Object-Oriented RuleML for RDF: Facts, Queries, and Inferences

Harold Boley, NRC IIT e-Business

(with help from Said Tabet, Duncan Johnston-Watt, Benjamin Grosof, Bruce Spencer, Steve Ross-Talbot, Mike Dean, and Gerd Wagner)

www.w3.org/RDF

www.ruleml.org

www.daml.org/committee

W3C Semantic Web Architecture Meeting, Technical Plenary and WG Meeting Event, Cambridge, MA, USA, 3-7 March 2003

Revised: 22 February 2004

Introduction

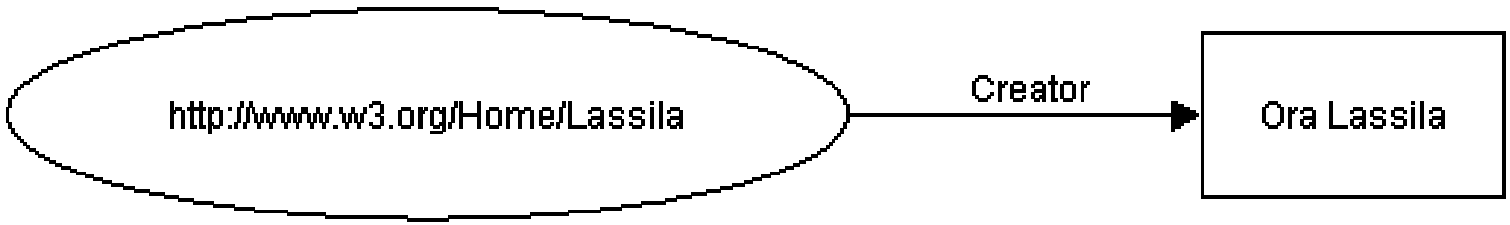
- Increased mutual RuleML-RDF(S) integration:
  A. RDF(S) needs **rules** for query, inference, transformation
  B. RuleML rules need alternative **syntactic encodings in** RDF and OWL
  C. RuleML and OWL overlap as KRs: Description Logic Programs
  D. RuleML variables need **types**: URIrefs to RDFS/OWL classes

- **re A.** Object-oriented RuleML is useable as an RDF query, inference, and transformation language:
  1. Rules over generic **positional (triple-like)** facts: 2001
  2. Rules over richer generic **object-oriented** facts: 2003
  3. **Queries and inferences** (conjunctive) over OO facts (linked via named – or anonymous/blank – nodes)
  4. Queries and inferences over OO facts with **bNode-embedded descriptions**

Intro

The ‘First RDF Graph’

How to serialize this RDF graph (from M&S):



RDF Triples as Positional Facts

- *RDF triples* map to *positional facts*, where
  the Property maps to a binary **relation**,
  the Subject to its **first argument**, and
  the Object to its **second argument**

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

```
<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>
```

_head : (system) role

RDF RuleML: Triple Roundtrip

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

```
<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>
```

RDF/RuleML Rules Over Positional Facts

- *RDF/RuleML rules over positional (triple-like) facts* derive new triples, bottom-up, or prove queried triples, top-down

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>
```

_body : (system) role

_head : (system) role

RDF Descriptions as Object-Oriented Facts

- *Object-Oriented RuleML* has been implemented as an extension of, and XSLT translator to, *Positional RuleML*

- *RDF descriptions* map to *object-oriented facts*, where
  the Subject maps to a **relation** (cf. rel.DB tuples),
  each Property maps to a **role**, and
  each Object maps to its **filler**

  - The 'First RDF Triple' above becomes the RDF/XML **about** description on the following slide

  - This maps to an object-oriented RDF/RuleML fact with a **uriref**-attributed empty **rel** shown underneath

```
<rdf:RDF>
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:s="http://dublincore.org/documents/dces/index.shtml.rdf">
  <rdf:Description about="http://www.w3.org/Home/Lassila">
   <s:Creator>Ora Lassila</s:Creator>
  </rdf:Description>
</rdf:RDF>
```

resource ↔ **rel**
literal ↔ **ind**

