

Distributed Rule Responder Querying on the Semantic Web

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Outline

- Rule Responder Overview
- Agent Types
 - Personal, Organizational, and External
- Infrastructure for Realizing Agents
 - Reaction RuleML Messages: Performatives
 - Mule ESB: Communication Middleware
 - Rule Engines: Prova, OO jDREW, and DR-Device
- Symposium Planner Use Case
 - Query Delegation and Answering
 - Knowledge in Organizational and Personal Agents
 - Role Assignment Ontology: Topic → Personal Agent
 - Assisting the General, Publicity, and Program Chairs
- Conclusion and Future Work

Overview of Rule Responder (I)

- Rule Responder is a multi-agent system for **collaborative team** and **community** support on the (Social Semantic) Web
- Enables rule-based collaboration between the distributed human members – **persons** – of such a *virtual organization*
- Persons of an organization are assisted by **semi-automated rule-based agents**, which use rules (and various ontologies) to describe the **decision** and **behavioral** logic

Overview of Rule Responder (II)

- Uses languages and engines of the RuleML family for rule serialization, based on logic and XML:
 - Hornlog RuleML: Reasoning (decision)
 - Reaction RuleML: Interaction (behavior)
- Implemented on top of a Mule-based Enterprise Service Bus (ESB) as a Service Oriented Architecture (SOA)

Personal Agents

- A personal agent assists a **person**
 - or a tight subteam – of an organization, semi-autonomously acting on their behalf
- It works on a profile of FOAF*-like **facts** plus FOAF-extending **rules** that encode 'routine' knowledge of its human owner(s)

* The Friend of a Friend (FOAF) project: <http://www.foaf-project.org>

Organizational Agents

- An organizational agent represents goals and strategies shared by each member of the **organization**
- It contains rule* sets that describe the policies, regulations, opportunities, and expertise of its organization

* For brevity the term 'rule' encompasses 'fact' (which is a rule without premises)

External Agents

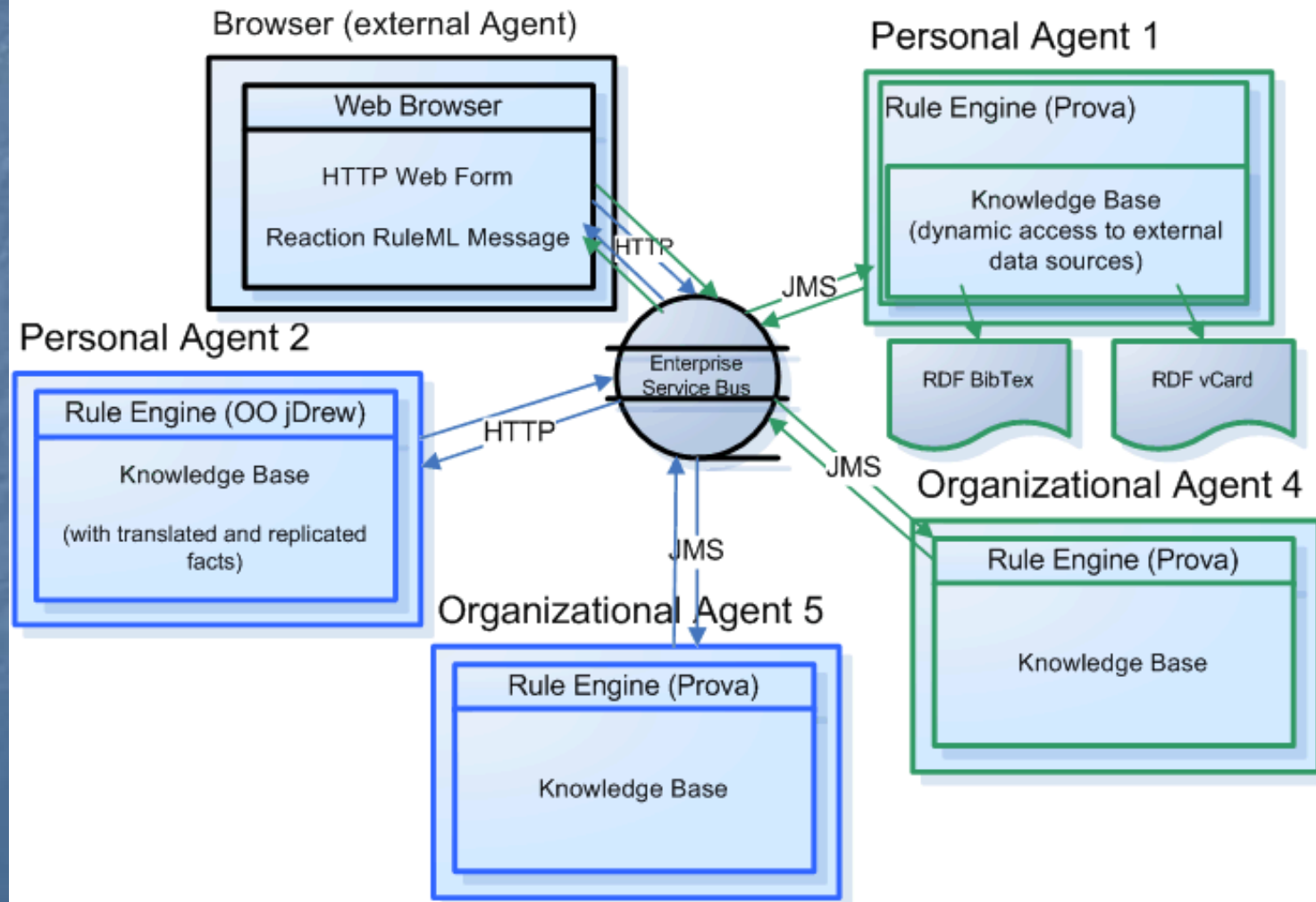
- External agents exchange messages with (the public interface of) organizational agents, sending queries (requests), receiving answers (results), or interchanging complete rule sets
- End users, via external agents, employ the Web (HTTP) interface of Rule Responder (currently an API-like browser interface)
- Support for simultaneous external agents:
 - Currently, end users (B2C)
 - Ultimately, other organizations (B2B)

