How to reason with OWL in a logic programming system

Markus Krötzsch
AIFB Karlsruhe

Denny Vrandecic
AIFB Karlsruhe

Pascal Hitzler
AIFB Karlsruhe

Michael Sintek
DFKI Kaiserslautern

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Semantic Web Languages: Seperate worlds

- OWL DL
  - open world
  - monotonic
  - description logics
  - first-order logic
  - decidable
- Logic Programming
  - closed world
  - non-monotonic
  - rules
  - procedural flavour
  - undecidable

- both approaches are needed for applications
- study of interoperability is imperative

- here: sound and complete reasoning for OWL with Prolog

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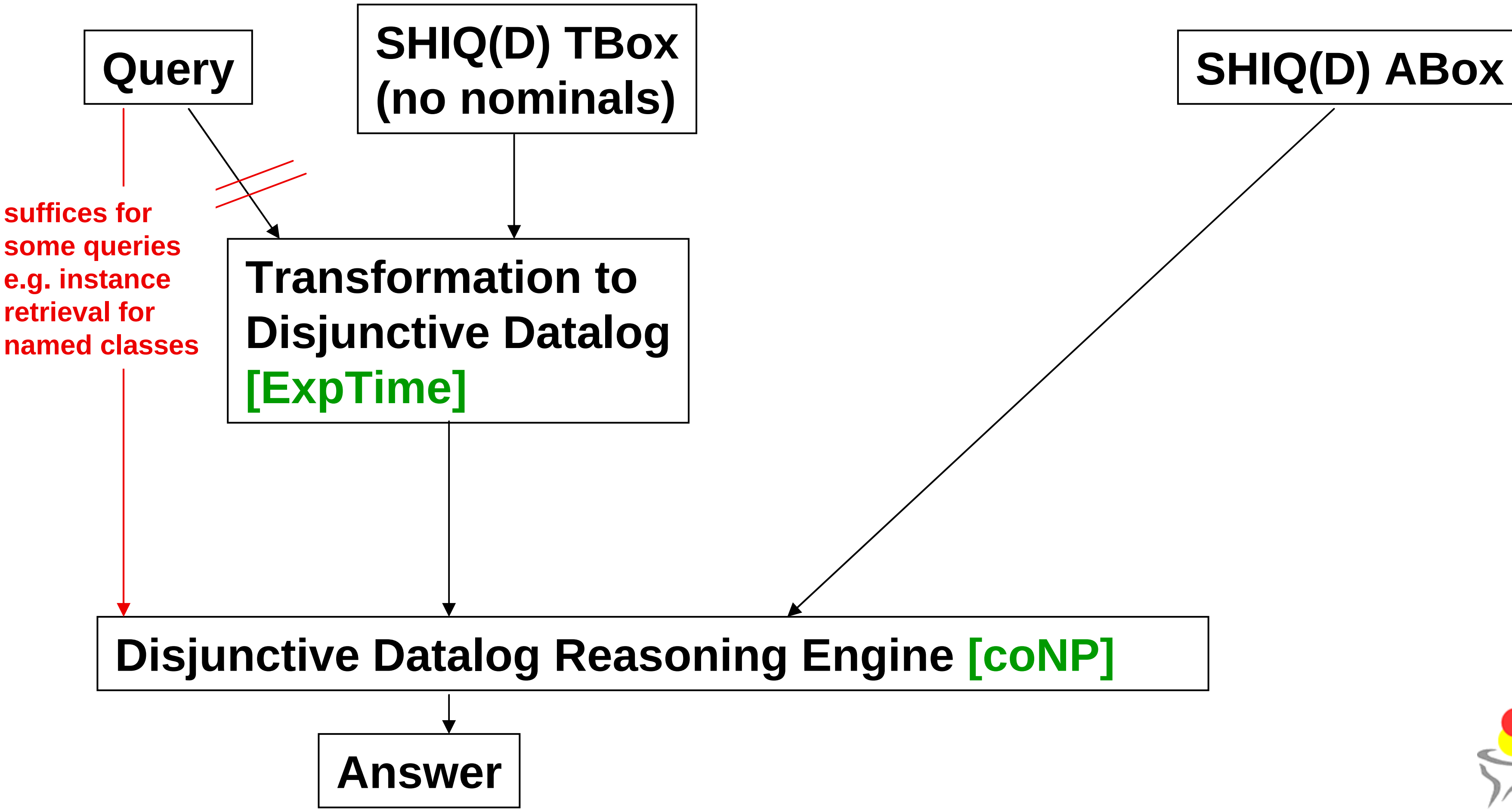
Approach

- We utilize results by Motik et al. on the KAON2 transformation algorithms and system.
- KAON2 OWL reasoner:
  http://kaon2.semanticweb.org
- KAON2 algorithms comprehensive details:
  Boris Motik, Reasoning in Description Logics using Resolution and Deductive Databases. Dissertation, AIFB Universität Karlsruhe, 2006.