```
<ruleml:rulebase>
   xmlns:ruleml="http://www.ruleml.org/dtd/0.83/ruleml-oodatalog.dtd"
   xmlns:s="http://dublincore.org/documents/dces/index.shtml.rdf">
  <fact>
   <_head>
    <atom>
     <_opr><rel uriref="http://www.w3.org/Home/Lassila"/></_opr>
     <_slot name="s:Creator"><ind>Ora Lassila</ind></_slot>
    </atom>
   </_head>
  </fact>
</ruleml:rulebase>
```

_slot : metarole

name : user-level name

RDF Types in Object-Oriented RuleML

- The use of a Qname in an *attribute value* such as the above **s:Creator** in **name="s:Creator"** has been discussed in TAG Finding 25 Jul 2002
- This has been extended to a Qname in *element content* such as **t:Person** in **<rel …>t:Person</rel>**, which provides one way to express RDF types in Object-Oriented RuleML
- *Typed RDF descriptions* map to *object-oriented facts*, where the rdf:type (abbreviation) maps to a **(non-empty) relation**
  - The earlier RDF/XML description is typed (abbreviated) via a **t:Person** tag in the following slide
  - This maps to an object-oriented RDF/RuleML fact typed via **t:Person** content, shown underneath

```
<rdf:RDF>
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:s="http://dublincore.org/documents/dces/index.shtml.rdf"
   xmlns:t="http://description.org/schema/">
  <t:Person about="http://www.w3.org/Home/Lassila">
   <s:Creator>Ora Lassila</s:Creator>
  </t:Person>
</rdf:RDF>

<ruleml:rulebase>
   xmlns:ruleml="http://www.ruleml.org/dtd/0.83/ruleml-oodatalog.dtd"
   xmlns:s="http://dublincore.org/documents/dces/index.shtml.rdf"
   xmlns:t="http://description.org/schema/">
  <fact>
   <_head>
    <atom>
     <_opr>
      <rel uriref="http://www.w3.org/Home/Lassila">t:Person</rel>
     </_opr>
     <_slot name="s:Creator"><ind>Ora Lassila</ind></_slot>
    </atom>
   </_head>
  </fact>
</ruleml:rulebase>
```

RDF/RuleML Rules Over Object-Oriented Facts

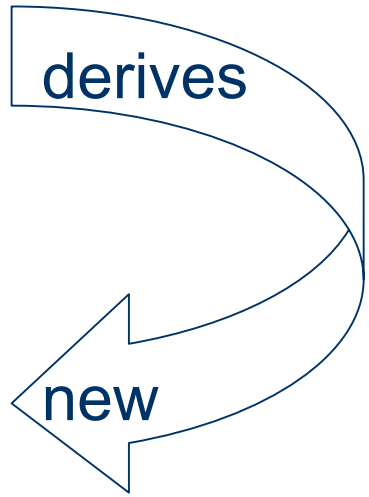
- *RDF/RuleML rules over object-oriented facts* can prove queried descriptions or derive new description-like facts

```
<ruleml:rulebase>
 <imp>                                                    IF
  <_body>
   <atom>
    <_opr><var>Page</var></_opr>                                  "Page
    <_slot name="s:Creator"><var>Person</var></_slot>        has creator
   </atom>                                                              Person"
  </_body>
  <_head>                                                   THEN
   <atom>
    <_opr><var>Page</var></_opr>                                  "Page
    <_slot name="t:Accessed"><var>Person</var></_slot>       was accessed by
   </atom>                                                              Person"
  </_head>
 </imp>
</ruleml:rulebase>
```

Bottom-Up: RDF/RuleML Derivations of Object-Oriented Facts

- RDF/RuleML rule over above object-oriented fact *derives a new description* in bottom-up / forward manner