Rule Responder as a Multi-Agent Infrastructure

- Rule Responder realizes virtual organizations in which an OA links between an EA and PAs
 - Built on top of the Mule ESB
- The OA is realized with an instance of a rule engine
- Each PA is realized with a servlet using a rule engine – sometimes several
- Combines methods of **multi-agent systems**, **distributed rule management systems**, as well as **service-oriented** and **event-driven** architectures

Two Simple Rule Responder Virtual Organizations on ESB Infrastructure

Use Case 4 Use Case 5



Translation Between PAs' Native Languages and OA's Interchange Language

- Each **rule engine** can use its *own rule language*
- Agents require an **interchange language** so they can communicate with each other
- Rule Responder uses RuleML as its interchange language
- Translations between the interchange language and the PA languages are done by the PAs

Reaction RuleML

- Reaction RuleML is a branch of the RuleML family that supports actions and events
- When two agents want to communicate, each others' Reaction RuleML **messages** are sent through the ESB
- The ESB carries RuleML queries (requests), answers (results), and rule bases to/from agents

Example Reaction RuleML Message

- `<RuleML xmlns="http://www.ruleml.org/0.91/xsd"`
- `xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"`
- `xsi:schemaLocation="http://www.ruleml.org/0.91/xsd`
- `http://ibis.in.tum.de/research/ReactionRuleML/0.2/rr.xsd"`
- `xmlns:ruleml2010="http://ibis.in.tum.de/projects/paw#">`
- `<Message mode="outbound" directive="query-sync">`
- `<oid> <Ind>RuleML-2010</Ind> </oid>`
- `<protocol> <Ind>esb</Ind> </protocol>`
- `<sender> <Ind>User</Ind> </sender>`
- `<content>`
- `<Atom>`
- `<Rel>getContact</Rel>`
- `<Ind>ruleml2010_PanelChair</Ind>`
- `<Ind>update</Ind>`
- `<Var>Contact</Var>`
- `</Atom>`
- `</content>`
- `</Message>`
- `</RuleML>`

Message Performatives

- The attribute **directive**="..." specifies the pragmatic performative
 - Message exchange/interaction protocols
- Rule Responder Performatives
 - In the tradition of KQML and FIPA-ACL
 - Currently implemented: Query and Answer
 - Retract and Update requests planned in collaboration with W3C RIF-PRD / OMG PRR

