atoms
- $\vec{x},\vec{y},\vec{z}_i$: pairwise disjoint lists of variables
- $\bigcup_{i=1}^{n}\vec{x}_i = \vec{x}$

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$$SalamiPizza(x) \to \exists z. hasBase(x, z) \land CheesePizza(z)$$

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Disjunctive Skolem Chase

$$\begin{aligned}
SalamiPizza(x) &\rightarrow \exists z.hasBase(x, z) \wedge CheesePizza(z) \\
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- $somePizza : Pizza$

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- $somePizza : Pizza, CheesePizza$

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$hasBase$

- $f^z(somePizza) : CheesePizza$

Disjunctive Skolem Chase

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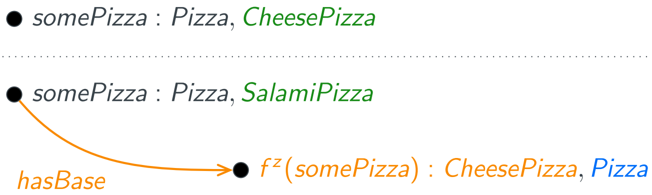

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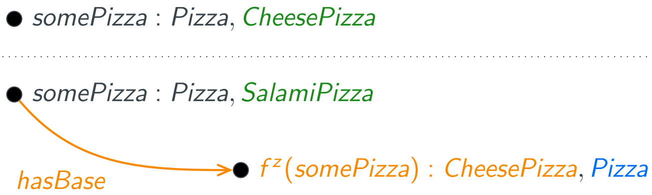

The *disjunctive skolem chase* yields a *universal model set*.

Acyclicity Notions

Problem: Termination of the chase is undecidable.
Sufficient conditions for termination have been introduced.

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Disjunctive Existential Rule Sets	
Terminating w.r.t. (disjunctive) restricted chase	RMFA [Carral et al., 2017]
Terminating w.r.t. disjunctive skolem chase	

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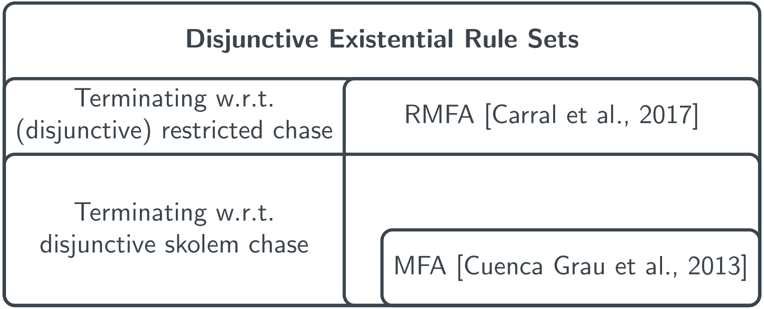

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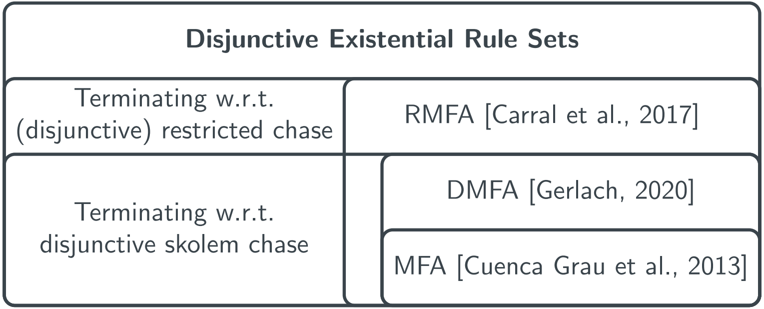

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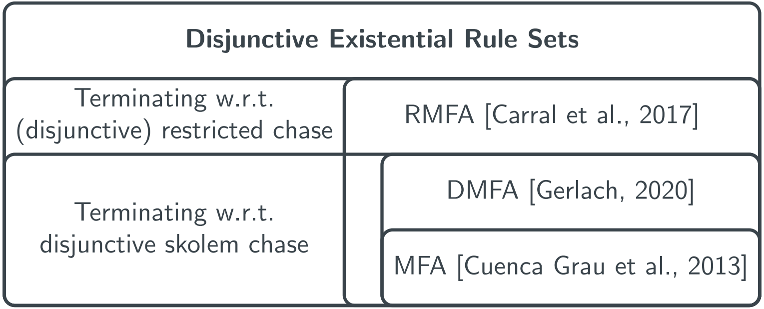

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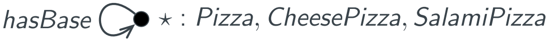

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The second rule is blocked now.
The rule set is DMFA since the computed fact set has no *cyclic terms*.