```
<ruleml:rulebase>
  <fact>
    <_head>
      <atom>
        <_opr><rel uriref="http://www.w3.org/Home/Lassila"/></_opr>
        <_slot name="s:Creator"><ind>Ora Lassila</ind></_slot>
      </atom>
    </_head>
  </fact>
  <fact>
    <_head>
      <atom>
        <_opr><rel uriref="http://www.w3.org/Home/Lassila"/></_opr>
        <_slot name="s:Accessed"><ind>Ora Lassila</ind></_slot>
      </atom>
    </_head>
  </fact>
</ruleml:rulebase>
```



Top-Down: RDF/RuleML Queries Over Object-Oriented Facts

- RDF/RuleML rule over above object-oriented fact *proves a queried description* in top-down / backward manner

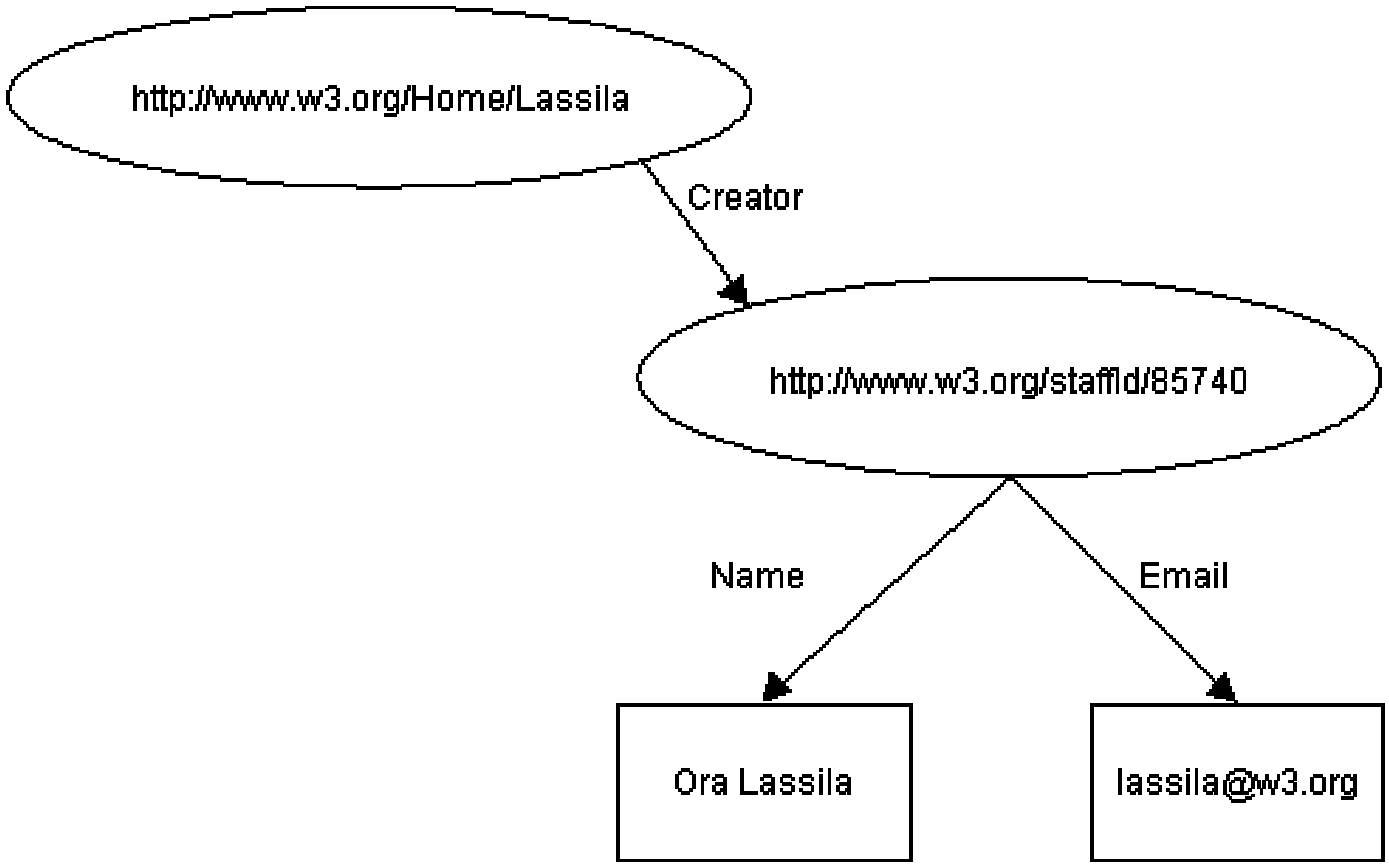
```
<ruleml:query>                                                    WHICH
  <_body>
    <atom>
      <_opr><var>Page</var></_opr>                                  "Page
      <_slot name="t:Accessed"><var>Person</var></_slot>             was accessed by
    </atom>                                                          Person"
  </_body>
</ruleml:query>
                                                                  ?
```

binds <var>Page</var> to <rel uriref="http://www.w3.org/Home/Lassila"/>

and <var>Person</var> to <ind>Ora Lassila</ind>

Intermediate Nodes for RDF Descriptions and Object-Oriented Facts

How to serialize this RDF graph (from M&S):



Intermediate Nodes for RDF Descriptions and Object-Oriented Facts (Cont'd)

- *RDF descriptions* and *object-oriented facts* can employ **named** intermediate nodes (e.g., staff IDs – as from a corporate relational DB – used as URIrefs)
  - The following classical two RDF/XML descriptions link Ora's homepage with his staff ID as a named intermediate node http://www.w3.org/staffId/85740, which gives further information via literals
  - These map to two object-oriented RDF/RuleML facts linked in the same fashion, shown interleaved: Both the RDF attributes about and resource map to the RuleML attribute uriref (to allow rel unification)

