Uncertainty Treatment in the Rule Interchange Format: From Encoding to Extension

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Talk Outline

• Introduction and Motivation
• DLP and Representation in RIF
• Encoding Uncertainty in RIF
  • Fuzzy LP
  • Using RIF Functions
  • Using RIF Predicates
• Uncertainty Extension of RIF
  • Definition of Truth Values and Truth Valuation
  • Proposed RIF-URD
• Fuzzy Description Logic Programs and Their Representation in RIF
• Conclusions and Future Work
RIF Background

- Literally *hundreds* of rule system implementations
- RIF: Rule Interchange Format
- RIF defines
  - a basic logic dialect: RIF-BLD
  - a framework in the form of a menu of syntactic and semantic features that can be combined into different specializations: RIF-FLD
- other specializations
Motivation

- DL and LP cover different but overlapping areas of knowledge representation
Motivation

- DL and LP cover different but overlapping areas of knowledge representation
- DL cannot represent “more than one free variable at a time”
- LP/Horn Logic cannot represent a disjunction or an existential in the head
Motivation

- DL and LP cover different but overlapping areas of knowledge representation
- Handling uncertain knowledge is becoming a critical research direction for the (Semantic) Web
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### DLP Expressive Power and DLP mappings

<table>
<thead>
<tr>
<th>LP syntax</th>
<th>DL syntax</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D(x) \leftarrow C(x) )</td>
<td>( C \sqsubseteq D )</td>
</tr>
<tr>
<td>( D(x) \leftarrow C(x), ) ( C(x) \leftarrow D(x) )</td>
<td>( C \equiv D )</td>
</tr>
<tr>
<td>( C(y) \leftarrow R(x,y) )</td>
<td>( T \sqsubseteq \forall R.C )</td>
</tr>
<tr>
<td>( C(x) \leftarrow R(x,y) )</td>
<td>( T \sqsubseteq \forall R^-.C )</td>
</tr>
</tbody>
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<tr>
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<tr>
<td>( C(a) )</td>
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<td>( R(a,b) )</td>
<td>( R(a,b) )</td>
</tr>
<tr>
<td>( R(x,y) \leftarrow P(x,y), ) ( P(x,y) \leftarrow R(x,y) )</td>
<td>( P \equiv R )</td>
</tr>
<tr>
<td>( R(x,y) \leftarrow P(y,x), ) ( P(y,x) \leftarrow R(x,y) )</td>
<td>( P \equiv R^- )</td>
</tr>
<tr>
<td>( R(x,z) \leftarrow R(x,y), R(y,z) )</td>
<td>( R^+ \sqsubseteq R )</td>
</tr>
<tr>
<td>( P(x,y) \leftarrow R(x,y) )</td>
<td>( R \sqsubseteq P )</td>
</tr>
</tbody>
</table>

| \( D(x) \leftarrow C_1(x) \land C_2(x) \) | \( C_1 \sqcap C_2 \sqsubseteq D \) |
| \( P(x,y) \leftarrow R_1(x,y) \land R_2(x,y) \) | \( R_1 \sqcap R_2 \sqsubseteq P \) |
| \( C_1(x) \leftarrow D(x), \) \( C_2(x) \leftarrow D(x) \) | \( D \sqsubseteq C_1 \sqcap C_2 \) |
| \( D(x) \leftarrow C_1(x), \) \( D(x) \leftarrow C_2(x) \) | \( C_1 \sqcup C_2 \sqsubseteq D \) |
| \( D(y) \leftarrow R(x,y) \land C(x) \) | \( C \sqsubseteq \forall R.D \) |
| \( D(x) \leftarrow R(x,y) \land C(y) \) | \( \exists R.C \sqsubseteq D \) |
Figure. Relationship between the fragments (profiles) of OWL 1.1
http://www.webont.org/owl/1.1/tractable.html
DLP comprises basic RDFS & more

- RDFS subset of DL permits the following statements:
  - Subclass, Domain, Range, Subproperty (also SameClass, SameProperty)
  - instance of class, instance of property
- more DL statements beyond RDFS:
  - Intersection in class descriptions
  - Transitive or symmetric property, inverse property
  - Disjunction or Existential in a subclass expression
  - Universal in a superclass expression
**DLP limitations**

- Does not allow using disjunction or existential in a superclass expression.
  