KAON2 Reasoner core architecture



Theorem (Hustadt, Motik, Sattler 2004)

Transformation of OWL knowledge base KB into Disjunctive Datalog DD(KB)

Then, the following hold:

1. KB is unsatisfiable if and only if DD(KB) is unsatisfiable.
2. KB $\models \alpha$ if and only if DD(KB) $\models \alpha$, where α is of the form A(a) or R(a, b), and A is an atomic concept.
3. KB $\models$ C(a) for a nonatomic concept C if and only if, for Q a new atomic concept, DD(KB $\cup$ {C $\sqsubseteq$ Q}) $\models$ Q(a).

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Simple example transformation (ALC)

KB
$\text{Person} \sqsubseteq \exists\, \text{parent.Person}$
$\exists\, \text{parent.}(\exists\, \text{parent.Person}) \sqsubseteq \text{Grandchild}$
$\text{Person}(a)$

DD(KB)
$Q_1(x), \text{Person}(y) \leftarrow \text{parent}(x,y)$
$\leftarrow \text{parent}(x,y), Q_1(y), \text{Grandchild}(x)$
$\leftarrow Q_1(x), \text{Person}(x)$
$\text{Grandchild}(x) \leftarrow \text{Person}(x)$
$\text{Person}(a)$

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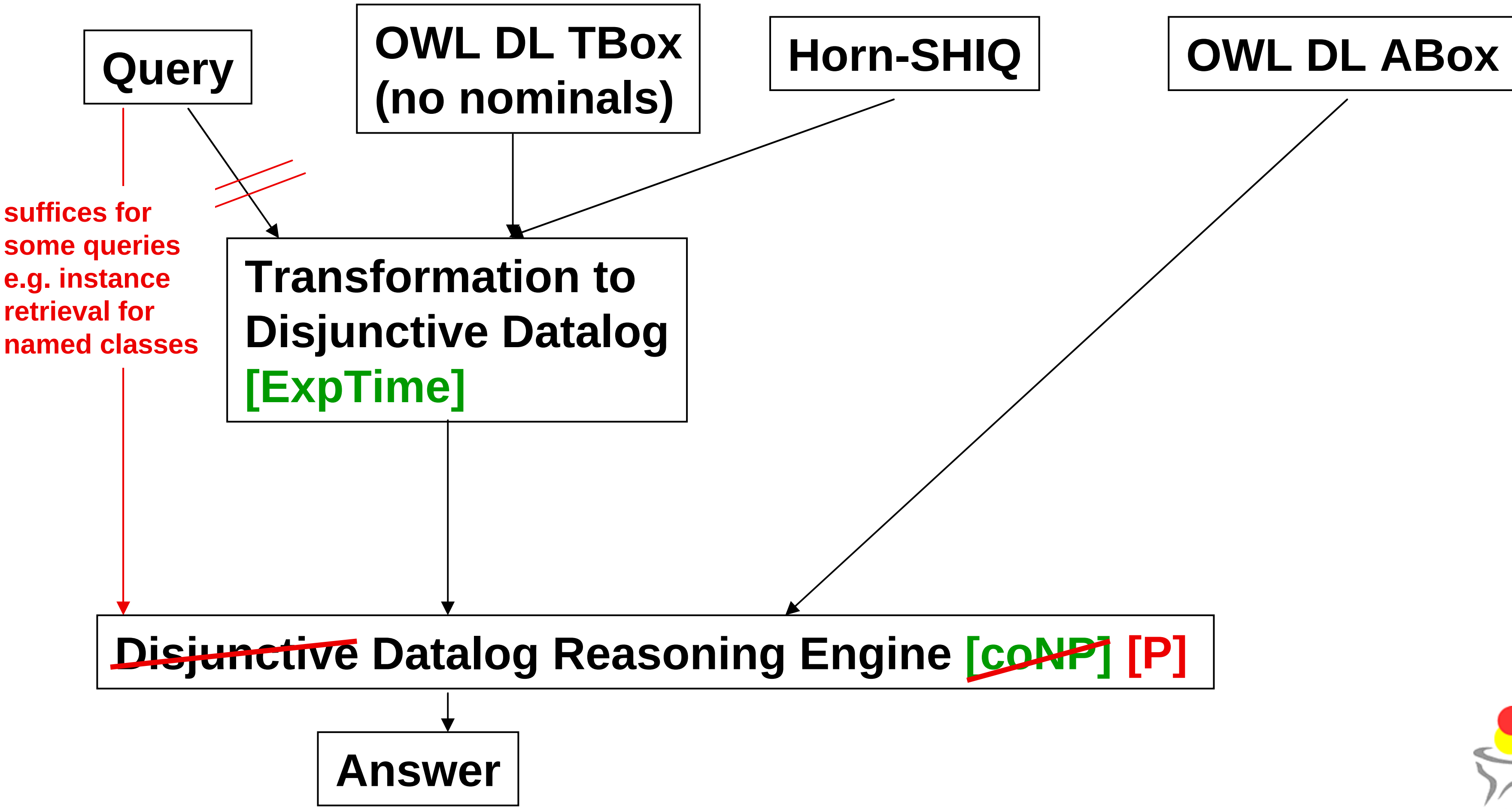
KAON2 Reasoner core architecture: Horn-SHIQ