```
<ruleml:rulebase>
 <fact>
  <_head>
   <atom>
    <_opr><rel uriref="http://www.w3.org/Home/Lassila"/></_opr>
    <_slot name="s:Creator"><rel uriref="http://www.w3.org/staffId/85740"/></_slot>
   </atom>
  </_head>
 </fact>

 <fact>
  <_head>
   <atom>
    <_opr><rel uriref="http://www.w3.org/staffId/85740"/></_opr>
    <_slot name="v:Name"><ind>Ora Lassila</ind></_slot>
    <_slot name="v:Email"><ind>lassila@w3.org</ind></_slot>
   </atom>
  </_head>
 </fact>
</ruleml:rulebase>
```

roles 'build in' commu-tativity

Conjunctive RDF/RuleML Queries Over Object-Oriented Node-Linked Facts

- *Conjunctive RDF/RuleML query of object-oriented facts* allows a (relational-like) **join over a link variable**

```
<ruleml:query>
 <_body>
  <and>
   <atom>
    <_opr><rel uriref="http://www.w3.org/Home/Lassila"/></_opr>
    <_slot name="s:Creator"><var>ID</var></_slot>
   </atom>
   <atom>
    <_opr><var>ID</var></_opr>
    <_slot name="v:Name"><var>N</var></_slot>
    <_slot name="v:Email"><var>E</var></_slot>
   </atom>
  </and>
 </_body>
</ruleml:query>
```

WHAT IS

"…/ Home/Lassila

Creator's ID"

AND

"that ID's

Name N

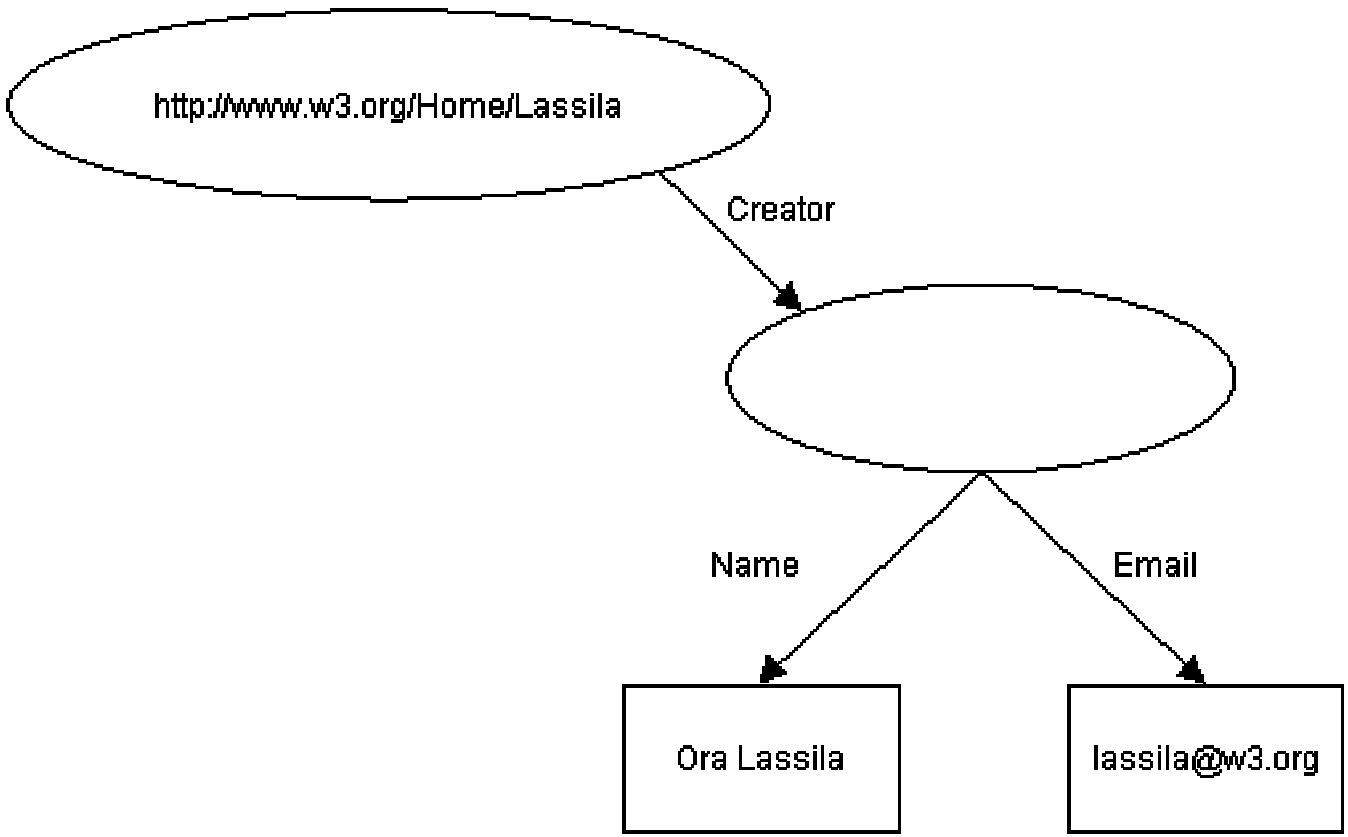
Email E"

?

binds **<var>ID</var>** to **<rel uriref="http://www.w3.org/staffId/85740"/>**
and **<var>N</var>** to **<ind>Ora Lassila</ind>**
and **<var>E</var>** to **<ind>lassila@w3.org</ind>**

