Perspectival Knowledge in PSOA RuleML 1.0: Representation, Model Theory, and Translation

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Positional-Slotted Object-Applicative (PSOA) RuleML permits atom to apply predicate – possibly identified by Object IDentifier (OID) typed by predicate – to bag of tupled descriptors, each representing argument sequence, and to bag of slotted descriptors, each representing attribute-value pair.

Dimensions of oidless-vs.-oidful predicate applications & tupled-vs.-slotted descriptors augmented by 3rd dimension of psoa atoms: predicate-independent (perspeneutral) vs. predicate-dependent (perspectival).
In advanced Artificial Intelligence (AI) Knowledge Bases (KBs), notions like “context” and “perspective” are becoming increasingly relevant. While context mechanism allows to partition clauses of KB, introduction of perspective allows to describe same OID differently via multiple clause conclusions — e.g., atoms employed as facts — having different predicates.
Rich TA in PSOA: Individual OID John Described Independently and Under the Perspectives of Predicates Teacher, TA, Student
- Upper part shows diamond-shaped taxonomy of four predicates – Scholar, Teacher, Student, and TA – connected by heavy arcs understood to be implicitly labeled with subClassOf, where TA – directly below both Teacher and Student – exemplifies multiple inheritance.

- Lower part uses three predicates for perspectival hyperarc arrows starting with predicate labelnode, e.g. Teacher, pointing to OID, John, and cutting through further nodes before pointing to the last node. Optional labels on these hyperarcs, e.g. dept, are slot names, thus distinguishing slot from tuple hyperarcs. E.g., Teacher hyperarcs indicate, from right to left, that – under perspective of Teacher – John is characterized by (length-2 tuple for) Wed followed by Thu, is in dep(artmen)t of Physics, and has salary of 29400. On extreme left, labeled arc, starting directly at OID, records John’s (total) income (also) as 29400 – independently of, e.g., Teacher, TA, and Student perspectives.
Since John is represented as OID node pointed to and cut through by hyperarcs starting with three different predicates – Teacher, TA, and Student – he is involved under these different perspectives

The “pointing to” also entails multi-membership of John in three predicates, here acting as classes

Abbreviating “under the perspective of” to “as a”, we say “as a” entails “is a”, where “is a” of Semantic Nets is often called “is member of” on Semantic Web
Teacher##Scholar   Student##Scholar
TA##Teacher       TA##Student

John#TA(workload->high)
John#Teacher([Wed Thu]
   dept->Physics
   salary->29400
   income->29400)

John#Student([Mon Tue Fri]
   -[1995 8 17]
   dept->Math
   gender->male)
In (\(KB2\))’s upper four clauses, representing TA-diamond taxonomy part of visualization, “##” infix indicates \texttt{subClassOf} relation.

In lower three clauses, representing rest as positional-slotted object-applicative (\texttt{psoa}) atoms asserted as ground facts, the following notation is employed.
Psoa atoms use three predicates for perspectival hyperarc arrows starting with predicate labelnode, e.g. Teacher, pointing to OID, John, and cutting through further nodes before pointing to last node.

Optional labels on these hyperarcs, e.g. dept, are slot names, thus distinguishing slot from tuple hyperarcs.
E.g., Teacher hyperarcs indicate, from right to left, that – under perspective of Teacher – John is characterized by (length-2 tuple for) Wed followed by Thu, is in dep(artmen)t of Physics, and has salary of 29400

On extreme left, labeled arc, starting directly at OID, records John’s (total) income (also) as 29400 – independently of, e.g., Teacher, TA, and Student perspectives
Dual prefix characters “+” vs. “−” uniformly used for, respectively, dependent vs. independent descriptors, leading to four kinds of descriptors (exemplified with descriptors of (KB2)’s Student atom):

- For tuples, “+” vs. “−” used prior to opening square brackets, yielding syntaxes
  
  \[
  + [\ldots] \quad \text{vs.} \quad - [\ldots], \quad \text{e.g.} \\
  + [\text{Mon Tue Fri}] \quad \text{vs.} \quad - [1995 8 17]
  \]

