Integrating Positional and Slotted Knowledge on the Semantic Web

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‘Human-Oriented’ POSL ↔ ‘Machine-Oriented’ RuleML

- POSL integrates positional and slotted knowledge for humans
  (e.g.: Prolog’s positional and F-logic’s slotted knowledge)
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▷ POSL ↔ OO RuleML translators in OO jDREW and as servlets:

  ▷ **Parser:** [http://www.ruleml.org:8080/converters/servlet/AsciiToRuleML](http://www.ruleml.org:8080/converters/servlet/AsciiToRuleML)
  
  ▷ **Generator:** [http://www.ruleml.org:8080/converters/servlet/RuleMLToAscii](http://www.ruleml.org:8080/converters/servlet/RuleMLToAscii)
Advantages of ‘Human-Oriented’ Web Knowledge Syntax

- Allow knowledge shorthand, presentation, and (even) exchange
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▷ Study expressive classes and formal semantics (cf. OWL)

▷ Develop knowledge bases and parse into XML markup (cf. N3):
  ◦ Parser reads for XML-aware tools
  ◦ Generator prints for stack-limited humans
Object-centered instance descriptions via binary properties (RDF)
Semantic Web Language Design Space

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- Taxonomies over classes and properties (RDFS)
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- Class-forming operations and class/property axioms (OWL DL)
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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

- Object-centered descriptions plus rules (N3, OO RuleML)
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- Description logic plus rules (Description Logic Programs, SWRL)
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→ Web information integration

E.g.: Mapping object-centered representations to positional ones
Orthogonal, Integrated Design for POSL

- Orthogonal (‘decoupled’) dimensions for systematic language development
Orthogonal, Integrated Design for POSL

▶ Orthogonal (‘decoupled’) dimensions for systematic language development

▶ Incorporate above notions so they can be used and revised independently
Both predated the (Semantic) Web, yet have been very useful for it

- Prolog: Positional language based on Horn logic with facts and rules
- F-logic: Slotted language with object-centered descriptions and rules
Prolog and F-logic Integrated in POSL

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Concise ASCII syntaxes, elegant semantics, and decent computational properties
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  - Prolog: Positional language based on Horn logic with facts and rules
  - F-logic: Slotted language with object-centered descriptions and rules
- Concise ASCII syntaxes, elegant semantics, and decent computational properties
- Often needed conjointly in the XML&RDF Web
Positional Notations

- Ordered sequences of possibly repeating objects
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- In logics used for the arguments to n-ary relations
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- E.g.: shipment relation with ordered arguments cargo, price, source, and destination
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- In logics used for the arguments to n-ary relations
- E.g.: shipment relation with ordered arguments cargo, price, source, and destination

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

  shipment(PC, 47.5, BostonMoS, LondonSciM).
Slotted Notations

-Unordered sets of attribute-value pairs
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- In frame logics used for molecular formulas
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- E.g.: shipment relation as slotted frame, with unordered *slot names* such as cargo

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

  shipment (cargo->PC; price->47.5; source->BostonMoS; dest->LondonSciM).
Positional-Slotted Notations

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Positional-Slotted Notations

▷ Ordered and unordered combined

▷ In Lisp used for some functions

▷ E.g.: shipment relation with two positional arguments, cargo and price, and two slots, source and destination

▷ POSL uses Prolog/F-logic-combining syntax, obtaining these facts:

  shipment(PC,47.5;source→BostonMoS;dest→LondonSciM).
  shipment(PDA,9.5;source→LondonSciM;dest→BostonMoS).
All three notations are possible for any complex term ($cterm$)
Complex Terms and Plexes

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▷ *plex* regarded as special case of a constructorless cterm
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- E.g.: Pair of stakeholders (“[…]” for constructor applications):
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▷ E.g.: Pair of stakeholders (“[…]” for constructor applications):

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Non-Ground Formulas for the Three Notations

- Variable arguments interpreted as: universally (existentially) quantified in facts (queries)
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▷ Variables can be named (prefix “?”) or anonymous (stand-alone “?”)

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

\[
\text{shipment}(PC, ?, BostonMoS, ?goal)
\]

succeeds, binding \( ?\text{goal} \) to LondonSciM
Rest Arguments – Basics

Rests permitted for \textit{(polyadic)} atoms

- One for positional arguments, one for slotted arguments
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▷ Positional arguments separated from positional rest by “|”
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✧ Rest itself normally a variable, for varying number of 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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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**

\[
\text{shipment (cargo->PC; price->47.5; source->BostonMoS; dest->LondonSciM)}.
\]

▷ the query

\[
\text{shipment (cargo->?what; price->?; source->BostonMoS; dest->?goal)}
\]

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

However, the query
shipment(owner->?who;cargo->?;price->?;source->BostonMoS;dest->?)
fails because of its excess slot named owner
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
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)
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
If anonymous rest slots are employed in all formulas, effect of F-logic’s implicit rest variables is obtained.
Rest Arguments – Novelty

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.
Rest Arguments – Unification

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Unify the zero or more remaining arguments
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▷ “|” and “!” rests can follow after zero or more fixed positional and slotted arguments

▷ 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 $[s_1 \rightarrow f_1; \ldots; s_Z \rightarrow f_Z]$, 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):

\[ r(s_1 \rightarrow f_1; \ldots; s_L \rightarrow f_L; e_1, \ldots, e_M|V; s_{L+1} \rightarrow f_{L+1}; \ldots; s_N \rightarrow f_N!Vf) \]
\[ c[s_1 \rightarrow f_1; \ldots; s_L \rightarrow f_L; e_1, \ldots, e_M|V; s_{L+1} \rightarrow f_{L+1}; \ldots; s_N \rightarrow f_N!Vf] \]
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,
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*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:

\[
\text{reciship}(\text{?cost}, \text{?A}, \text{?B}) : - \\
\text{shipment}(\text{?}, \text{?cost1}, \text{?A}, \text{?B}), \\
\text{shipment}(\text{?}, \text{?cost2}, \text{?B}, \text{?A}), \\
\text{add}(\text{?cost}, \text{?cost1}, \text{?cost2}).
\]
Variable Typing

