Integrating Positional and Slotted Knowledge

on the Semantic Web

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'Human-Oriented' POSL ⟷ 'Machine-Oriented' RuleML

▷ POSL integrates **po**sitional and **sl**otted knowledge for humans

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▷ POSL ↔ OO RuleML translators in OO jDREW and as servlets:

  ▷ Parser: `http://www.ruleml.org:8080/converters/`
     `servlet/AsciiToRuleML`

  ▷ Generator: `http://www.ruleml.org:8080/converters/`
     `servlet/RuleMLToAscii`

Advantages of 'Human-Oriented' Web Knowledge Syntax

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▷ Develop knowledge bases and parse into XML markup (cf. N3):

  ▷ Parser reads for XML-aware tools
  ▷ Generator prints for stack-limited humans

Semantic Web Language Design Space

▷ Object-centered instance descriptions via binary properties (RDF)

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▷ Taxonomies over classes and properties (RDFS)

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▷ Taxonomies over classes and properties (RDFS)

▷ Class-forming operations and class/property axioms (OWL DL)

▷ Derivation, integrity, transformation, and reaction rules (RuleML)

Integrations of Semantic Web Languages

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⤳ Web information integration

E.g.: Mapping object-centered representations to positional ones

Orthogonal, Integrated Design for POSL

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▷ Incorporate above notions so they can be used and revised independently

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▷ Often needed conjointly in the XML&RDF Web

Positional Notations

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▷ POSL uses Prolog-like syntax, e.g. for ground facts:

```
shipment(PC,47.5,BostonMoS,LondonSciM).
shipment(PDA,9.5,LondonSciM,BostonMoS).
```

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▷ POSL uses F-logic-inspired syntax, obtaining these facts:

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shipment(cargo->PC;price->47.5;source->BostonMoS;dest->LondonSciM).
shipment(cargo->PDA;price->9.5;source->LondonSciM;dest->BostonMoS).
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▷ POSL uses Prolog/F-logic-combining syntax, obtaining these facts:

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Complex Terms and Plexes

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notation	cterm	plex
positional	`stakepair[MM,SS]`	`[MM,SS]`
slotted	`stakepair[owner->MM;shipper->SS]`	`[owner->MM;shipper->SS]`
positional-slotted	`stakepair[MM;shipper->SS]`	`[MM;shipper->SS]`

Non-Ground Formulas for the Three Notations

▷ Variable arguments interpreted as: universally (existentially) quantified in facts (queries)

▷ Variables can be named (prefix "?") or anonymous (stand-alone "?")

▷ E.g.: Non-ground query of earlier positional `shipment` ground fact:

`shipment(PC,?,BostonMoS,?goal)`

succeeds, binding `?goal` to `LondonSciM`

Rest Arguments – Basics

▷ Rests permitted for (*polyadic*) atoms

    ▷ One for positional arguments, one for slotted arguments

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▷ Slotted arguments separated from slotted rest by " ! "

▷ Rest itself normally a variable, for varying number of arguments

▷ 'Fixed-arity/polyadic' is orthogonal to 'positional/slotted'

Rest Arguments – Anonymous

▷ Anonymous variable usable as positional or slotted "don't care" rest

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▷ Anonymous variable usable as positional or slotted "don't care" rest

▷ Slotted "don't care" rest "!?" makes option from F-logic's convention: to tolerate arbitrary *excess slots* in either formula (e.g., a fact), having slot names not used by any slot of the other ("!?"-)formula (e.g., a query), for unification

Rest Arguments – Examples (I)

For the earlier slotted `PC-shipment` fact

`shipment(cargo->PC;price->47.5;source->BostonMoS;dest->LondonSciM).`

▷ the query

  `shipment(cargo->?what;price->?;source->BostonMoS;dest->?goal)`

  succeeds, binding `?what` to `PC` and `?goal` to `LondonSciM`

Rest Arguments – Examples (I)

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▷ the query

`shipment(cargo->?what;price->?;source->BostonMoS;dest->?goal)`

succeeds, binding `?what` to `PC` and `?goal` to `LondonSciM`

▷ However, the query

`shipment(owner->?who;cargo->?;price->?;source->BostonMoS;dest->?)`

fails because of its excess slot named `owner`

Rest Arguments – Examples (II)

Similarly, for the earlier slotted `PC-shipment` fact

`shipment(cargo->PC;price->47.5;source->BostonMoS;dest->LondonSciM).`

▷ the query

  `shipment(cargo->?what;source->BostonMoS;dest->?goal)`

  fails because of the fact's excess slot named `price`

Rest Arguments – Examples (II)