Agent Communication Protocols

WSDL-like communication protocols:

■ In-Only

- Message is sent from agent₁ to agent₂;
then agent₂ executes performative

■ Request-Response

- Performs above In-Only;
then agent₂ sends response to agent₁

■ Request-Response-Acknowledge

- Performs Request-Response;
then agent₁ sends an acknowledgement to agent₂

■ Workflows

- Generalizes the above protocols to allow other compositions of message interchange between agents

Communication Middleware

- **Mule Enterprise Service Bus (ESB)**
 - Mule* is used to create communication end points at each personal and organizational agent of Rule Responder
 - Mule supports around 50 transport protocols (including HTTP, JMS, JDBC, and SOAP)
 - Rule Responder currently uses HTTP and JMS as transport protocols

* **Mule – The open source SOA infrastructure:**
<http://mulesource.com>

Rule Engines

- Prova: Prolog + Java
- OO jDREW: Object Oriented
java Deductive Reasoning Engine for the Web
- DR-Device: Defeasible Logic Reasoner for the
Semantic Web

Prova

- Prova is mainly used to realize the organizational agents of Rule Responder
- It implements Reaction RuleML for agent interaction (event-condition-action rules)

OO jDREW

- OO jDREW is used to realize the personal agents of Rule Responder
- It implements Hornlog RuleML for agent reasoning (Horn logic rules)
- Supports rules in two formats:
 - POSL: Positional Slotted presentation syntax
 - RuleML: XML interchange syntax
(can be generated from POSL:
<http://www.ruleml.org/posl/converter.jnlp>)

Use Case: Symposium Planner

- RuleML-20xy Symposia
 - An external agent linked to an organizational agent acts as the single point of entry to **support** the symposium organization:
 - Currently, query answering about the symposium
 - Ultimately, preparing and running the symposium
 - Personal agents have **assisted** symposium chairs since 2007 (deployed as [Q&A](#) since 2008)
 - General Chair, Publicity Chair, Program Chair, Panel Chair, etc.

