RuleML Meets RDF: Triples, Rules, and Taxonomies

www.ruleml.org

www.w3.org/RDF

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Introduction

- Increased mutual RuleML-RDF(S) interest:
  1. RDF and RDF Schema need **rules** for metadata and taxonomy deduction, transformation, etc.; so rules should be interchangeable much like RDF(S) itself, and RuleML can be employed for this
  2. RuleML rules may also be expressed in RDF
  3. RuleML rules need **types** for constraining variables, which should be able to reuse the growing taxonomic vocabularies in the Semantic Web
- In the following we treat these three RuleML-RDF(S) topics:
  1. RDF triples and rules in RuleML
  2. RDF formats for RuleML rules
  3. RDFS taxonomies for typed RuleML
- RuleML's RDF form (1.) allows roundtrip to RDF RuleML (2.), typed RuleML (3.) could also be given an RDF format (2.), and RDFS (3.) could be written in RuleML as well (1.)

Overview of RDF Triples & Rules in RuleML

- **RuleML 0.8 uses**
  - ***RDF triples* as special binary facts and**
  - ***RDF rules* over such facts**
- **Both are defined as part of the hierarchy of RuleML DTDs**
- RDF's bNodes in **RuleML** not treated here, but several approaches have been discussed

RuleML 0.8: RDF Triples as Binary Facts

- *RDF triples* become special binary facts where the **relation** and **first argument** must be urirefs, and the **second argument** can be urirefs or literals

"http://www.w3.org/Home/Lassila has creator Ora Lassila" Original online

```
<fact>
 <_head>
  <atom>
   <_opr>
    <rel href="http://dublincore.org/documents/dces/index.shtml.rdf#Creator"/>
   </_opr>
   <ind href="http://www.w3.org/Home/Lassila"/>
   <ind>Ora Lassila</ind>
  </atom>
 </_head>
</fact>
```

Original online

RuleML 0.8: RDF Rules Over Triple Facts

- ***RDF rules*** **over triple facts can prove implicit triples, top-down, or can derive new triples, bottom-up**

IF "**Page has creator Person**" THEN "**Page was accessed by Person**"