Similarly, for the earlier slotted `PC-shipment` fact

```
shipment(cargo->PC;price->47.5;source->BostonMoS;dest->LondonSciM).
```

▷ the query

```
shipment(cargo->?what;source->BostonMoS;dest->?goal)
```
fails because of the fact's excess slot named `price`

▷ On the other hand, the query

```
shipment(cargo->?what;source->BostonMoS;dest->?goal!?)
```
again succeeds with initial bindings, since slotted "rest doesn't care",

"`!?`", unifies `price` slot (independent of where it occurs in fact)

Rest Arguments – Examples (III)

▷ Conversely, earlier fact would tolerate excess query slots such as in above `owner` query after making it non-ground via anonymous rest:

`shipment(cargo->PC;price->47.5;source->BostonMoS;dest->LondonSciM!?).`

Rest Arguments – Examples (III)

▷ Conversely, earlier fact would tolerate excess query slots such as in above `owner` query after making it non-ground via anonymous rest:

`shipment(cargo->PC;price->47.5;source->BostonMoS;dest->LondonSciM!?).`

▷ If query also contains anonymous rest, both it and the fact can contain excess slots, as in

`shipment(owner->?who;cargo->?what;source->BostonMoS;dest->?goal!?)`

which succeeds with initial bindings, since query rest unifies fact's `price` slot and fact rest unifies query's `owner` slot, leaving variable `?who` free, and querier agnostic about the owner

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Rest Arguments – Novelty

$\rightsquigarrow$

▷ If anonymous rest slots are employed in all formulas, effect of F-logic's implicit rest variables is obtained

▷ More precise, "!"-free slotted formulas can enforce more restricted unifications where needed

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▷ Unify the zero or more remaining arguments

▷ Before being bound to a variable, polyadic rest $e_1, \ldots, e_Z$ or $s_1 \rightarrow f_1; \ldots; s_Z \rightarrow f_Z$ made into single complex term, namely plex $[e_1, \ldots, e_Z]$ or $[s_1 \mathord{-}\mathord{>} f_1; \ldots; s_Z \mathord{-}\mathord{>} f_Z]$, respectively

Atom and Cterm Syntax Summary

With both kinds of rests, these are the most general (non-normal) forms of positional-slotted atoms and cterms (for normal forms all slots go to the right):

```
r(s1->f1;...;sL->fL;e1,...,eM|Ve;sL+1->fL+1;...;sN->fN!Vf)
c[s1->f1;...;sL->fL;e1,...,eM|Ve;sL+1->fL+1;...;sN->fN!Vf]
```

Semantics of Atoms and Cterms – Instantiation & Equality

Based on slotted extensions to the positional (here, LP) notions of clause instantiation and ground equality (model-theoretic semantics) as well as unification (proof-theoretic semantics)

▷ *Slotted instantiation* recursively walks through fillers of slots, substituting dereferenced values from substitution (environment) for any variables encountered

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Based on slotted extensions to the positional (here, LP) notions of clause instantiation and ground equality (model-theoretic semantics) as well as unification (proof-theoretic semantics)

▷ *Slotted instantiation* recursively walks through fillers of slots, substituting dereferenced values from substitution (environment) for any variables encountered

▷ *Slotted ground equality* recursively compares two ground atoms or cterms after lexicographic sorting of slots encountered

Semantics of Atoms and Cterms – Unification

Slotted unification performs sorting, uses the slotted instantiation of variables, and otherwise proceeds left-to-right as for positional unification,

▷ pairing up identical slot names before recursively unifying their fillers,

▷ while collecting excess slots on each level in the plex value of corresponding slotted rest variable

Positional Rules

▷ Horn rules, in POSL written using Prolog-like syntax, but again employing "?"(-prefixed) variables

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▷ `reciship` example starts as Datalog rule for reciprocal shippings of unspecified cargos at a total cost between two sites:

```
reciship(?cost,?A,?B) :-
    shipment(?,?cost1,?A,?B),
    shipment(?,?cost2,?B,?A),
    add(?cost,?cost1,?cost2).
```

Variable Typing

▷ Types can be defined as RDFS or OWL classes

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▷ Use types `Float`, `Address`, and `Product` in `reciship` rule:

```
reciship(?cost:Float,?A:Address,?B:Address) :-
    shipment(?:Product,?cost1:Float,?A,?B),
    shipment(?:Product,?cost2:Float,?B,?A),
    add(?cost,?cost1,?cost2).
```

Slotted Rules

▷ Much like in F-logic (typing could be added, as above)