Rule Responder Architecture

OA: Organizational Agent

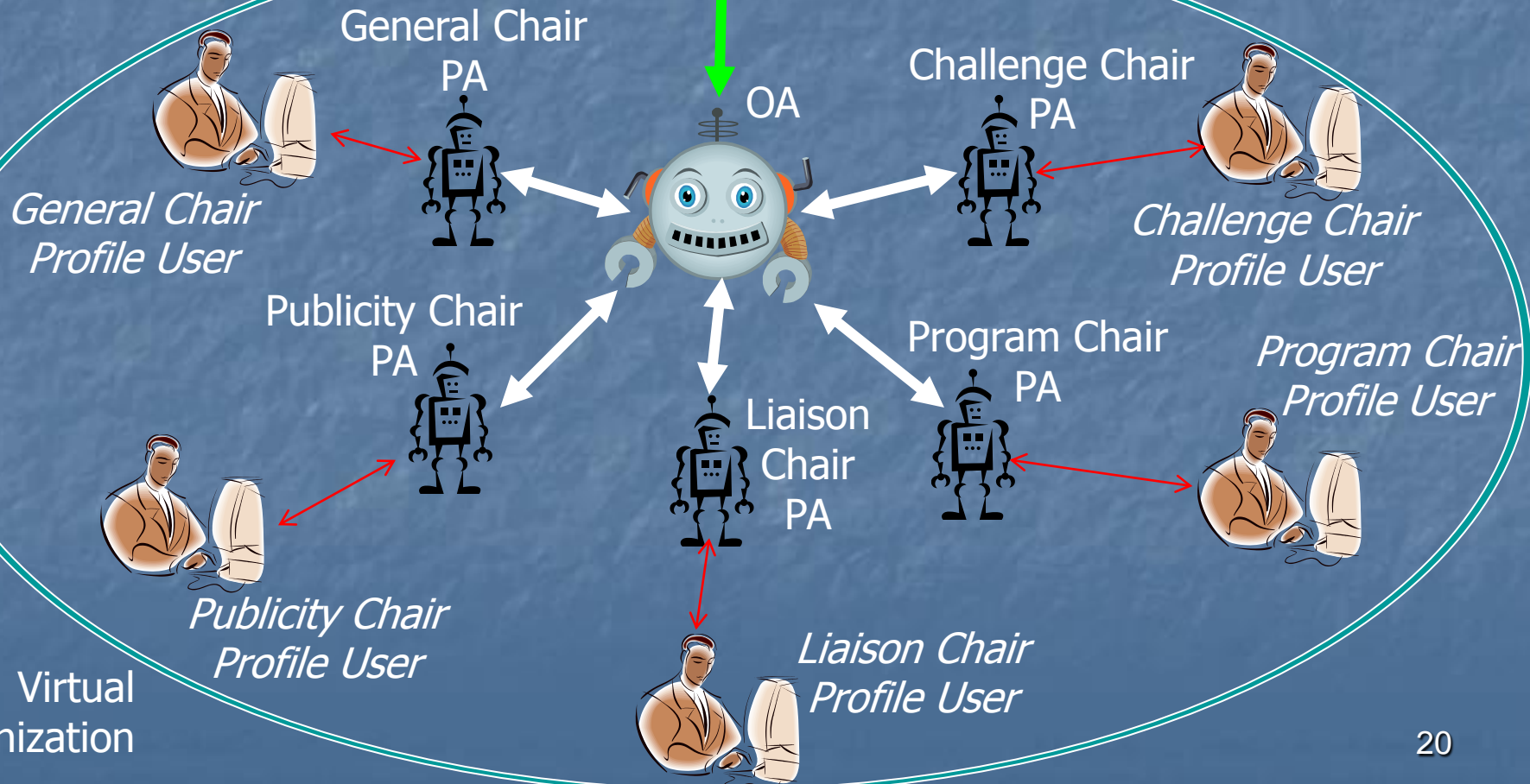
PA: Personal Agent



Enquiry User



EA: External Agent



Online Use Case Demos

- Rule Responder:
<http://responder.ruleml.org>
- Virtual organizations for RuleML-2007/.../2010 Symposia:
 - External agents:
Each an HTTP browser interface using Reaction RuleML:
<http://ibis.in.tum.de/projects/paw/ruleml-2007>
<http://ruleml.org/RuleML-2008/RuleResponder>
<http://ruleml.org/RuleML-2009/RuleResponder>
<http://ruleml.org/RuleML-2010/RuleResponder/RuleResponder.htm>
 - Organizational agents:
Each supporting one symposium as a whole
 - Personal agents:
Supporting all Chair subteams of a symposium