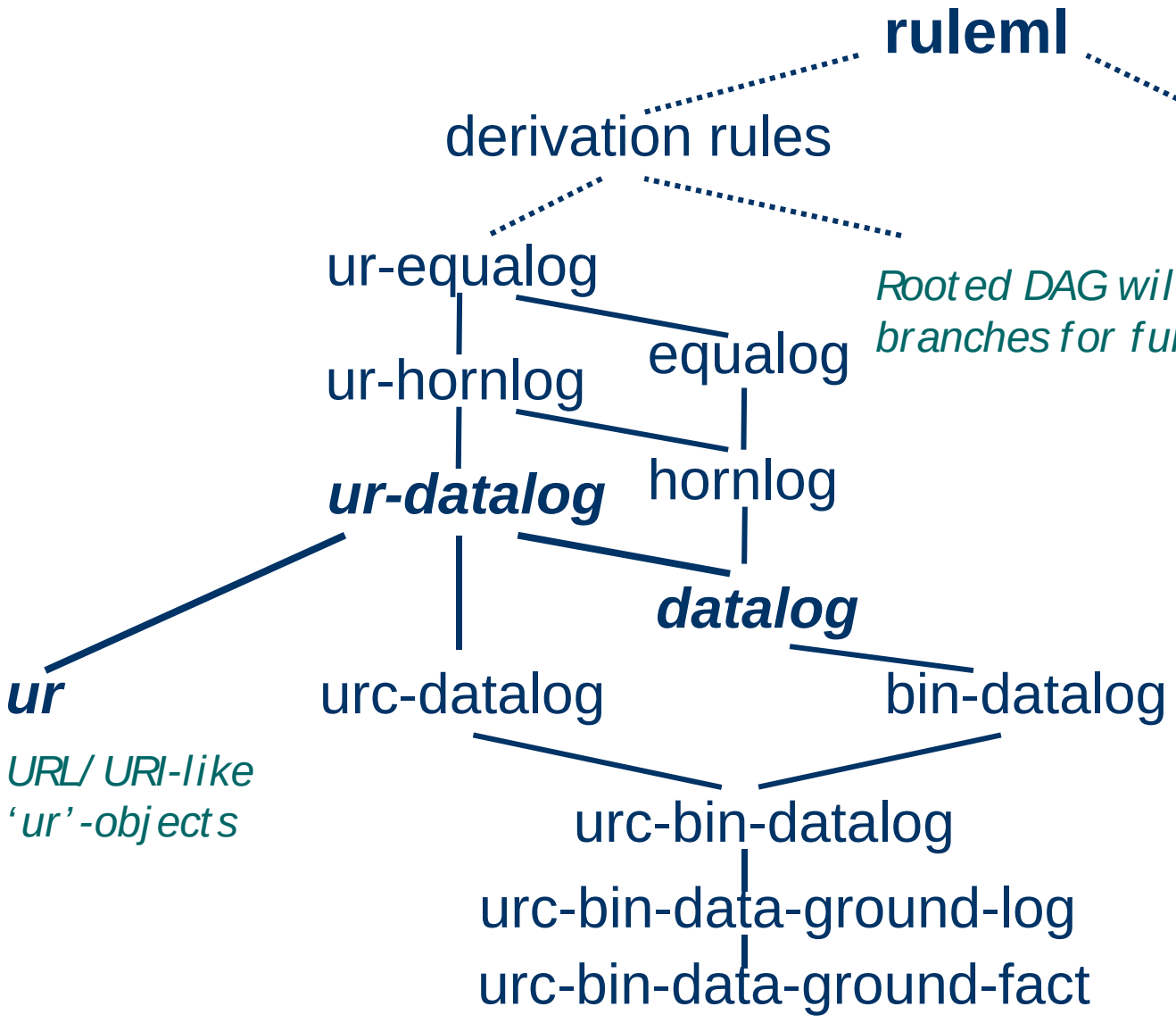
```
<imp>
 <_body>
  <atom>
   <_opr>
    <rel href="http://dublincore.org/documents/dces/index.shtml.rdf#Creator"/>
   </_opr>
   <var>Page</var>
   <var>Person</var>
  </atom>
 </_body>
 <_head>
  <atom>
   <_opr>
    <rel href="http://logging.org/vocabulary/xyz.rdf#Accessed"/>
   </_opr>
   <var>Page</var>
   <var>Person</var>
  </atom>
 </_head>
</imp>
```

Original online

Structure of the RuleML DTD Hierarchy

- Our system of DTDs (current version: 0.8) uses a modularization approach similar to XHTML in order to **accomodate** the various **rule subcommunities**
- The evolving hierarchy of RuleML DTDs forms a *partial order* with **ruleml** as the greatest element (a **ruleml**-rooted DAG) -- many ‘smallest’ elements
- Each DTD node in the hierarchy (conformance “lattice”) corresponds to a specific RuleML sublanguage, **syntactically and semantically**:
  - ‘Union’ (*join*) of sublanguages reached via outgoing links: to smaller or equal nodes below
  - ‘Intersection’ (*meet*) of sublanguages via incoming links: from greater or equal nodes above

The Module Hierarchy of RuleML DTDs



Rooted DAG will be extended with branches for further sublanguages

ur-datalog = join(ur, datalog)

ur

URL/ URI-like 'ur'-objects

RDF rules (without bNodes)

RDF-like triples (without bNodes)

Overview of RDF Formats for RuleML Rules

- An experimental translator for the XML-based RuleML 0.7 to RDF has been available in XSLT:
  This was the first RuleML in RDF
- The current RuleML 0.8 stands in a direct RDF Context:
  It integrates the XML and RDF data models
- Michael Sintek has implemented translators between Prolog and an RDF-based RuleML 0.8
- Massimo Paolucci used this RDF RuleML in DAML-S Semantic Matchmaking for Web Services Discovery to describe constraints related to input and output, and also preconditions and effects for planning
- We recently further developed RDF RuleML 0.8 using the W3C RDF Validation Service:
  http://www.w3.org/RDF/Validator/