▷ Types can be defined as RDFS or OWL classes
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- Use types **Float**, **Address**, and **Product** in reciship rule:

  ```prolog
  reciship(?cost:Float, ?A:Address, ?B:Address) :-
  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).
```
Positional-Slotted Rules

Positional and slotted relations *for* conclusion or premises, or positional-slotted relations *within* conclusion or premises
Positional-Slotted Rules

▷ Positional and slotted relations for conclusion or premises, or positional-slotted relations within conclusion or premises

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

\[
\text{reciship}(\texttt{?cost}, \texttt{?A}, \texttt{?B}) : - \\
\text{shipment} \texttt{(cargo->?;price->?cost1;source->?A;dest->?B)}, \\
\text{shipment} \texttt{(cargo->?;price->?cost2;source->?B;dest->?A)}, \\
\text{add} \texttt{(?cost, ?cost1, ?cost2)}.
\]
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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- Further semantic treatment via Herbrand models and resolution proof theory directly follows positional treatment.
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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
Implementation of POSL’s (Positional-)Slotted Clauses

- OO jDREW: Ball04 has realized semantics via extension of Java-based jDREW interpreter by Spencer02
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Implementation of POSL’s (Positional-)Slotted Clauses

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▶ Adapts sorted indexing techniques to RDFS and to OO jDREW
Applications of POSL

- Product-seeking/advertising trees in the tree-similarity-based AgentMatcher system
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- Music filtering rules in the collaborative system RACOFI Music
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- Music filtering rules in the collaborative system RACOFI Music
- Business-analysis rules in New Brunswick Business Knowledge Base
POSLS Webizing

- POSL language elements can be given URIs: individuals (and constructors), relations, slots, and types
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Occurrences of the same language element can thus be disambiguated.
POSL Webizing

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- Orthogonal to the positional/slotted distinction
An (active) URI is enclosed in a pair of angular brackets, `<...>`, following IETF’s generic URI syntax
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Symbolic language element occurrences can be associated with URIs via juxtaposition: symbol<...>
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Symbols can still be used without URIs.
Webized Individuals

- URIs in place of, or in addition to, individual-constant symbols
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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):

  or, associated with it:
Webized Relations

- URIs in place of, or in addition to, symbolic relation names
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- URIs in place of, or in addition to, symbolic relation names

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

- 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;
Webized Types

- URI references to an RDFS or OWL class
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>
Use Product<...> for typing anonymous variable of earlier positional rule, Float from XML Schema Datatypes for its cost-like variables, and webized Address type:

```prolog
rciship(?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

Webizing is also possible for entire atoms, as a way of associating them with names.
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- Fact atom can be *anchored* by OID (symbolic name or URI, possibly prefixed by symbolic name)
Anchored POSL Atoms

▷ Webizing is also possible for entire atoms, as a way of associating them with names

▷ 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 “^”: $relation(oid^arg_1...arg_N)$
Anchoring Examples

Earlier 4-ary positional and slotted facts (see “%” comments) can now be anchored using variously webized versions of names like $s_1$ and $s_2$:

\[
\text{shipment}(s_1^\text{PC}, 47.5, \text{BostonMoS}, \text{LondonSciM}). \quad \% \text{ positional}
\]

\[
\text{shipment}(\langle \text{http://sphip.com/event#s2} \rangle^\text{PDA}, 9.5, \text{LondonSciM}, \text{BostonMoS}).
\]

\[
\text{shipment}(s_1\langle \text{http://sphip.com/event#s1} \rangle^\text{cargo->PC;price->47.5;}
\quad \source->\text{BostonMoS;dest->LondonSciM}). \quad \% \text{ slotted}
\]

\[
\text{shipment}(\langle \text{http://sphip.com/event#s2} \rangle^\text{...}).
\]
RDF Descriptions as Anchored Facts

▷ RDF descriptions can be conceived as anchored slotted POSL facts
RDF Descriptions as Anchored Facts

- RDF descriptions can be conceived as anchored slotted POSL facts
- In the absence of `rdf:type` these facts have null relation
RDF Descriptions as Anchored Facts

▷ RDF descriptions can be conceived as anchored slotted POSL facts

▷ 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
<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.
Blank nodes are used for OIDs local to current document
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For example, earlier shipping description can be refined by referring to a local cargo description using blank node identifier PeterMillerPC.
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For example, earlier shipping description can be refined by referring to a local cargo description using blank node identifier PeterMillerPC.

In the following again compare RDF and POSL.
Comparison: RDF Blank Node ...

```xml
<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 the *New Skolem constant* primitive (written as a stand-alone "\_")
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▷ Module-scoped, unique Skolem constants can be generated by New Skolem constant primitive (written as a stand-alone “_”)

▷ All occurrences “_”, “_”, … semantically replaced by fresh constants _1, _2, …

▷ 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):

```plaintext
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.
In bottom-up derivations, “_” of conclusion generates fresh Skolem constants, obtaining facts such as \texttt{reciship(_4711^...)}.
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Such rules can be employed within semantic search engine on RDF/POSL-described metadata for high-precision results.
Metadata Deduction Rules

▷ In bottom-up derivations, “_” of conclusion generates fresh Skolem constants, obtaining facts such as reci\text{ship}(_{4711}^\ldots).

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