Evaluation Outline

Datasets:

- Oxford ontology repository (OXFD)
  797 ontologies[1]
- OWL Reasoner Evaluation 2015 (ORE15)
  1920 ontologies[2]

Steps:

[1] OXFD - https://www.cs.ox.ac.uk/isg/ontologies/

[2] ORE15 - https://zenodo.org/record/18578

[3] Ontology Normalizer - https://github.com/dcarralma/OntologyNormalizer

[4] Translation - https://gitlab.com/m0nstR/owl-to-disjunctive-existential-rules-converter

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$$SalamiPizza \sqsubseteq \geq 1 hasBase.CheesePizza$$
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Steps:

1. Normalize Ontologies using an existing tool[3]

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3. Check MFA, DMFA, and RMFA[5]

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not MFA but DMFA and RMFA

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Translation of normalized Axioms

$$A_1 \sqcap \cdots \sqcap A_n \sqsubseteq B \qquad A_1(x) \land \cdots \land A_n(x) \to B(x) \tag{1}$$

Here, $A, A_1, \ldots, A_n, B, B_1, \ldots, B_{n'}$ are classes, $R, R_1, \ldots, R_k, S$ are (inverse) properties, $a_1, \ldots, a_l$ are individuals, and m, m' are integers ≥ 0.

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$$A \sqsubseteq B_1 \sqcup \cdots \sqcup B_{n'} \qquad A(x) \rightarrow B_1(x) \vee \cdots \vee B_{n'}(x) \tag{2}$$

Here, $A, A_1, \ldots, A_n, B, B_1, \ldots, B_{n'}$ are classes, $R, R_1, \ldots, R_k, S$ are (inverse) properties, $a_1, \ldots, a_l$ are individuals, and m, m' are integers ≥ 0.

Translation of normalized Axioms

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\begin{array}{lll}
A_1 \sqcap \cdots \sqcap A_n \sqsubseteq B & A_1(x) \wedge \cdots \wedge A_n(x) \rightarrow B(x) & (1) \\
A \sqsubseteq B_1 \sqcup \cdots \sqcup B_{n'} & A(x) \rightarrow B_1(x) \vee \cdots \vee B_{n'}(x) & (2) \\
A \sqsubseteq \forall R.B & A(x) \wedge R(x,y) \rightarrow B(y) & (3) \\
A \sqsubseteq \geq mR.B & \text{(more involved)} & (4) \\
A \sqsubseteq \leq m'R.B & \text{(more involved)} & (5) \\
A \sqsubseteq \{ a_1, \ldots, a_l \} & \text{(more involved)} & (6) \\
R_1 \circ \cdots \circ R_k \sqsubseteq S & R_1(x_1,x_2) \wedge \cdots \wedge R_k(x_k,x_{k+1}) \rightarrow S(x_1,x_{k+1}) & (7) \\
R \sqcap S \sqsubseteq \bot & R(x,y) \wedge S(x,y) \rightarrow \bot & (8) \\
A \sqsubseteq \exists R.\mathrm{Self} & A(x) \rightarrow R(x,x) & (9) \\
\exists R.\mathrm{Self} \sqsubseteq A & R(x,x) \rightarrow A(x) & (10)
\end{array}
$$

Here, $A, A_1, \ldots, A_n, B, B_1, \ldots, B_{n'}$ are classes, $R, R_1, \ldots, R_k, S$ are (inverse) properties, $a_1, \ldots, a_l$ are individuals, and m, m' are integers ≥ 0.

Complicated Axioms

The translation for $A \sqsubseteq {\geq}2R.B$ is more involved:

$$
\begin{array}{lll}
A(x) \to \exists z_1.R_1(x, z_1) \wedge B(z_1) & R_1(x, y) \to R(x, y) & R(x, y) \to R_1(x, y) \vee R_2(x, y) \\
A(x) \to \exists z_2.R_2(x, z_2) \wedge B(z_2) & R_2(x, y) \to R(x, y) & R_1(x, y) \wedge R_2(x, y) \to \bot
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$$A(x) \to \exists z_2.R_2(x, z_2) \land B(z_2) \quad R_2(x, y) \to R(x, y) \quad R_1(x, y) \land R_2(x, y) \to \bot$$

For $A \sqsubseteq {\leq}1R.B$ and $A \sqsubseteq \{a, b\}$, we require equality:

$$A(x) \land R(x, u) \land B(u) \land R(x, v) \land B(v) \to u = v \qquad A(x) \to x = a \lor x = b$$

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$$A(x) \wedge R(x, u) \wedge B(u) \wedge R(x, v) \wedge B(v) \rightarrow u = v \qquad A(x) \rightarrow x = a \vee x = b$$

Problem: DMFA does not support equality.
For now: Omit axioms that require equality.
Later on: Axiomatize equality as suggested in [Carral and Urbani, 2020].