From Natural Language to Horn Logic

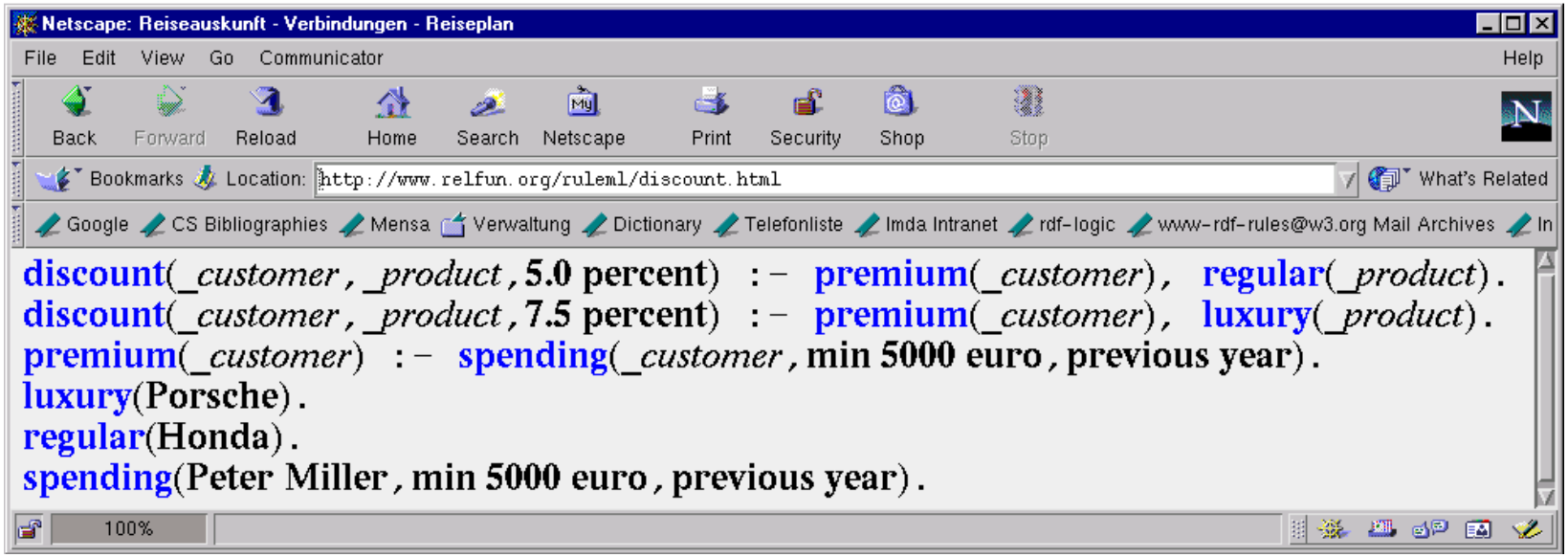
English Business Rules:

"The **discount** for a *customer* buying a *product* is **5.0 percent** if the *customer* is **premium** and the *product* is **regular**."

"The **discount** for a *customer* buying a *product* is **7.5 percent** if the *customer* is **premium** and the *product* is **luxury**."

. . .