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▷ `reciship` **relation with slot names** `price, site1,` **and** `site2.`
Analogously, `add` **relation with slot names** `sum, addend1,` **and**
`addend2:`

```
reciship(price->?cost;site1->?A;site2->?B) :-
    shipment(cargo->?;price->?cost1;source->?A;dest->?B),
    shipment(cargo->?;price->?cost2;source->?B;dest->?A),
    add(sum->?cost;addend1->?cost1;addend2->?cost2).
```

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▷ `reciship` rule can be positional for conclusion and `add` premise, and slotted for the `shipment` premises:

```
reciship(?cost,?A,?B) :-
   shipment(cargo->?;price->?cost1;source->?A;dest->?B),
   shipment(cargo->?;price->?cost2;source->?B;dest->?A),
   add(?cost,?cost1,?cost2).
```

Semantics of (Positional-)Slotted Clause Sets

On top of the earlier semantic basis for atoms and complex terms

▷ On clause level, three notations have same interpretation, hence earlier treatment naturally extends to (positional-)slotted generalizations of positional (LP) clauses

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▷ On clause level, three notations have same interpretation, hence earlier treatment naturally extends to (positional-)slotted generalizations of positional (LP) clauses

▷ Further semantic treatment via Herbrand models and resolution proof theory directly follows positional treatment

▷ Typing (sorts) can be reduced to unsorted case

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▷ Adapts sorted indexing techniques to RDFS and to OO jDREW

Applications of POSL

▷ Product-seaking/advertising trees in the tree-similarity-based AgentMatcher system

▷ Music filtering rules in the collaborative system RACOFI Music

▷ Business-analysis rules in New Brunswick Business Knowledge Base

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▷ Occurrences of the same language element can thus be disambiguated

▷ Orthogonal to the positional/slotted distinction

URIs in POSL

▷ An (active) URI is enclosed in a pair of angular brackets, $<\ldots>$, following IETF's generic URI syntax

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▷ Symbols can also be entirely replaced by URIs

▷ Symbols can still be used without URIs

Webized Individuals

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▷ Can use URI for the intended `SpeedShip` company's homepage `<http://sphip.com>`

    ▷ employed in place of the individual symbol, as practiced in RDF, N3, and other Web languages (here, first argument of a 5-ary fact):

    `shipment(<http://sphip.com>,PC,47.5,BostonMoS,LondonSciM).`

    ▷ or, associated with it:

    `shipment(SpeedShip<http://sphip.com>,PC,47.5,BostonMoS,LondonSciM).`

Webized Relations

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▷ The 4-ary and 5-ary positional `shipment` relations can be uniquely distinguished via URIs pointing to different signatures:

```
shipment<http://transport.org/rels/pos/shipment#4>
shipment<http://transport.org/rels/pos/shipment#5>
```

Webized Slots

▷ URIs in place of, as pioneered by RDF, or in addition to, symbolic slot names

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▷ `shipment` slots may be drawn from URIs containing fragmentid's #*id* with slot names, except for `charge` fragmentid, for which local slot name `price` is kept:

```
shipment(<http://transport.org/slots/shipment#shipper>->SpeedShip;
         <http://transport.org/slots/shipment#cargo>->PC;
         price<http://ebizguide.org/slots#charge>->47.5;
         <http://trajectory.org/slots/movement#source>->BostonMoS;
         <http://trajectory.org/slots/movement#dest>->LondonSciM).
```

Webized Types

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▷ `Product` type can be associated with a URI for the corresponding OWL class:

```
Product<http://www.daml.org/services/owl-s/1.0/
              ProfileHierarchy.owl#Product>
```

Web-Typed Rule Example

Use `Product<...>` for typing anonymous variable of earlier positional rule, `Float` from XML Schema Datatypes for its `cost`-like variables, and webized `Address` type:

```
reciship(?cost:Float<http://www.w3.org/TR/2001/
                     REC-xmlschema-2-20010502/#float>,
         ?A:<http://ebizguide.org/types#Address>,
         ?B:<http://ebizguide.org/types#Address>) :-
   shipment(?:Product<http://www.daml.org/services/owl-s/1.0/
                      ProfileHierarchy.owl#Product>,
            ?cost1:Float<http://www.w3.org/TR/2001/
                         REC-xmlschema-2-20010502/#float>,
            ?A,?B),                                      ... .
```

Anchored POSL Atoms

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▷ Fact atom can be *anchored* by OID (symbolic name or URI, possibly prefixed by symbolic name)

▷ Special 'zeroth' argument separated from further arguments by hat infix "ˆ": $relation(oid\hat{}\ arg_1...arg_N)$