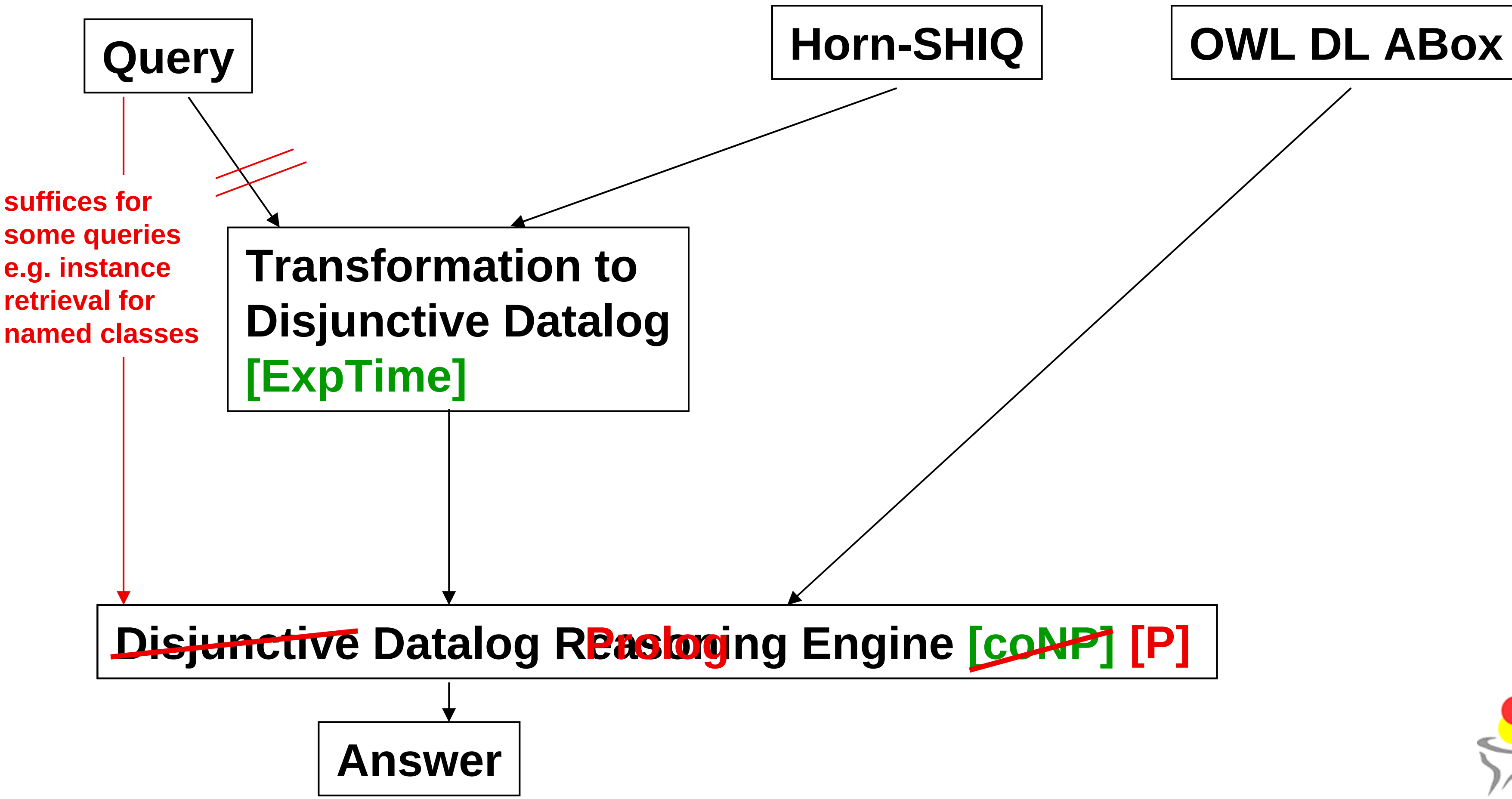


Horn-SHIQ

- Fragment of OWL DL
  - Polynomial data complexity (ABox)
  - ExpTime combined complexity (ABox+TBox) [OWLED06]

$$
\begin{aligned}
\mathbf{C}_0^+ &\rightarrow \top \mid \bot \mid \neg\mathbf{C}_0^- \mid \mathbf{C}_0^+ \sqcap \mathbf{C}_0^+ \mid \mathbf{C}_0^+ \sqcup \mathbf{C}_0^+ \mid \forall \mathbf{R}.\mathbf{C}_0^+ \\
\mathbf{C}_0^- &\rightarrow \top \mid \bot \mid \neg\mathbf{C}_0^+ \mid \mathbf{C}_0^- \sqcap \mathbf{C}_0^- \mid \mathbf{C}_0^- \sqcup \mathbf{C}_0^- \mid \exists \mathbf{R}.\mathbf{C}_0^- \mid \mathbf{A} \\
\mathbf{C}_1^+ &\rightarrow \top \mid \bot \mid \neg\mathbf{C}_1^- \mid \mathbf{C}_1^+ \sqcap \mathbf{C}_1^+ \mid \mathbf{C}_0^+ \sqcup \mathbf{C}_1^+ \mid \exists \mathbf{R}.\mathbf{C}_1^+ \mid \forall \mathbf{R}.\mathbf{C}_1^+ \mid \geq n\, \mathbf{R}.\mathbf{C}_1^+ \mid \leq 1\, \mathbf{R}.\mathbf{C}_0^- \mid \mathbf{A} \\
\mathbf{C}_1^- &\rightarrow \top \mid \bot \mid \neg\mathbf{C}_1^+ \mid \mathbf{C}_0^- \sqcap \mathbf{C}_1^- \mid \mathbf{C}_1^- \sqcup \mathbf{C}_1^- \mid \exists \mathbf{R}.\mathbf{C}_1^- \mid \forall \mathbf{R}.\mathbf{C}_1^- \mid \geq 2\, \mathbf{R}.\mathbf{C}_0^- \mid \leq n\, \mathbf{R}.\mathbf{C}_1^+ \mid \mathbf{A}
\end{aligned}
$$

KAON2 Reasoner core architecture: Horn-SHIQ Using Prolog