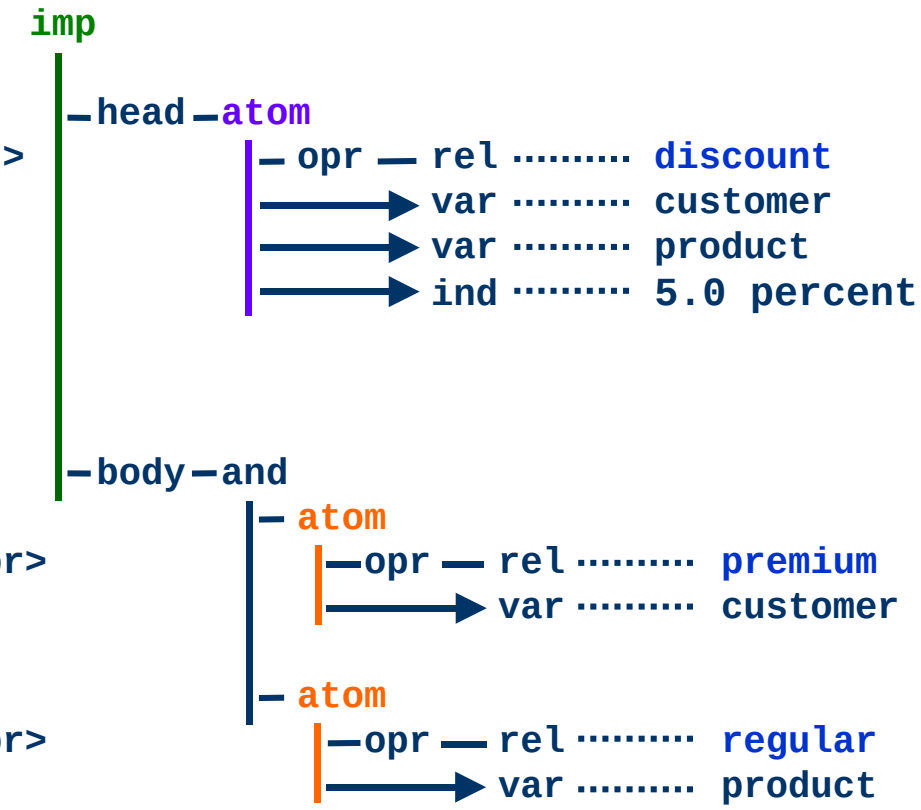
Prolog-like formalization (syntax generated from XML):



XML-RDF RuleML 0.8: Markup and Tree

"The **discount** for a *customer* buying a *product* is **5.0 percent** if the *customer* is **premium** and the *product* is **regular**."

```
<imp>
  <_head>
    <atom>
      <_opr><rel>discount</rel></_opr>
      <var>customer</var>
      <var>product</var>
      <ind>5.0 percent</ind>
    </atom>
  </_head>
  <_body>
    <and>
      <atom>
        <_opr><rel>premium</rel></_opr>
        <var>customer</var>
      </atom>
      <atom>
        <_opr><rel>regular</rel></_opr>
        <var>product</var>
      </atom>
    </and>
  </_body>
</imp>
```



'Cartesian' **OrdLab** Tree Version:
Has tag-labeled nodes (drawn as vertical lines) and three kinds of (horizontal) arcs:

1. **Ord**ered (unlabeled) arcs, XML-like: drawn as arrows
2. **Lab**eled (unordered) arcs, RDF-like: drawn as labeled lines
3. PCDATA arcs: drawn as dotted lines

RDF RuleML 0.8: Principles

- Use abbreviated 'type - property'-alternating ("striped") RDF syntax (similar to nested property lists), which nests subtrees and employs types as `rdf:Descriptions`:
  - A particular rule base becomes a (normally anonymous) RDF resource of type `rulebase` with a `_clauses` property/role leading to its `rdf:Seq`-type of rules labeled `rdf:li` for `rdf:_1`, `rdf:_2`, ...
  - An `imp` rule has `_head` and `_body` properties/roles leading to type-`atom` or type-`and` resources
  - Etc., down to RuleML's PCDATA leaves for relation symbols, individual constants, and variables, which become corresponding resources with `ruleml:cdata` literals in RDF
  - For closing off nodes, e.g. to fix the arity of `atom`ic formulas, DAML+OIL or OWL constructs could be used

