The PSOATransRun 1.0 System for Object-Relational Reasoning in RuleML

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Gen Zou

Faculty of Computer Science,
University of New Brunswick, Fredericton, Canada
Outline

1. Introduction
2. Normalization of PSOA Source
3. Mapping the Normalized PSOA Source to Prolog
4. Conclusions
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Uses **positional-slotted object-applicative (psoa)** terms, permitting the application of a predicate (acting as a relation) to be [in an *oidless/oidful* dimension] without or with an Object IDentifier (OID) – typed by the predicate (acting as a class) – and the predicate’s arguments to be [in an orthogonal dimension] *positional, slotted, or combined*

**General case (multi-tuple), where “#” means “member of”:**

\[
\text{o # f([t_1,1 \ldots t_{1,n_1}] \ldots [t_m,1 \ldots t_{m,n_m}] \ p_1->v_1 \ldots p_k->v_k)}
\]

**Special cases (optional single-tuple brackets):**

- **Relationship:** \[ f([t_1 \ldots t_n]) \]
- **Shelf:** \[ \text{o # f([t_1 \ldots t_n])} \]
- **Frame:** \[ \text{o # f(p_1->v_1 \ldots p_k->v_k)} \]
- **Shelframe:** \[ \text{o # f([t_1 \ldots t_n] \ p_1->v_1 \ldots p_k->v_k)} \]

**For an **oidless** psoa term**, i.e. one without a ‘user’ OID, **objectification** will introduce a ‘system’-generated OID

**Psoa terms without class typing are expressed by Top**, specifying the root of class hierarchy
PSOA RuleML – Presentation Syntax (PS)

Integrates W3C RIF for relationships and frames (see above)

As in RIF PS:

- “oid is member of class” written as “oid#class” (see above)
- “class₁ is subclass of class₂” written as “class₁##class₂”
- Local constants prefixed by underscore (‘_’); variables prefixed by question mark (‘?’)
Introduction – PSOA TransRun 1.0

- **Efficient** reasoning in PSOA RuleML enabled
  - All forms of psoa terms, including relationships, shelves, pairships, and (shel)frames
  - (OID-)head-existential rules
  - Equality in the body, restricted to unification and external-function evaluation
  - Subclass formulas for ‘ABox’ reasoning only
  - Built-in arithmetic functions

Includes a composition of translator **PSOA2Prolog** and well-known **XSB Prolog** engine

- PSOA2Prolog translates Knowledge Bases (KBs) and queries in PSOA RuleML presentation syntax into a subset of the logic programming language **ISO Prolog**
- XSB Prolog engine provides efficient query answering over translated Prolog KB

**PSOA2Prolog** performs a multi-step source-to-source normalization followed by a mapping to the pure (Horn) subset of ISO Prolog
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Normalization

1. Objectification
2. Skolemization
3. Slotribution and Tupribution
4. Flattening
5. Rule Splitting
KB:
_hire(_Ernie _Kate)

Query:
?q0#_hire(?X ?Y)

Static: Generate fresh OID constant from ‘_1’, ‘_2’, ...
(transform above KB ground atom, use query unchanged):
_1#_hire(_Ernie _Kate)

Dynamic: Virtualize with ‘_oidcons’ function and equality ‘=’
(keep above KB unchanged, transform query atom):
Objectification – From Static to Static/Dynamic

- Static: generate OIDs for all of the KB’s oidless atoms
- Static/Dynamic (novel refinement)
  - Leave unchanged as many of the KB’s oidless atoms as possible, instead dynamically constructing virtual OIDs as query variable bindings
  - Partition the set of KB predicates into two disjoint subsets: *non-relational* (at least one occurrence in a multi-tuple, oidful, or slotted atom, or in a subclass formula) and *relational* (no such occurrence)
  - Statically generate OIDs only for the KB’s oidless psoa atoms with non-relational predicates
Perform OID virtualization for queries with OID variables corresponding to the KB’s psoa atoms with relational predicates