  E.g., $C \sqsubseteq D_1 \sqcup D_2$, $C \sqsubseteq \exists P.D$

- A universal restriction as a subclass of an inclusion axiom
  
  E.g. $\forall P.D \sqsubseteq C$

- Negation ($\neg$) and cardinality restrictions ($\leq, \geq$)
OWL 2 RL

• Created by W3C OWL Working Group
• Is a syntactic profile of OWL 2 DL
• Based on Description Logic Programs (DLP)
• Syntactic restrictions

http://www.w3.org/2007/OWL/wiki/Profiles#OWL_2_RL
RIF-BLD Overview

- Definite Horn rules
- Functions
- Equality (in conclusion and condition)
- Internationalized resource identifiers (IRIs)
- XML syntax
- Presentation syntax
- Published “Last Call” draft in July
  - Slides 14-17 are adapted from Chris Welty’s talk on RIF-BLD
Rules

- IF <condition> THEN <conclusion>
  - <condition> aka rule body, antecedant
  - <conclusion> aka rule head, consequent

- BLD rule:
  - **Forall** var* (<conclusion> :- <condition>)
  - Conclusions may contain conjunction
  - Conditions may contain conjunction, disjunction, and existential

- Restrictions on conclusion
  - No existential, disjunction, external functions
Document Structure
(in presentation syntax)

- Groups occur in Documents
  - Document(
    - Group(Forall ?x (Q(?x) :- P(?x))
    - Forall ?x (Q(?x) :- R(?x))
    - Group(Forall ?y (R(?y) :- ex:op(?y))))

- Rules occur in Groups
  - Group(Forall ?x (Q(?x) :- P(?x))
    - Forall ?x (Q(?x) :- R(?x) )
    - ex:op(?y)))
## DLP in RIF

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Fuzzy LP

• Syntax of a fuzzy rule
  \[ H(\tilde{x}) \leftarrow B_1(\tilde{x}_1), \ldots, B_n(\tilde{x}_n) \quad / c \]

• Semantics
  • The body: Gödel’s semantics
    \[ \text{val}(B_1, \ldots, B_n, H_I) = \min\{\text{val}(B_i, H_I) \mid i \in \{1, \ldots, n\}\} \]

• The implication: product
  \[ \text{val}(H, H_I) = c \times \text{val}(B_1, \ldots, B_n, H_I) \]
Fuzzy LP example: cheapFlight

\( \text{cheapFlight}(x, y) \leftarrow \text{affordable Flight}(x, y) / 0.9 \)  \hspace{1cm} (1)

\( \text{affordable Flight}(x, y) / \text{left shoulder} 0k 4k 1k 3k(y) \)  \hspace{1cm} (2)

\( KB_{LP} \models \text{cheapFlight}(flight0001, 1800) / 0.63 \)
Encoding Uncertainty in RIF: Using RIF Functions

- Map all predicates to functions
- Use equality for letting the functions return uncertainty values
- A fuzzy rule in RIF-BLD

```
Document(
  Group
    Forall ?x₁ ... ?xₖ (  
        h(t₁ ... tₗ)=?cₙ :- And(b₁(t₁,₁ ... t₁,s₁)=?c₁ ... bₚ(tₚ,₁ ... tₚ,sₚ)=?cₚ  
            ?cₜ=External(numeric-minimum(?c₁ ... ?cₚ))  
            ?cₙ=External(numeric-multiply(c ?cₜ)) )
    )
)
```

- The semantics of the fuzzy rules is encoded using built-in functions from RIF_DTB and planned extensions
Example cheapFlight encoded in RIF-BLD

```riff
(* <http://example.org/fuzzy/membershipfunction> *)
Document(
  Group
  
  ( (* "Definition of membership function  left _ shoulder(0, 4000,1000,3000) "] "*)
    Forall ?y(
      left__shoulder0k4k1k3k(?y)=1 :- And(External(numeric-less-than-or-equal(0 ?y))
                                      External(numeric-less-than-or-equal(?y 1000))))

    Forall ?y(
      left__shoulder0k4k1k3k(?y)=External(numeric-add(External(numeric-multiply(-0.0005 ?y)) 1.5))
          :- And(External(numeric-less-than(1000 ?y))
                   External(numeric-less-than-or-equal(?y 3000))))

    Forall ?y(
      left__shoulder0k4k1k3k(?y)=0 :- And(External(numeric-less-than(3000 ?y))
                                      External(numeric-less-than-or-equal(?y 4000))))

  )
)
```

```riff
Document(
  Import (<http://example.org/fuzzy/membershipfunction >)
  Group
  
  ( Forall ?x ?y(cheapFlight(?x ?y)=?c : - And(affordableFlight(?x ?y)=?c1
                                     ?c1=External(numeric-multiply(0.4 ?c1))))

    Forall ?x ?y(affordableFlight(?x ?y)=left__shoulder0k4k1k3k(?y))

  )
)
```
Encoding Uncertainty in RIF: Using RIF Predicates