- For slots, “+” vs. “−” used as shafts of infix arrows, yielding syntaxes
  
  \[
  \ldots + > \ldots \quad \text{vs.} \quad \ldots - > \ldots, \quad \text{e.g.} \\
  \text{dept} + > \text{Math} \quad \text{vs.} \quad \text{gender} - > \text{male}
  \]
For all $o$ $ht$ $hs$ ( % (R1)

$o#TA(workload+>high)

:-

And(

  $o#Teacher(coursehours+>ht)

  External(
    pred:numeric-greater-than($ht 10))  % $ht>10

  $o#Student(coursehours+>hs)

  External(
    pred:numeric-greater-than($hs 18)))  % $hs>18

)
Rule conclusion deduces – for any OID $\circledast$ that is member of TA – TA-dependent slot workload$\rightarrow$high from condition doing arithmetic threshold comparisons for Teacher-dependent slot coursehours$\rightarrow$?ht and Student-dependent slot coursehours$\rightarrow$?hs

Three $\circledast$ occurrences refer to same individual, but under different perspectives

Rule thus augments each quantitative-condition-satisfying OID $\circledast$ with dependent qualitative workload slot
Assuming that (KB2)’s Teacher/Student descriptors for John are augmented by corresponding dependent quantitative coursehours slots,

John#Teacher(... coursehours+>12 ...)  
John#Student(... coursehours+>20 ...)

rule used to answer dependent-slot query

John#TA(workload+>high)  

by unifying with conclusion, followed by retrieval of Teacher/Student-perspectival coursehours 12/20 in first/third conditions and “>”-comparing them with thresholds 10/18 in second/fourth conditions.
Similarly, rule will make dependent-slot non-ground (variable-containing) query

\(?\text{who}\#\text{TA} (\text{workload+} \rightarrow ?\text{level})\)

succeed, with bindings \(?\text{who} = \text{John}\) and \(?\text{level} = \text{high}\)
Four lines of subsequences for four kinds of descriptors, where superscripts indicate subterms that are part of dependent \((^+)\) vs. independent \((-)\) descriptors, and right-slot, right-independent normal form is assumed:

\[
o#f \left( + \left[ t_{1,1}^+ \ldots t_{1,n_1^+}^+ \right] \ldots + \left[ t_{m^+,1}^+ \ldots t_{m^+,n_{m^+}^+}^+ \right] \\
- \left[ t_{1,1}^- \ldots t_{1,n_1^-}^- \right] \ldots - \left[ t_{m^-,1}^- \ldots t_{m^-,n_{m^-}^-}^- \right] \\
p_{1^+}^+ > v_{1^+} \ldots p_{k^+}^+ > v_{k^+}^+ \\
p_{1^-}^- > v_{1^-} \ldots p_{k^-}^- > v_{k^-}^-
\]

Presentation Syntax: Principles

- Employs document root RuleML, rather than earlier Document, and Assert, rather than earlier Group, complementing it with Query
- Refines all descriptors for ("DI"-)distinction of Dependent vs. Independent tuples (TUPLEDI) and slots (SLOTDI)
- Reflects use of (a) oidless and oidful psoa terms as Atoms in/as FORMULAs, (b) oidful Atoms (for unnesting, leaving behind the OID term) as TERMS in Atoms and Expressions, as well as (c) oidless psoa terms as Expressions
- Revises CLAUSE, Implies, and HEAD productions for closure under objectification and slotribution/tupribution
RuleML ::= 'RuleML' '(' Base? Prefix* Import* 
(Assert | Query)* ')' 
Base ::= 'Base' '(' ANGLEBRACKIRI ')' 
Prefix ::= 'Prefix' '(' Name ANGLEBRACKIRI ')' 
Import ::= 'Import' '(' ANGLEBRACKIRI PROFILE? ')' 
Assert ::= 'Assert' '(' (RULE | Assert)* ')' 
Query ::= 'Query' '(' FORMULA ')' 
RULE ::= ('Forall' Var+ '(' CLAUSE ')') | CLAUSE 
CLAUSE ::= Implies | HEAD 
Implies ::= HEAD '}:-' FORMULA 
HEAD ::= ATOMIC | 'Exists' Var+ '( HEAD ')' | 
'And' '(' HEAD* ')' 
PROFILE ::= ANGLEBRACKIRI
Presentation Syntax: EBNF for Condition Language