DMFA Implementation

Input: Ruleset R
Output: Is R DMFA?

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while $\Delta F \neq \emptyset$ **do**

  `// keeps track of already computed facts internally`

  $\Delta F := \Delta F \cup \mathit{vlogReasoner.newFactsFromVlogDatalogClosure}(\Delta F)$

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ΔF := criticalInstance(R)
vlogReasoner := VlogReasoner(R) // uses VLog bindings of Rulewerk
exisReasoner := ExistentialReasoner(R)
while ΔF ≠ ∅ do
    // keeps track of already computed facts internally
    ΔF := ΔF ∪ vlogReasoner.newFactsFromVlogDatalogClosure(ΔF)
    // non-exhaustive application
    // keeps track of already computed facts internally
    ΔF := exisReasoner.newFactsFromUnblockedNonDatalogRules(ΔF)
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Evaluation Results

OXFD: 797
ORE15: 1920

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$$\begin{array}{rl} \text{OXFD: } 797 & \xrightarrow{\text{Normalization}} 791 \\ \text{ORE15: } 1920 & \quad\quad\quad\quad\quad\quad 1910 \end{array}$$

Evaluation Results

OXFD: 797 —Normalization→ 791 —Translation→ 789

ORE15: 1920 → 1910 → 1888

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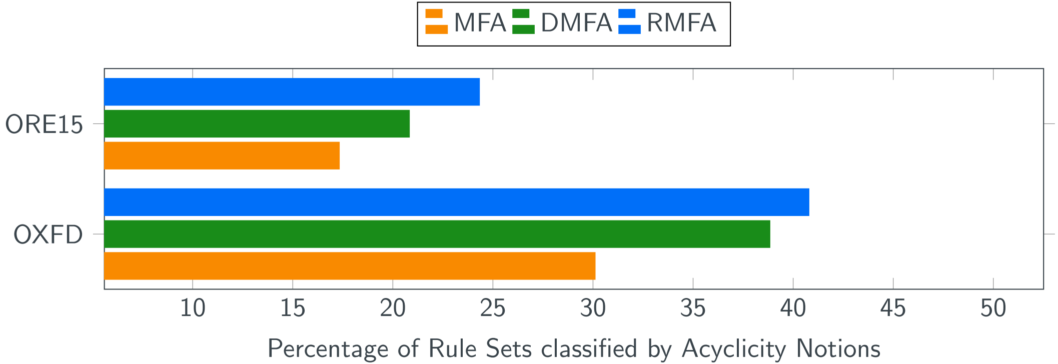

Where are the differences?

Observation: 6 out of 9 rule sets for OXFD and 11 out of 18 rule sets for ORE15 that are DMFA but not MFA come from BioPAX.[6]

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OXFD 00007: DMFA but not MFA

$$
\begin{aligned}
\mathit{Evidence}(x) &\rightarrow \exists z.\mathit{ConfidenceProp}(x, z) \\
\mathit{ConfidenceProp}(x, y) &\rightarrow \mathit{Confidence}(y) \\
\mathit{Confidence}(x) &\rightarrow \mathit{Xref}(x) \\
\mathit{Xref}(x) &\rightarrow \mathit{Evidence}(x) \lor \mathit{Confidence}(x) \\
\mathit{Evidence}(x) \land \mathit{Confidence}(x) &\rightarrow \bot
\end{aligned}
$$

[6] BioPAX - `http://www.biopax.org/`

Where are the differences?

Observation: 6 out of 9 rule sets for OXFD and 11 out of 18 rule sets for ORE15 that are DMFA but not MFA come from BioPAX.[6]
They are similar or even identical.

We have to careful in generalizing our findings here.

OXFD 00007: DMFA but not MFA

$$\begin{aligned}
\mathit{Evidence}(x) &\to \exists z.\mathit{ConfidenceProp}(x,z) \\
\mathit{ConfidenceProp}(x,y) &\to \mathit{Confidence}(y) \\
\mathit{Confidence}(x) &\to \mathit{Xref}(x) \\
\mathit{Xref}(x) &\to \mathit{Evidence}(x) \vee \mathit{Confidence}(x) \\
\mathit{Evidence}(x) \wedge \mathit{Confidence}(x) &\to \bot
\end{aligned}$$

OXFD 00114: RMFA but not DMFA

$$\begin{aligned}
\mathit{Sibling}(x) &\to \exists z.\mathit{hasSibling}(z,x) \wedge \mathit{Person}(z) \\
\mathit{Person}(x) \wedge \mathit{hasSibling}(x,y) &\to \mathit{Sibling}(y) \\
\mathit{Sibling}(x) &\to \mathit{Person}(x) \\
\mathit{hasSibling}(x,y) &\to \mathit{hasSibling}(y,x)
\end{aligned}$$

Not even terminating w.r.t. the disjunctive skolem chase.