- Query atoms using the KB’s relational predicates with OID variables are rewritten via equalities that unify an OID variable with a (Skolem-like) OID-constructor (‘_oidcons’) function application
- Allow users to pose queries with OIDs regardless of whether the underlying KB clauses have OIDs or not
- Make maximum use of the underlying Prolog engine for efficient inference on KB clauses with relational predicates
Dynamic Objectification by OID Virtualization

- Leave all **KB atoms** with relational predicates unchanged.
- For each **query atom** $\psi$ using a relational KB predicate $f$:
  - If $\psi$ is a relationship, keep it unchanged.
  - If $\psi$ has a **non-variable** OID or a slot, rewrite it to explicit falsity, here encoded as $\text{Or}()$.
  - If $\psi$ has an **OID variable** and $m$ tuples, being of the form $?O#f([t_{1,1} \ldots t_{1,n_1}] \ldots [t_{m,1} \ldots t_{m,n_m}])$, equivalent to a tupribution-like conjunction, copying $?O#f$.
    
    
    $\text{And}(?O#f(t_{1,1} \ldots t_{1,n_1}) \ldots ?O#f(t_{m,1} \ldots t_{m,n_m})$, rewrite it to a relational conjunction using equality
    
    $$\text{And}(f(t_{1,1} \ldots t_{1,n_1}) \ ?O = \_oidcons(f \ t_{1,1} \ldots t_{1,n_1})$$

    $\ldots$

    $$f(t_{m,1} \ldots t_{m,n_m}) \ ?O = \_oidcons(f \ t_{m,1} \ldots t_{m,n_m})$$
Skolemization

- Specialized FOL Skolemization is employed to eliminate existentials in rule conclusions or facts, which are not allowed in Prolog.
- Replace each existential formula $\text{Exists } ?X (\sigma)$ in a rule conclusion or a fact with $\sigma[?X/_\text{skolem}k (?v_1 \ldots ?v_m)]$, where each occurrence of $?X$ in $\sigma$ becomes a Skolem function $/_\text{skolem}k$ applied to all universally quantified variables $?v_1 \ldots ?v_m$ from the clause’s quantifier prefix.
- **New skolem function name** $/_\text{skolem}k (k = 1, 2, \ldots)$ generated for each existential variable.
Slotribution and Tupribution

- Rewrite each psoa atom
  \[ \circ\#f([t_{1,1} \ldots t_{1,n_1}] \ldots [t_{m,1} \ldots t_{m,n_m}] \\
  p_1 \rightarrow v_1 \ldots p_k \rightarrow v_k) \]
  into a conjunction

  \[ \text{And}(\circ\#f \\
  \circ\#\text{Top}(t_{1,1} \ldots t_{1,n_1}) \ldots \circ\#\text{Top}(t_{m,1} \ldots t_{m,n_m}) \\
  \circ\#\text{Top}(p_1 \rightarrow v_1) \ldots \circ\#\text{Top}(p_k \rightarrow v_k)) \]
Flattening

- Extract each embedded interpreted function application as a separate equality
- Each atomic formula $\varphi$ (in a rule premise or a query) that embeds an external function application $\psi$, which is not on the top level of an equality, is replaced with $\text{And}(\varphi = \psi \ [\psi/\varphi], \text{where } \varphi \text{ is the first variable in } \varphi_1, \varphi_2, \ldots \text{ that does not occur in the enclosing rule}$
Rule Splitting

- Remove conjunctions in rule conclusions, which are not supported in Prolog
- Each rule with an $n$-ary conjunction in the conclusion

\[ \text{Forall } ?v_1 \ldots \ ?v_m \ (\text{And}(\varphi_1 \ldots \ \varphi_n) :- \ \varphi') \]

is split into $n$ rules

\[ \text{Forall } ?v_1 \ldots \ ?v_m \ (\varphi_1 :- \ \varphi') \]

\[ \ldots \]

\[ \text{Forall } ?v_1 \ldots \ ?v_m \ (\varphi_n :- \ \varphi') \]
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Simple Terms