RDF RuleML 0.8: Striped Serialization

The **discount** rule (as a rulebase) in RDF:

```
<rdf:RDF xmlns:rdf="&rdf;" xmlns:ruleml="&ruleml;" xmlns="&ruleml;">
<rulebase>
 <_clauses>
  <rdf:Seq>
   <rdf:li>
    <imp>
     <_head>
      <atom>
       <_opr><rel ruleml:cdata="discount"/></_opr>
       <_arg>
        <rdf:Seq>
         <rdf:li><var ruleml:cdata="customer"/></rdf:li>
         <rdf:li><var ruleml:cdata="product"/></rdf:li>
         <rdf:li><ind ruleml:cdata="5.0 percent"/></rdf:li>
        </rdf:Seq>
       </_arg>
      </atom>
     </_head>
```

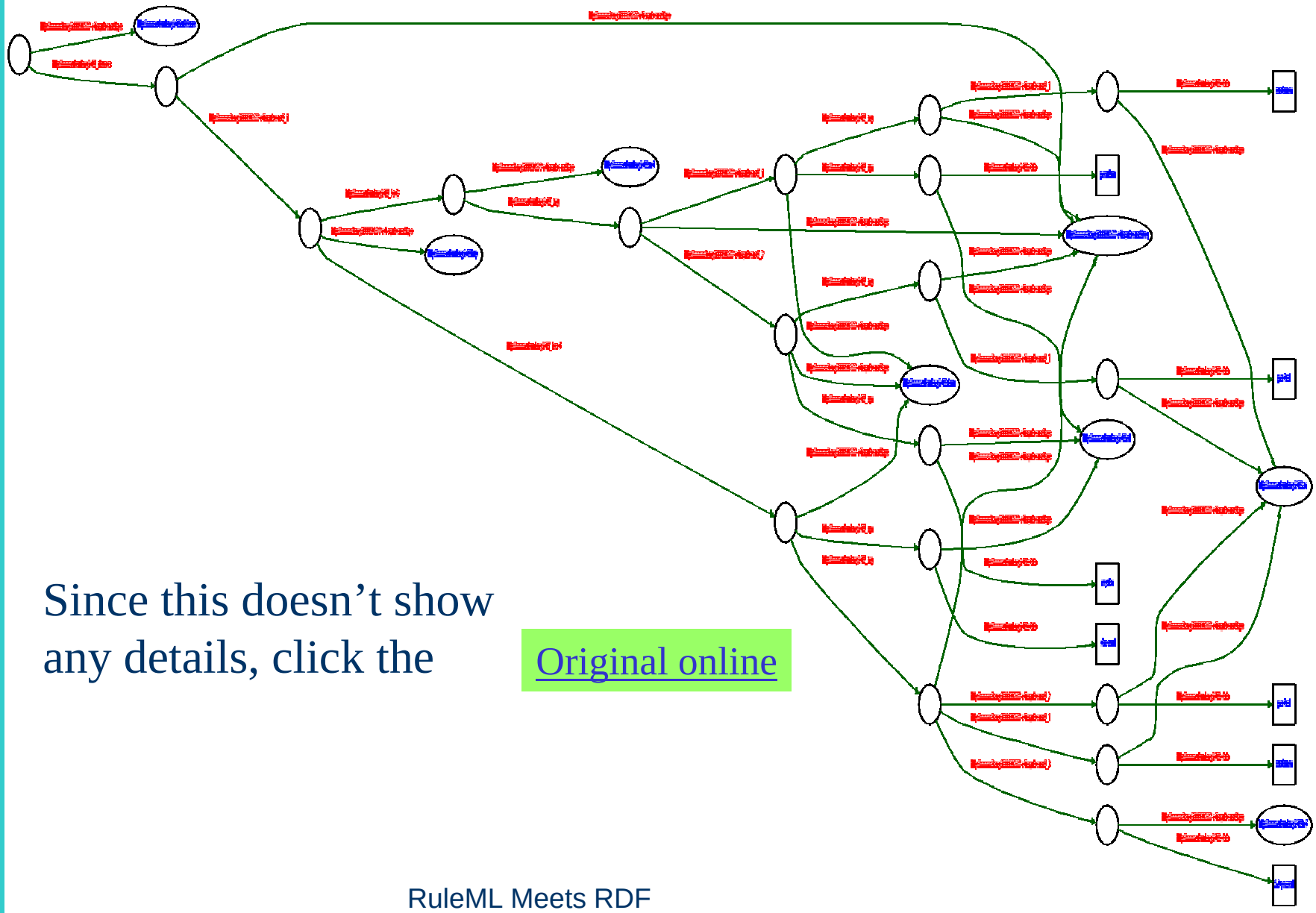
```
     <_body>
      <and>
       <_arg>
        <rdf:Seq>
         <rdf:li>
          <atom>
           <_opr><rel ruleml:cdata="premium"/></_opr>
           <_arg>
            <rdf:Seq>
             <rdf:li>
              <var ruleml:cdata="customer"/>
             </rdf:li>
            </rdf:Seq>
           </_arg>
          </atom>
         </rdf:li>
         <rdf:li>
          <atom>
           <_opr><rel ruleml:cdata="regular"/></_opr>
           <_arg>
            <rdf:Seq>
             <rdf:li>
              <var ruleml:cdata="product"/>
             </rdf:li>
            </rdf:Seq>
           </_arg>
          </atom>
         </rdf:li>
        </rdf:Seq>
       </_arg>
      </and>
     </_body>
    </imp>
   </rdf:li>
  </rdf:Seq>
 </_clauses>
</rulebase>
</rdf:RDF>
```