FORMULA ::= 'And'/'Or' '(' FORMULA* ')' | 'Exists' Var+ '(' FORMULA ')' | ATOMIC | 'External' '(' Atom ')' 

ATOMIC ::= Atom | Equal | Subclass 

Atom ::= ATOMOIDLESS | ATOMOIDFUL 

ATOMOIDLESS/FUL ::= PSOAOIDLESS/FUL 

Equal ::= TERM '=' TERM Subclass ::= TERM '##' TERM 

PSOA ::= PSOAOIDLESS | PSOAOIDFUL 

PSOAOIDLESS ::= TERM '(' (TERM* | TUPLEDI*) SLOTDI* ')' 

PSOAOIDFUL ::= TERM '#' PSOAOIDLESS 

TUPLEDI ::= ('+' | '-') '[ [' TERM* ' ] ] 

SLOTDI ::= TERM ('+' | '->') TERM 

TERM ::= Const | Var | ATOMOIDFUL | Expr | 

Expr ::= PSOAOIDLESS 'External' '(' Expr ')' 

Const ::= '"' UNICODESTRING '"^^' SYMSPACE | 

Var ::= '?' PN_LOCAL? 

SYMSPACE ::= ANGLEBRACKIRI | CURIE
PSOA RuleML 1.0/XML serialization syntax extends Hornlog RuleML 1.02/XML.

XML serialization syntax of PSOA RuleML 1.0 can be derived from presentation syntax.

Mainly differs from presentation syntax in being “striped”, alternating between edges (absent from presentation syntax) & Nodes.

For (dependent and independent) descriptor-defining EBNF-grammar productions of presentation syntax (reproduced – slightly modified – with “P(resentation):” label), we give EBNF-like productions of serialization syntax (introduced with “X(ML):” label).
P: TUPLEDI ::= `+` `['TERM* `']` | `-` `['TERM* `']`
X: TUPLEDI ::= tupdep | tup  % Different edges
X: tupdep ::= Tuple  % lead into same
X: tup ::= Tuple  % Tuple Node

P: SLOTDI ::= TERM `+>` TERM | TERM `->` TERM
X: SLOTDI ::= slotdep | slot  % Different edges
X: slotdep ::= TERM TERM  % lead into same
X: slot ::= TERM TERM  % pair of TERM Nodes
General case of psoa terms in serialization syntax can be instantiated for atoms as follows (decorated letters $t$, $p$, and $v$ are understood here to stand for serialized terms, properties, i.e. slot names, and values, i.e. slot fillers):

```
<Atom>
  <oid><Ind>o</Ind></oid><op><Rel>f</Rel></op>
  <tupdep><Tuple>t_{1,1}^+ \ldots t_{1,n_1^+}^+</Tuple></tupdep> \ldots
  <tupdep><Tuple>t_{m^+,1}^+ \ldots t_{m^+,n_{m^+}}^+</Tuple></tupdep>
  <tup><Tuple>t_{1,1}^- \ldots t_{1,n_1^-}^-</Tuple></tup> \ldots
  <tup><Tuple>t_{m^-,1}^- \ldots t_{m^-,n_{m^-}}^-</Tuple></tup>
  <slotdep>p_{1}^+ v_{1}^+</slotdep> \ldots <slotdep>p_{k^+}^+ v_{k^+}^+</slotdep>
  <slot>p_{1}^- v_{1}^-</slot> \ldots <slot>p_{k^-}^- v_{k^-}^-</slot>
</Atom>
```
Psoa-atom facts of Rich TA example (KB2) in presentation syntax result in this serialization:

<Atom>
  <oid><Ind>John</Ind></oid><op><Rel>TA</Rel></op>
  <slotdep><Ind>workload</Ind><Ind>high</Ind></slotdep>
</Atom>