• Make all n-ary predicates into (1+n)-ary predicates
• A fuzzy rule in RIF-BLD
• The semantics of the fuzzy rules is also encoded using built-in functions from RIF_DT_B and planned extensions

Document(
  Group
    (Forall ?x1 ... ?xk (h(?c_h t1 ... t_r) :- And(b1(?c_1 t1,1 ... t1,s1) ... b_n(?c_n t_n,1 ... t_n,s_n)
       ?c_r = External(numeric-minimum(?c_1 ... ?c_n))
       ?c_h = External(numeric-multiply(c ?c_r))
    )))
)
Example cheapFlight encoded in RIF-BLD

Document(
  Import (<http://example.org/fuzzy/membershipfunction >)
  Group
    ( 
      Forall ?x ?y( 
        cheapFlight(?c_h ?x ?y) :- And(affordableFlight(?c_1 ?x ?y)
                                 ?c_h=External(numeric-multiply(0.4 ?c_1)))
      )
      Forall ?x ?y(affordableFlight(?c_1 ?x ?y) :- ?c_1=left__shoulder0k4k1k3k(?y))
    ) )
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Uncertainty Extension of RIF

• Set of Truth Values $\mathcal{TV}$ from FLD: the interval $[0,1]$
• Let $\leq$ denote the numerical truth order

**Definition 1. (Set of truth values as a specialization of the set in RIF-FLD)**

1. The set $TV$ is a complete lattice with respect to $\leq$, i.e., the least upper bound (lub) and the greatest lower bound (glb) exist for any subset of $\leq$.
2. Antisymmetry. If $e_i \leq e_j$ and $e_j \leq e_i$ then $e_i = e_j$.
3. Transitivity. If $e_i \leq e_j$ and $e_j \leq e_k$ then $e_i \leq e_k$.
4. Totality. Any two elements should satisfy one of these two relations: $e_i \leq e_j$ or $e_j \leq e_i$.
5. The set $TV$ has an operator of negation, $\sim: TV \rightarrow TV$, such that
   a. $\sim e_i = 1 - e_i$.
   b. $\sim$ is self-inverse, i.e., $\sim \sim e_i = e_i$. 

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Uncertainty Extension of RIF

• Truth Valuation

**Definition 2. (Truth valuation adapted from RIF-FLD).** Truth valuation for well-formed formulas in RIF-URD is determined as in RIF-FLD, adapting the following three cases.

(8) Conjunction (glob becomes min): $TVal_1(\text{And}(B_1 \cdots B_n)) = \min(TVal(B_1) \cdots TVal(B_n))$.

(9) Disjunction (lub becomes max): $TVal_1(\text{Or}(B_1 \cdots B_n)) = \max(TVal(B_1) \cdots TVal(B_n))$

(11) Rule implication ($t$ becomes 1, $f$ becomes 0, condition valuation is multiplied with $c$):

- $TVal_1(\text{conclusion} : - \text{condition} / c) = 1$ if $TVal_1(\text{conclusion}) \geq c \times TVal_1(\text{condition})$
- $TVal_1(\text{conclusion} : - \text{condition} / c) = 0$ if $TVal_1(\text{conclusion}) < c \times TVal_1(\text{condition})$
RIF Uncertainty Rule Dialect: URD

- Proposed RIF-URD
- Rule
- Fact

```
Document(
  Group
    (  
      Forall ?x_1 ... ?x_k ( 
        h(t_1 ... t_r) :- And(b_1(t_{1,s1}) ... b_n(t_{n,sn}))
      ) / c 
    )
  )

h(t_1 ... t_r) / c
```

```
Document(
  Import (<http://example.org/fuzzy/membershipfunction >)
  Group
    ( 
      Forall ?x ?y(  
        cheapFlight(?x ?y) :- affordableFlight(?x ?y)
      ) / 0.4
      Forall ?x ?y(affordableFlight(?x ?y)) / left__shoulder0k4k1k3k(?y)
    )
)```