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Difficulty: Integrity constraints

- Some OWL statements become integrity constraints which are not usually supported under Prolog.

- $C \sqcap D \equiv \bot$

  translates to

  $\leftarrow C(x) \land D(x)$

- workaround: $inc \leftarrow C(x) \land D(x)$

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Difficulty: Equality

- Some OWL statements require equality for expressing them in first-order logic.
- For our purposes, the following Horn rules suffice:

$$X \approx X, \quad X \approx Y \leftarrow Y \approx X, \quad X \approx Z \leftarrow X \approx Y \wedge Y \approx Z$$
$$C(Y) \leftarrow C(X) \wedge X \approx Y \quad \text{for every concept name } C$$
$$R(Y_1, Y_2) \leftarrow R(X_1, X_2) \wedge X_1 \approx Y_1 \wedge X_2 \approx Y_2 \text{ for every role name } R$$

Example

TBox/RBox				ABox
(1)	Parent	$\equiv$	$\exists\,\mathsf{hasChild}.\top$	$\mathsf{hasChild}(\text{Elaine, Sir Lancelot})$
(2)	Person	$\sqsubseteq$	$\exists\,\mathsf{childOf}.\mathsf{Person}$	$\mathsf{noSiblings}(\text{Lancelot du Lac})$
(3)	$\mathsf{ManyChildren}$	$\sqsubseteq$	$\geq 2\ \mathsf{hasChild}.\top$	$\mathsf{childOf}(\text{Lancelot du Lac, Elaine})$
(4)	$\mathsf{NoSiblings}$	$\sqsubseteq$	$\mathsf{Person} \sqcap \forall\,\mathsf{childOf}.(\leq 1\ \mathsf{hasChild}.\top)$	
(5)	$\mathsf{childOf}$	$\equiv$	$\mathsf{hasChild}^{-1}$	