<Atom>
  <oid><Ind>John</Ind></oid><op><Rel>Teacher</Rel></op>
  <tupdep><Tuple><Ind>Wed</Ind><Ind>Thu</Ind></Tuple></tupdep>
  <slotdep><Ind>dept</Ind><Ind>Physics</Ind></slotdep>
  <slotdep><Ind>salary</Ind><Ind>29400</Ind></slotdep>
  <slot><Ind>income</Ind><Ind>29400</Ind></slot>
</Atom>
<Atom>
  <oid><Ind>John</Ind></oid><op><Rel>Student</Rel></op>
  <tupdep>
    <Tuple><Ind>Mon</Ind><Ind>Tue</Ind><Ind>Fri</Ind></Tuple>
  </tupdep>
  <tup>
    <Tuple><Ind>1995</Ind><Ind>8</Ind><Ind>17</Ind></Tuple>
  </tup>
  <slotdep><Ind>dept</Ind></slotdep>
  <slot><Ind>gender</Ind></slot>
</Atom>
To incorporate perspectival descriptors, slotribution/tupribution is revised to replace every oidful psoa atom having general form

\[
\text{o#f}(+ [t^+_1,1 \ldots t^+_1,n^+_1] \ldots + [t^+_m,1 \ldots t^+_m,n^+_m] \\
- [t^-_1,1 \ldots t^-_1,n^-_1] \ldots - [t^-_m,1 \ldots t^-_m,n^-_m] \\
p^+_1 \rightarrow v^+_1 \ldots p^+_k \rightarrow v^+_k \\
p^-_1 \rightarrow v^-_1 \ldots p^-_k \rightarrow v^-_k)
\]

with the conjunction

\[
\text{And}(\text{o#f} \\
\text{o#f}(+ [t^+_1,1 \ldots t^+_1,n^+_1] \ldots + [t^+_m,1 \ldots t^+_m,n^+_m]) \\
\text{o#Top}(- [t^-_m,1 \ldots t^-_m,n^-_m]) \ldots \text{o#Top}(- [t^-_m,1 \ldots t^-_m,n^-_m]) \\
\text{o#f}(p^+_1 \rightarrow v^+_1) \ldots \text{o#f}(p^+_k \rightarrow v^+_k) \\
\text{o#Top}(p^-_1 \rightarrow v^-_1) \ldots \text{o#Top}(p^-_k \rightarrow v^-_k))
\]
Slotribution/tupribution-yielded conjuncts are converted to relational-only logic using reserved predicates \textit{tupterm}, \textit{prdtupterm}, \textit{sloterm}, and \textit{prdsloterm} for independent tuple terms, dependent tuple terms, independent slot terms, and dependent slot terms, respectively, as shown in table where $\rho$ denotes recursive mapping from PSOA to Prolog, TPTP, etc.

<table>
<thead>
<tr>
<th>Psoa Atoms</th>
<th>Prolog and TPTP Atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>o#f</td>
<td>memterm($\rho(o), \rho(f)$)</td>
</tr>
<tr>
<td>o#Top([-t_1...t_n])</td>
<td>tupterm($\rho(o), \rho(t_1), \ldots, \rho(t_n)$)</td>
</tr>
<tr>
<td>o#f([+t_1...t_n])</td>
<td>prdtupterm($\rho(o), \rho(f), \rho(t_1), \ldots, \rho(t_n)$)</td>
</tr>
<tr>
<td>o#Top(p-&gt;v)</td>
<td>sloterm($\rho(o), \rho(p), \rho(v)$)</td>
</tr>
<tr>
<td>o#f(p-&gt;v)</td>
<td>prdsloterm($\rho(o), \rho(f), \rho(p), \rho(v)$)</td>
</tr>
</tbody>
</table>
Conclusions

- Model-theoretic semantics uses ‘built-in’ slotribution/tupribution
- PSOATransRun implementation realizes this as part of a transformation chain
  - Efficient Java/ANTLR-based open-source system
- Schema for serialization syntax is being standardized in Relax NG