```
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## fhDLP

- **Mappings in fhDLP**

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<th>DL syntax</th>
</tr>
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<tbody>
<tr>
<td>$D(x) \leftarrow C_1(x), \ldots, C_n(x) / c$</td>
<td>$\bigcap_{i=1}^{n} C_i \subseteq D = c$</td>
</tr>
<tr>
<td>$P(x, y) \leftarrow R_1(x, y), \ldots, R_n(x, y) / c$</td>
<td>$\bigcap_{i=1}^{n} R_i \subseteq P = c$</td>
</tr>
<tr>
<td>$C(x) \leftarrow D(x) / c_1$,</td>
<td>$C \equiv D = \min(c_1, c_2)$</td>
</tr>
<tr>
<td>$D(x) \leftarrow C(x) / c_2$</td>
<td></td>
</tr>
<tr>
<td>$R(x, y) \leftarrow P(x, y) / c_1$,</td>
<td>$R \equiv P = \min(c_1, c_2)$</td>
</tr>
<tr>
<td>$P(x, y) \leftarrow R(x, y) / c_2$</td>
<td></td>
</tr>
<tr>
<td>$R(x, y) \leftarrow P(y, x) / c_1$,</td>
<td>$P \equiv R^\ast = \min(c_1, c_2)$</td>
</tr>
<tr>
<td>$P(x, y) \leftarrow R(x, y) / c_2$</td>
<td></td>
</tr>
<tr>
<td>$C(y) \leftarrow R(x, y) / c$</td>
<td>$T \sqsubseteq \forall R.C = c$</td>
</tr>
<tr>
<td>$C(x) \leftarrow R(x, y) / c$</td>
<td>$T \subseteq \forall R^\ast.C = c$</td>
</tr>
<tr>
<td>$R(x, z) \leftarrow R(x, y), R(y, z) / c$</td>
<td>$R^+ \sqsubseteq R = c$</td>
</tr>
<tr>
<td>$C(a) / c$</td>
<td>$C(a) = c$</td>
</tr>
<tr>
<td>$R(a, b) / c$</td>
<td>$R(a, b) = c$</td>
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### fhDLP

#### Semantics

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<th>DL syntax</th>
<th>Semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D(x) \leftarrow C_1(x), \ldots, C_n(x) \quad / c$</td>
<td>$\bigcap_{i=1}^n C_i \sqsubseteq D = c$</td>
<td>$\forall x \in \Delta^H \quad \text{val}(D(x), H_I) \geq c \times \min{\text{val}(C_i(x), H_I)</td>
</tr>
<tr>
<td>$C(y) \leftarrow R(x, y) \quad / c$</td>
<td>$T \sqsubseteq \forall R.C = c$</td>
<td>$\forall x, y \in \Delta^H \quad \text{val}(C(y), H_I) \geq c \times \text{val}(R(x, y), H_I)$</td>
</tr>
<tr>
<td>$C(a) \quad / c$</td>
<td>$C(a) = c$</td>
<td>$\text{val}(C(a), H_I) \geq c$</td>
</tr>
</tbody>
</table>
fhDLP in RIF functions, RIF predicates and RIF-URD

<table>
<thead>
<tr>
<th>Syntax Type</th>
<th>LP syntax</th>
<th>DL syntax</th>
<th>RIF function</th>
<th>RIF predicate</th>
<th>RIF-URD</th>
</tr>
</thead>
</table>
| LP syntax       | $P(x, y) \leftarrow R_1(x, y), \ldots, R_n(x, y) \quad /c$               | $\bigcap_{i=1}^{n} R_i \sqsubseteq P = c$   | Forall $?x \ ?y( P(?x \ ?y) = ?c_h : 
And(R_1(?x \ ?y) = ?c_1 \ldots R_n(?x \ ?y) = ?c_n 
?c_t = \text{External}(\text{numeric-minimum}(?c_1 \ldots ?c_n)) 
?c_h = \text{External}(\text{numeric-multiply}(c \ ?c_t)) )$ | Forall $?x ?y( P(?c_h \ ?x \ ?y) : 
And(R_1(?c_h \ ?x \ ?y) \ldots R_n(?c_n \ ?x \ ?y) 
?c_t = \text{External}(\text{numeric-minimum}(?c_1 \ldots ?c_n)) 
?c_h = \text{External}(\text{numeric-multiply}(c \ ?c_t)) )$ | Forall $?x \ ?y( P(?x \ ?y) : - \text{And}(R_1(?x \ ?y) \ldots R_n(?x \ ?y)) \quad /c )$ |
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Conclusions

• Presented two different principles of encoding uncertainty in RIF-BLD

• Proposed an extension of RIF leading to RIF-URD

• Presented fhDLP, a fuzzy extension to Description Logic Programs
Future Work

• Parameterize RIF-URD to support different theories of uncertainty in a unified manner

• Complement RIF-URD presentation syntax with RIF-URD XML syntax

• Explore further combination strategies of DL and LP
Questions?