$$
\begin{array}{rlrl}
\mathsf{person}(X) & \text{:-}\ \mathsf{nosiblings}(X). & \mathsf{person}(X_{f3}) & \text{:-}\ \mathsf{person}(X), S_{f3}(X, X_{f3}).\\
\mathsf{parent}(X) & \text{:-}\ \mathsf{haschild}(X, Y). & \mathsf{parent}(X) & \text{:-}\ \mathsf{manychildren}(X).\\
\mathsf{haschild}(Y, X) & \text{:-}\ \mathsf{childof}(X, Y). & \mathsf{haschild}(X, X_{f1}) & \text{:-}\ \mathsf{manychildren}(X), S_{f1}(X, X_{f1}).\\
\mathsf{haschild}(X, X_{f2}) & \text{:-}\ \mathsf{parent}(X), S_{f2}(X, X_{f2}). & \mathsf{haschild}(X, X_{f0}) & \text{:-}\ \mathsf{manychildren}(X), S_{f0}(X, X_{f0}).\\
\mathsf{childof}(X, X_{f3}) & \text{:-}\ \mathsf{person}(X), S_{f3}(X, X_{f3}). & \mathsf{childof}(Y, X) & \text{:-}\ \mathsf{haschild}(X, Y).
\end{array}
$$

$$
\begin{array}{rl}
Y_1 \approx Y_2 & \text{:-}\quad \mathsf{nosiblings}(X), \mathsf{childof}(X, Z), \mathsf{haschild}(Z, Y_1), \mathsf{haschild}(Z, Y_2).\\
\mathsf{inc} & \text{:-}\quad \mathsf{manychildren}(X), \mathsf{nosiblings}(X_0), \mathsf{childof}(X_0, X).\\
\mathsf{inc} & \text{:-}\quad X_{f1} \approx X_{f0}, \mathsf{manychildren}(X), S_{f1}(X, X_{f1}), S_{f0}(X, X_{f0}).
\end{array}
$$

$$S_f(X, f(X)) \text{ :- }\quad \mathsf{O}(X). \qquad \mathsf{HU}(X) \text{ :- } \mathsf{O}(X). \quad \mathsf{HU}(f(X)) \text{ :- } \mathsf{O}(X). \qquad (\text{for } f \in \{f_0, f_1, f_2, f_3\})$$

$$
\begin{array}{rl}
X \approx X & \text{:-}\ \mathsf{HU}(X).\\
X \approx Y & \text{:-}\quad Y \approx X, \mathsf{HU}(X), \mathsf{HU}(Y).\\
X \approx Z & \text{:-}\quad X \approx Y, Y \approx Z, \mathsf{HU}(X), \mathsf{HU}(Y), \mathsf{HU}(Z).
\end{array}
$$

$$C(Y) \text{ :- }\quad C(X), X \approx Y, \mathsf{HU}(X), \mathsf{HU}(Y).$$

(for $C \in \{\mathsf{person}, \mathsf{parent}, \mathsf{manychildren}, \mathsf{nosiblings}\}$)

$$R(Y_1, Y_2) \text{ :- }\quad R(X_1, X_2), X_1 \approx Y_1, X_2 \approx Y_2, \mathsf{HU}(X_1), \mathsf{HU}(X_2), \mathsf{HU}(Y_1), \mathsf{HU}(X_2).$$

(for $R \in \{\mathsf{childof}, \mathsf{haschild}\}$)

$\mathsf{O}(\text{Elaine}).\quad \mathsf{O}(\text{Sir Lancelot}).\quad \mathsf{O}(\text{Lancelot du Lac}).$

Implementation

Transformation available through KAON2
http://kaon2.semanticweb.org

or via owltools command line interface *dlpconvert*
http://owltools.ontoware.org
see software demo [OWLED06] this evening

- optional serialisations:
  - **Prolog**
  - **F-Logic**
  - **RuleML0.9**
  - **SWRL**

Acknowledgement

- The presented results are corollaries from the work by Boris Motik on KAON2.
- Very helpful discussions with Boris are gratefully acknowledged.

Thank you!

- related [OWLED06]-presentations:
  - Today, 1345 hrs:
    M. Krötzsch, S. Rudolph and P. Hitzler. On the Complexity of Horn Description Logics
  - Today, 1700 hrs:
    D. Vrandecic: OWL Tools demo