Use recursive mapping function denoted by $\rho_{psoa}$

- **Constants**
  - If $c$ is a number, $\rho_{psoa}(c)$ is the corresponding Prolog number
  - If $c$ is an arithmetic built-in, $\rho_{psoa}(c)$ is the corresponding Prolog built-in
  - Otherwise, $\rho_{psoa}(c)$ is the single-quoted version of $c$

- **Variables**
  For a ‘?’-prefixed variable $v$, $\rho_{psoa}(v)$ replaces ‘?’ with the upper-case letter ‘Q’ (Question mark)
Central PSOA Constructs

Mapping from PSOA/PS constructs to Prolog constructs
(To accommodate the relationships preserved by dynamic objectification, the 4th-row mapping of \( f(t_1 \ldots t_k) \) has to be extended from functions to predicates \( f \))

<table>
<thead>
<tr>
<th>PSOA/PS Constructs</th>
<th>Prolog Constructs</th>
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</thead>
<tbody>
<tr>
<td>( \circ # \text{Top}(t_1 \ldots t_k) )</td>
<td>( \text{tupterm}(\rho_{\text{psoa}}(\circ), \rho_{\text{psoa}}(t_1) \ldots \rho_{\text{psoa}}(t_k)) )</td>
</tr>
<tr>
<td>( \circ # \text{Top}(p \rightarrow v) )</td>
<td>( \text{sloterm}(\rho_{\text{psoa}}(\circ), \rho_{\text{psoa}}(p), \rho_{\text{psoa}}(v)) )</td>
</tr>
<tr>
<td>( \circ # c() )</td>
<td>( \text{memterm}(\rho_{\text{psoa}}(\circ), \rho_{\text{psoa}}(c)) )</td>
</tr>
<tr>
<td>( f(t_1 \ldots t_k) )</td>
<td>( \rho_{\text{psoa}}(f)(\rho_{\text{psoa}}(t_1), \ldots, \rho_{\text{psoa}}(t_k)) )</td>
</tr>
<tr>
<td>( \text{And}(f_1 \ldots f_n) )</td>
<td>( (\rho_{\text{psoa}}(f_1), \ldots, \rho_{\text{psoa}}(f_n)) )</td>
</tr>
<tr>
<td>( \text{Or}(f_1 \ldots f_n) )</td>
<td>( (\rho_{\text{psoa}}(f_1) ; \ldots ; \rho_{\text{psoa}}(f_n)) )</td>
</tr>
<tr>
<td>( \text{Exists} \ ?v_1 \ldots \ ?v_m (\varphi) )</td>
<td>( \rho_{\text{psoa}}(\varphi) )</td>
</tr>
<tr>
<td>( \text{Forall} \ ?v_1 \ldots \ ?v_m (\varphi) )</td>
<td>( \rho_{\text{psoa}}(\varphi) )</td>
</tr>
<tr>
<td>( \varphi : - \psi )</td>
<td>( \rho_{\text{psoa}}(\varphi) : - \rho_{\text{psoa}}(\psi) ).</td>
</tr>
<tr>
<td>( \text{?v=External}(f(t_1 \ldots t_k)) )</td>
<td>( \text{is}(\rho_{\text{psoa}}(?v), \rho_{\text{psoa}}(f)(\rho_{\text{psoa}}(t_1), \ldots, \rho_{\text{psoa}}(t_k))) )</td>
</tr>
<tr>
<td>( c_1 # c_2 )</td>
<td>( \text{memterm}(X, \rho_{\text{psoa}}(c_2)) : - \text{memterm}(X, \rho_{\text{psoa}}(c_1)). )</td>
</tr>
</tbody>
</table>
Conclusions

- PSOATransRun 1.0 supports reasoning in PSOA RuleML by composing the efficient translator PSOA2Prolog and the efficient run-time engine XSB Prolog.
- Normalization employs a novel static/dynamic approach for the objectification step, which makes optimal use of the underlying Prolog engine for efficient inference on KB clauses with relational predicates.
- Future work includes adding support of other PSOA features, e.g. an expanded set of built-ins, and more detailed functionality and performance comparisons with realizations of other rule languages, e.g. Flora-2 and EYE.