[6] BioPAX - http://www.biopax.org/

Second Example in Detail

$$Sibling(x) \rightarrow \exists z.hasSibling(z, x) \land Person(z)$$
$$Person(x) \land hasSibling(x, y) \rightarrow Sibling(y)$$
$$Sibling(x) \rightarrow Person(x)$$
$$hasSibling(x, y) \rightarrow hasSibling(y, x)$$

Second Example in Detail

$$Sibling(x) \rightarrow \exists z.hasSibling(z, x) \wedge Person(z)$$
$$Person(x) \wedge hasSibling(x, y) \rightarrow Sibling(y)$$
$$Sibling(x) \rightarrow Person(x)$$
$$hasSibling(x, y) \rightarrow hasSibling(y, x)$$

$me : Sibling$ ●

Second Example in Detail

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$$Person(x) \wedge hasSibling(x, y) \rightarrow Sibling(y)$$
$$Sibling(x) \rightarrow Person(x)$$
$$hasSibling(x, y) \rightarrow hasSibling(y, x)$$

$me : Sibling, Person$ ●

Second Example in Detail

$$Sibling(x) \rightarrow \exists z. hasSibling(z, x) \wedge Person(z)$$
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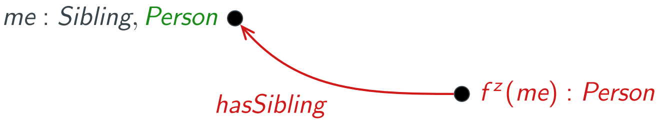
$$hasSibling(x, y) \rightarrow hasSibling(y, x)$$



Second Example in Detail

$$Sibling(x) \rightarrow \exists z.hasSibling(z, x) \wedge Person(z)$$
$$Person(x) \wedge hasSibling(x, y) \rightarrow Sibling(y)$$
$$Sibling(x) \rightarrow Person(x)$$
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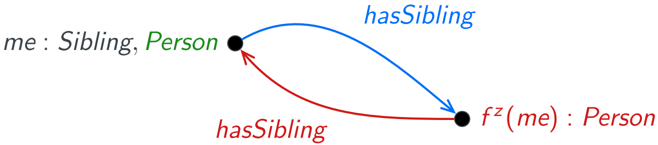

Second Example in Detail

$$Sibling(x) \rightarrow \exists z.hasSibling(z, x) \land Person(z)$$
$$Person(x) \land hasSibling(x, y) \rightarrow Sibling(y)$$
$$Sibling(x) \rightarrow Person(x)$$
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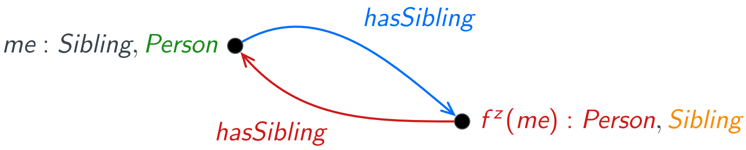

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$$Sibling(x) \rightarrow \exists z.hasSibling(z, x) \wedge Person(z)$$
$$Person(x) \wedge hasSibling(x, y) \rightarrow Sibling(y)$$
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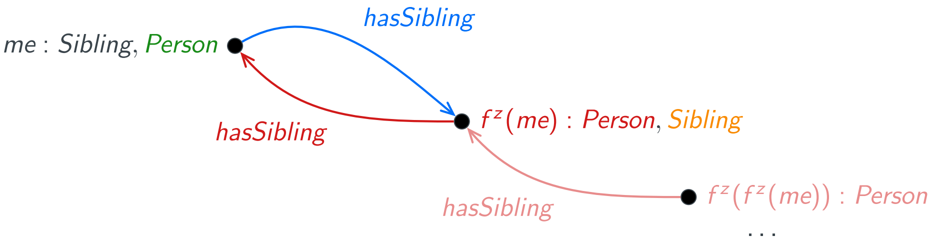

Conclusion

Results:

- DMFA improves upon MFA and comes closer to RMFA in practice.
- A significant number of rule sets is not even RMFA.
- We find rule sets that are RMFA but not DMFA that do not terminate w.r.t. the disjunctive skolem chase.

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Open Questions:

- What is the impact of the translation (especially equality) on the results?
- How tight is DMFA?

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Open Questions:

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- How tight is DMFA?

Future Work:

- Handling for equality in the translation.
- Investigation and evaluation of cyclicity notions for the disjunctive skolem chase.
- Performance centric evaluation of DMFA.
- Implementation of the disjunctive skolem chase, e.g. with ASP solvers with lazy grounding.

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