Original online

RDF RuleML 0.8: N-Triples Format

```
_:j17476 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#rulebase> .
_:j17477 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.w3.org/1999/02/22-rdf-syntax-ns#Seq> .
_:j17478 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#imp> .
_:j17479 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#atom> .
_:j17480 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#rel> .
_:j17480 <http://www.ruleml.org/rdf#cdata> "discount" .
_:j17479 <http://www.ruleml.org/rdf#_opr> _:j17480 .
_:j17481 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.w3.org/1999/02/22-rdf-syntax-ns#Seq> .
_:j17482 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#var> .
_:j17482 <http://www.ruleml.org/rdf#cdata> "customer" .
_:j17481 <http://www.w3.org/1999/02/22-rdf-syntax-ns#_1> _:j17482 .
_:j17483 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#var> .
_:j17483 <http://www.ruleml.org/rdf#cdata> "product" .
_:j17481 <http://www.w3.org/1999/02/22-rdf-syntax-ns#_2> _:j17483 .
_:j17484 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#ind> .
_:j17484 <http://www.ruleml.org/rdf#cdata> "5.0 percent" .
_:j17481 <http://www.w3.org/1999/02/22-rdf-syntax-ns#_3> _:j17484 .
_:j17479 <http://www.ruleml.org/rdf#_arg> _:j17481 .
_:j17478 <http://www.ruleml.org/rdf#_head> _:j17479 .
_:j17485 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#and> .
_:j17486 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.w3.org/1999/02/22-rdf-syntax-ns#Seq> .
_:j17487 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#atom> .
_:j17488 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#rel> .
_:j17488 <http://www.ruleml.org/rdf#cdata> "premium" .
_:j17487 <http://www.ruleml.org/rdf#_opr> _:j17488 .
_:j17489 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.w3.org/1999/02/22-rdf-syntax-ns#Seq> .
_:j17490 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#var> .
_:j17490 <http://www.ruleml.org/rdf#cdata> "customer" .
_:j17489 <http://www.w3.org/1999/02/22-rdf-syntax-ns#_1> _:j17490 .
_:j17487 <http://www.ruleml.org/rdf#_arg> _:j17489 .
_:j17486 <http://www.w3.org/1999/02/22-rdf-syntax-ns#_1> _:j17487 .
_:j17491 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#atom> .
_:j17492 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#rel> .
_:j17492 <http://www.ruleml.org/rdf#cdata> "regular" .
_:j17491 <http://www.ruleml.org/rdf#_opr> _:j17492 .
_:j17493 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.w3.org/1999/02/22-rdf-syntax-ns#Seq> .
_:j17494 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.ruleml.org/rdf#var> .
_:j17494 <http://www.ruleml.org/rdf#cdata> "product" .
_:j17493 <http://www.w3.org/1999/02/22-rdf-syntax-ns#_1> _:j17494 .
_:j17491 <http://www.ruleml.org/rdf#_arg> _:j17493 .
_:j17486 <http://www.w3.org/1999/02/22-rdf-syntax-ns#_2> _:j17491 .
_:j17485 <http://www.ruleml.org/rdf#_arg> _:j17486 .
_:j17478 <http://www.ruleml.org/rdf#_body> _:j17485 .
_:j17477 <http://www.w3.org/1999/02/22-rdf-syntax-ns#_1> _:j17478 .
_:j17476 <http://www.ruleml.org/rdf#_clauses> _:j17477 .
```