Blank Nodes in RDF Descriptions and Object-Oriented Facts

How to serialize this RDF graph (from M&S):



Blank Nodes in RDF Descriptions and Object-Oriented Facts (Cont'd)

- *RDF descriptions* and *object-oriented facts* can employ **anonymous (blank)** intermediate nodes (as implicit in RDF's most abbreviated 'purely striped' syntax)
  - The following RDF/XML description embeds – in Ora's homepage – a blank intermediate node, which gives two bits of literal information
  - This maps to an object-oriented RDF/RuleML fact embedding an object-oriented cterm in a similar way, shown underneath

```
<rdf:RDF>
 <rdf:Description about="http://www.w3.org/Home/Lassila">
  <s:Creator>
   <rdf:Description>
    <v:Name>Ora Lassila</v:Name>
    <v:Email>lassila@w3.org</v:Email>
   </rdf:Description>
  </s:Creator>
 </rdf:Description>
</rdf:RDF>
```

```
<ruleml:rulebase>
 <fact>
  <_head>
   <atom>
    <_opr><rel uriref="http://www.w3.org/Home/Lassila"/></_opr>
    <_slot name="s:Creator">
     <cterm>
      <_opc><ctor/></_opc>
      <_slot name="v:Name"><ind>Ora Lassila</ind></_slot>
      <_slot name="v:Email"><ind>lassila@w3.org</ind></_slot>
     </cterm>
    </_slot>
   </atom>
  </_head>
 </fact>
</ruleml:rulebase>
```

RDF/RuleML Rules Over Object-Oriented Facts with bNode-Embedded Descriptions

- *RDF/RuleML rules over object-oriented facts* can also prove queried descriptions with embedded descriptions