Anchoring Examples

Earlier 4-ary positional and slotted facts (see "%" comments) can now be anchored using variously webized versions of names like `s1` and `s2`:

```
shipment(s1^PC,47.5,BostonMoS,LondonSciM).              % positional

shipment(<http://sphip.com/event#s2>^PDA,9.5,LondonSciM,BostonMoS).

shipment(s1<http://sphip.com/event#s1>^                 % slotted
        cargo->PC;price->47.5;
        source->BostonMoS;dest->LondonSciM).

shipment(<http://sphip.com/event#s2>^
        ...).
```

RDF Descriptions as Anchored Facts

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▷ In the absence of `rdf:type` these facts have null relation

▷ For the following comparison assume `shipper` slot etc. determine `shipment` relationship, so no relation is needed

Comparison: RDF Description ...

```
<rdf:RDF
 xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
 xmlns:s="http://transport.org/slots/shipment#"
 xmlns:p="http://ebizguide.org/slots#"
 xmlns:m="http://trajectory.org/slots/movement#">
 <rdf:Description about="http://sphip.com/event#s1">
  <s:shipper rdf:resource="http://sphip.com"/>
  <s:cargo>PC</s:cargo>
  <p:charge>47.5</p:charge>
  <m:source rdf:resource="http://www.mos.org/info/contact.html"/>
  <m:dest rdf:resource="http://www.sciencemuseum...location.asp"/>
 </rdf:Description>
</rdf:RDF>
```

Comparison: ... POSL Fact

```
(<http://sphip.com/event#s1>^
 <http://transport.org/slots/shipment#shipper>->
                         <http://sphip.com>;
 <http://transport.org/slots/shipment#cargo>->PC;
 <http://ebizguide.org/slots#charge>->47.5;
 <http://trajectory.org/slots/movement#source>->
                         <http://www.mos.org/info/contact.html>;
 <http://trajectory.org/slots/movement#dest>->
                         <http://www.sciencemuseum...location.asp>).
```

Symbolic and webized individuals are represented in the same manner here, so that symbolic name like `PC` can later be replaced by blank node or URI, without changing enclosing slot

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▷ In the following again compare RDF and POSL

Comparison: RDF Blank Node ...

```
<rdf:RDF
  ...
  <rdf:Description about="http://sphip.com/event#s1">
      ...
    <s:cargo rdf:nodeID="PeterMillerPC"/>
    ...
  </rdf:Description>
  <rdf:Description rdf:nodeID="PeterMillerPC">
    <p:value>2500.0</p:value>
    <p:weight>17.5</p:weight>
  </rdf:Description>
</rdf:RDF>
```

Comparison: ... POSL Skolem Constant

```
{
  (<http://sphip.com/event#s1>^
   ...
   <http://transport.org/slots/shipment#cargo>->_PeterMillerPC;
   ...).
  (_PeterMillerPC^
   <http://ebizguide.org/slots#value>->2500.0;
   <http://ebizguide.org/slots#weight>->17.5).
}
```

Module "{…}" of two facts connected by an existential variable, in POSL a local Skolem constant (global to clauses), _PeterMillerPC

Generating New Skolem Constants

▷ Module-scoped, *unique Skolem constants* can be generated by *New Skolem constant* primitive (written as a stand-alone "_")

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▷ Model theory for (New) Skolem constants in rules has been developed on top of *anonymous-domain-augmented Herbrand universe* by Yang&Kifer03

RDF-Like Rule Example in POSL

Earlier slotted rule modified to query such facts, inferring, as new "_"-anchored atoms, OIDs and aggregated cost of reciprocal shippings (webized slot names abridged using symbolic names):

```
reciship(_^forth->?oid1;back->?oid2;
             price->?cost;site1->?A;site2->?B) :-
   (?oid1^shipper->?;cargo->?;price->?cost1;source->?A;dest->?B),
   (?oid2^shipper->?;cargo->?;price->?cost2;source->?B;dest->?A),
   add(sum->?cost;addend1->?cost1;addend2->?cost2).
```

Notice that ?oid1/?oid2 variables occur in two roles: to the left of "^", as proper OIDs, and to the right of "^", as ordinary data values

Metadata Deduction Rules

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▷ Such rules can be employed within semantic search engine on RDF/POSL-described metadata for high-precision results

▷ E.g.: Priced pairs of Web objects about A-to-B and B-to-A shippings

Conclusions

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▷ Extensions in online POSL document `www.ruleml.org/submission/ruleml-shortation.html`

▷ Current work concerns general POSL treatment of slot cardinalities (cf. exact, min, and max cardinality restrictions in OWL DL)

▷ Future research on extending OIDs for general object identity: From OO rules to OOP-like reaction rules and Web Services