RDF RuleML 0.8: GraphViz Shape



Since this doesn't show any details, click the Original online

RDF RuleML 0.8: Triple Roundtrip

Turn the **has creator** triple, as a RuleML rulebase, again into RDF:

Original online

Original online

```
<rdf:RDF xmlns:rdf="&rdf;" xmlns:ruleml="&ruleml;" xmlns="&ruleml;">
<rulebase>
 <_clauses>
  <rdf:Seq>
   <rdf:li>
    <fact>
     <_head>
      <atom>
       <_opr> <rel href="http://dublincore.org/documents/dces/index.shtml.rdf#Creator"/> </_opr>
       <_arg>
        <rdf:Seq>
         <rdf:li> <ind href="http://www.w3.org/Home/Lassila"/> </rdf:li>
         <rdf:li> <ind ruleml:cdata="Ora Lassila"/> </rdf:li>
        </rdf:Seq>
       </_arg>
      </atom>
     </_head>
    </fact>
   </rdf:li>
  </rdf:Seq>
 </_clauses>
</rulebase>
</rdf:RDF>
```

Original online

Overview of RDFS Taxonomies for RuleML

- RuleML 0.8 still uses an unsorted logic, although this can simulate typed/sorted variables by applying distinguished unary predicates to those variables: Predicates defined extensionally or via a taxonomy
- Based on a special treatment of sort predicates and sorted variables in rules, proofs can be kept at a more abstract level, thus reducing the search space
- A sort hierarchy is definable independently as the taxonomy of an Order-Sorted Logic or Description Logic, and be notated in RDFS, DAML+OIL, or OWL
- We are discussing preliminary constructs to link RuleML predicates/variables to externally defined RDFS classes (a similar mechanism is usable for 'built-in' XML datatypes)

How Typed RuleML Variables Can Link to RDFS / DAML+OIL / OWL Classes

- RuleML and Order-Sorted Logic or Description Logic class hierarchies – e.g. in RDFS, DAML+OIL, or OWL – go together well (RDFS, … properties will be harder)
- 'Lift' RDF's use of `rdf:type` for taxonomic RDFS typing of **individuals**/resources (also for RuleML's `inds`)
- New RDFS use: Access unchanged RDFS for typing of RuleML **variables**
  - RDFS taxonomy for typing must be cycle-free
  - If DAML+OIL or OWL taxonomy used, must also be consistent

“Type by Application” Technique

- In RuleML's conjunctive rule-body tag `and`
- give a taxonomic RDFS type to a logic variable
- by applying an RDFS class via a `rel`
  - containing the RDF attribute `rdf:resource`
  - to that logic variable

The ‘CARIN principle’ to not modify any taxonomic predicate via rules is fulfilled since this `rel` is an empty element, which cannot be defined via rules