```
<ruleml:rulebase>
 <imp>                                                    IF
  <_body>
   <atom>
    <_opr><var>Page</var></_opr>                          "Page
    <_slot name="s:Creator"><var>descr</var></_slot>       has creator descr"
   </atom>
  </_body>                                                THEN
  <_head>
   <atom>
    <_opr><var>Page</var></_opr>                          "Page
    <_slot name="t:Accessed"><var>descr</var></_slot>      was accessed
   </atom>                                                          by descr"
  </_head>
 </imp>
</ruleml:rulebase>
```

RDF/RuleML Queries Over Object-Oriented Facts with bNode-Embedded Descriptions

- RDF/RuleML rule over above object-oriented fact *proves a queried description with an embedded description*

```
<ruleml:query>
 <_body>
  <atom>
   <_opr><var>Page</var></_opr>
   <_slot name="t:Accessed"><var>descr</var></_slot>
  </atom>
 </_body>
</ruleml:query>
```

WHICH

"Page was accessed by descr"

?

binds `<var>Page</var>` to `<rel uriref="http://www.w3.org/Home/Lassila"/>`

and `<var>descr</var>` to

```
<cterm>
  <_opc><ctor/></_opc>
  <_slot name="v:Name"><ind>Ora Lassila</ind></_slot>
  <_slot name="v:Email"><ind>lassila@w3.org</ind></_slot>
</cterm>
```

Conclusions

- RDF mapped to Object-Oriented RuleML:
  resource → **rel** element with a uriref attribute
  literal → **ind** element *(then mapped to RDF)*
- Object-oriented ***queries*** can
  - employ **resource-linked variables** in conjunctions
  - invoke object-oriented rules in a **backward** manner
- ***Object-oriented rules*** can also be invoked in a **forward** manner to derive new OO facts, e.g. using *CommonRules*, *jDREW*, *Jess*, or *cwm*
- Handle **bNodes** in **RDF trees**: via embedding; in general **RDF graphs**: via generated URIrefs
- Model theory can build on RuleML's **RDF-XML-integrating data model**: via F-Logic or TRIPLE

References

• Harold Boley: Relationships Between Logic Programming and RDF, in: R. Kowalczyk, S.W. Loke, N.E. Reed, G. Graham (Eds.), Advances in Artificial Intelligence, LNAI 2112, Springer-Verlag, 2001

• Harold Boley: A Web Data Model Unifying XML and RDF. Draft, September 2001.

• Harold Boley: The Rule Markup Language: RDF-XML Data Model, XML Schema Hierarchy, and XSL Transformations, Invited Talk, INAP2001, Tokyo, October 2001.

• Harold Boley, Said Tabet, and Gerd Wagner: Design Rationale of RuleML: A Markup Language for Semantic Web Rules, Proc. SWWS'01, Stanford, July/August 2001.

• Andreas Eberhart, An Agent Infrastructure based on Semantic Web Standards, Workshop on Business Agents and the Semantic Web at the AI 2002, Calgary, Canada

• Andreas Eberhart, Automatic Generation of Java/SQL based Inference Engines from RDF Schema and RuleML, International Semantic Web Conference 2002, Sardinia

• Benjamin Grosof: Representing E-Business Rules for the Semantic Web: Situated Courteous Logic Programs in RuleML, Proc. Workshop on Information Technologies and Systems (WITS '01), New Orleans, December, 2001.

• Benjamin Grosof, Mahesh D. Gandhe, and Timothy W. Finin: SweetJess: Translating DamlRuleML to Jess, Proc. International Workshop on Rule Markup Languages for Business Rules on the Semantic Web, Sardinia (Italy), June 2002.

• Benjamin Grosof and Terrence Poon: Representing Agent Contracts with Exceptions using XML Rules, Ontologies, and Process Descriptions, Proc. International Workshop on Rule Markup Languages for Business Rules on the Semantic Web, Sardinia (Italy), June 2002.

• Steve Ross-Talbot, Harold Boley, and Said Tabet: Playing by the Rules, Application Development Advisor 6(5), June 2002, 38-43.

• Michael Schroeder and Gerd Wagner (Eds.): Proceedings of the International Workshop on Rule Markup Languages for Business Rules on the Semantic Web. Sardinia, Italy, June 14, 2002. CEUR-WS Publication Vol-60.

• Gerd Wagner: How to Design a General Rule Markup Language?, Invited Talk, Workshop XML Technologien für das Semantic Web (XSW 2002), Berlin, June 2002.