A Discounting Rule with Customer and Product Variables Typed by Applications:

```
<imp>
 <_head>
  <atom>
   <_opr><rel>discount</rel></_opr>
   <var>cust</var>        <!-- typed as Customer, see below -->
   <var>prod</var>        <!-- typed as Product, see below -->
   <ind>5.0 percent</ind>
  </atom>
 </_head>
 <_body>
  <and>
   <atom>
    <_opr><rel rdf:resource="http://description.org/ebiz#Customer"/></_opr>
    <var>cust</var>
   </atom>
   <atom>
    <_opr><rel>premium</rel></_opr>
    <var>cust</var>        <!-- typed as Customer, see above -->
   </atom>
   <atom>
    <_opr><rel rdf:resource="http://description.org/ebiz#Product"/></_opr>
    <var>prod</var>
   </atom>
   <atom>
    <_opr><rel>regular</rel></_opr>
    <var>prod</var>        <!-- typed as Product, see above -->
   </atom>
  </and>
 </_body>
</imp>
```

Given that
cust has type Customer
and
prod has type Product,

the discount for
a **cust**
buying
a **prod**
is 5.0 percent

if

the **cust** is premium
and
the **prod** is regular.

“Type by Declaration” Technique

- In RuleML's Horn-clause tags `fact` and `imp`
- give a taxonomic RDFS type to a logic variable
- by referring to an RDFS class via an `rdf:type`-like
  - RuleML role `_taxo`
  - containing the RDF attribute `rdf:resource`

The ‘CARIN principle’ to not modify any taxonomic predicate via rules is fulfilled since this `_taxo` role directly links to the external RDFS taxonomy

A Discounting Rule with Customer and Product Variables Typed by Declarations

```
<imp>
 <_taxo rdf:resource="http://description.org/ebiz#Customer"> <var>cust</var> </_taxo>
 <_taxo rdf:resource="http://description.org/ebiz#Product"> <var>prod</var> </_taxo>
 <_head>
  <atom>
   <_opr><rel>discount</rel></_opr>
   <var>cust</var>        <!-- typed as Customer, see above -->
   <var>prod</var>        <!-- typed as Product, see above -->
   <ind>5.0 percent</ind>
  </atom>
 </_head>
 <_body>
  <and>
   <atom>
    <_opr><rel>premium</rel></_opr>
    <var>cust</var>        <!-- typed as Customer, see above -->
   </atom>
   <atom>
    <_opr><rel>regular</rel></_opr>
    <var>prod</var>        <!-- typed as Product, see above -->
   </atom>
  </and>
 </_body>
</imp>
```

Given that
cust has type Customer
and
prod has type Product,

the discount for
a **cust**
buying
a **prod**
is 5.0 percent

if

the **cust** is premium
and
the **prod** is regular.

Typing Scope and Multiple Typing

- Reflecting the scope of logic variables – which is a single clause (`fact` or `imp`) – the typing scope is the clause containing the `rel` application or the `_taxo` role
- To express RDF-like multiple (intersection) types, just use these multiple types for one logic variable, e.g. the intersection European ? Customer would be expressed with the two techniques by

```
<atom>
  <_opr><rel rdf:resource="http://description.org/ebiz#Customer"/></_opr>
  <var>cust</var>
</atom>
<atom>
  <_opr><rel rdf:resource="http://description.org/ebiz#European"/></_opr>
  <var>cust</var>
</atom>
```

or

```
<_taxo rdf:resource="http://description.org/ebiz#Customer"> <var>cust</var> </_taxo>
<_taxo rdf:resource="http://description.org/ebiz#European"> <var>cust</var> </_taxo>
```

Types, Description Logics, and Ontologies

- Order-Sorted Horn logics have provided a solid foundation for implementing such hierarchical types, possibly employing
  - a DL-like classifier during unification or even
  - a corresponding mechanism during indexing
- Summary:

  Such RDFS-RuleML links begin to realize a ‘loose coupling’ of taxonomies and rules, but much more work is needed for full ontologies

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