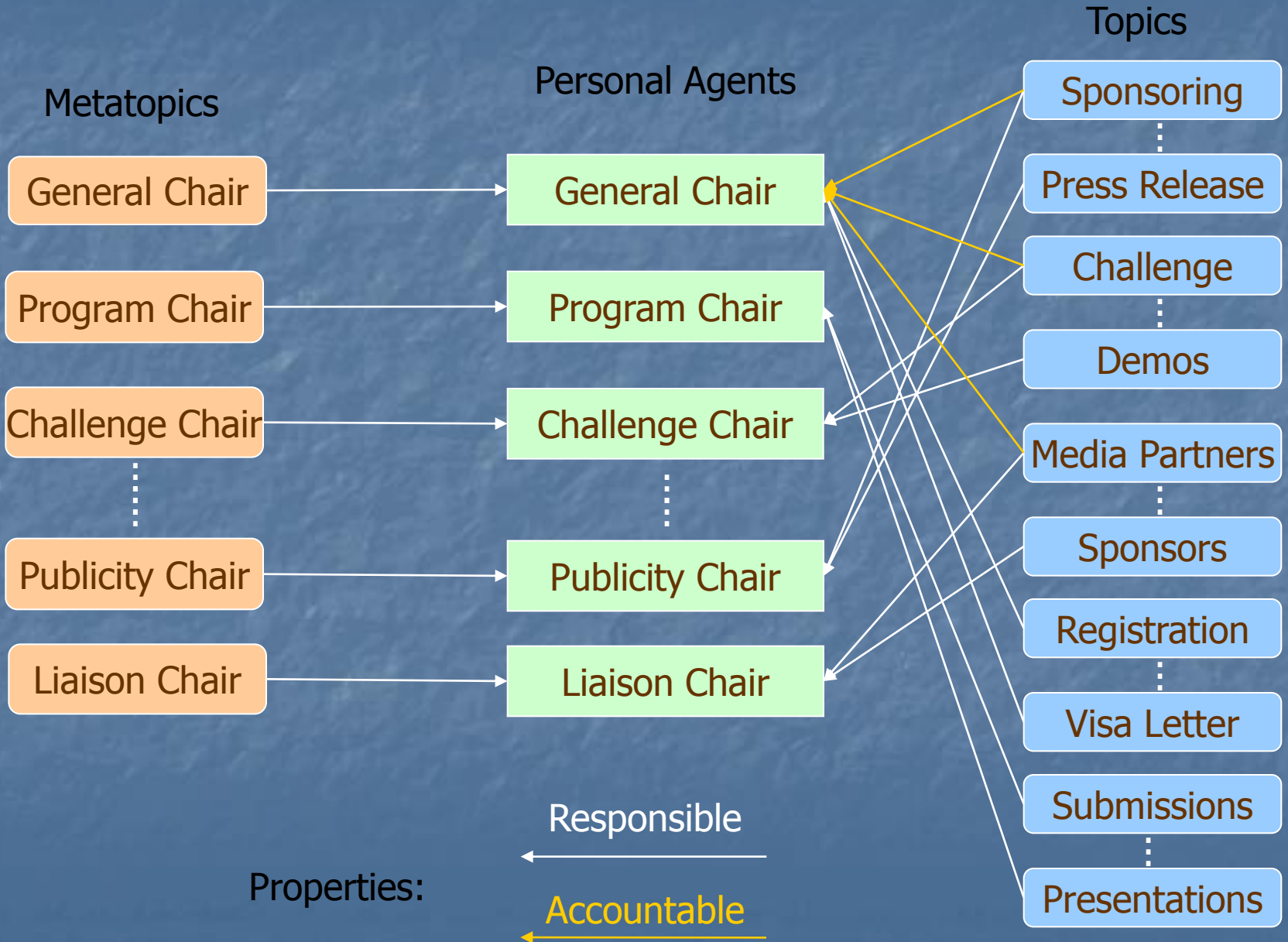


Online

Query Delegation

- The organizational agent delegates queries to appropriate personal agents
- Tasks for the symposium organization are managed via a **role assignment matrix**
- Defined here by an OWL Lite ontology (alternatives: RDFS, RuleML, ...)
- Assigns (meta)topics to PAs within the virtual organization: *... see next slide ...*

Role Assignment Ontology



Multiple Query Answers by PAs

- Some queries have more than one answer
- The PA will send the answers one at a time to the OA
 - Interleaving backtracking and transmission
- When the PA finds no more answers, it sends an end-of-transmission message

Knowledge Shared Between Personal Agents

- Rules can be shared among personal agents
- Rules that apply to all PAs can be lifted to the OA level
- *... see next slide ...*

Symposium OA Knowledge Base

% Sample Prova rule stored in the OA:

```
getContact(XID,Topic,Request,  
           person(Role,Name,Title,EMail,Telephone)) :-
```

% Retrieve the responsible PA (Agent) for the Topic

```
assigned(XID,Agent,Topic,ruleml2009_responsible),
```

% Query contact information from that PA

```
sendMsg(XID,esb,Agent,"query",  
        person(Role,Name,Title,Email,Telephone) ),
```

% Receive the answer(s)

```
rcvMult(XID,esb,Agent,"answer",  
        substitutions(Role,Name,Title,EMail,Telephone)).
```

General Chair PA

Knowledge Base: Facts


*% OA rule delegates queries to PAs which use FOAF-like facts
% such as to the General Chair PA which uses this fact:*

```
person(  
  symposiumChair[ ruleML_2009, general ],  
  foafname[ firstName[ Adrian ], lastName[ Paschke ]],  
  foaftitle[ title[ Dr ]],  
  foafmbox[  
    email[ adrianDOTpaschkeATbiotecDOTtuDASHdresdenDOTde ]],  
  exphones[ telephoneNumbers[ office[ 4935146340074 ]]]).
```

*% Sample query in RuleML syntax:
... see next slide ...*

Sample Message to Organizational Agent

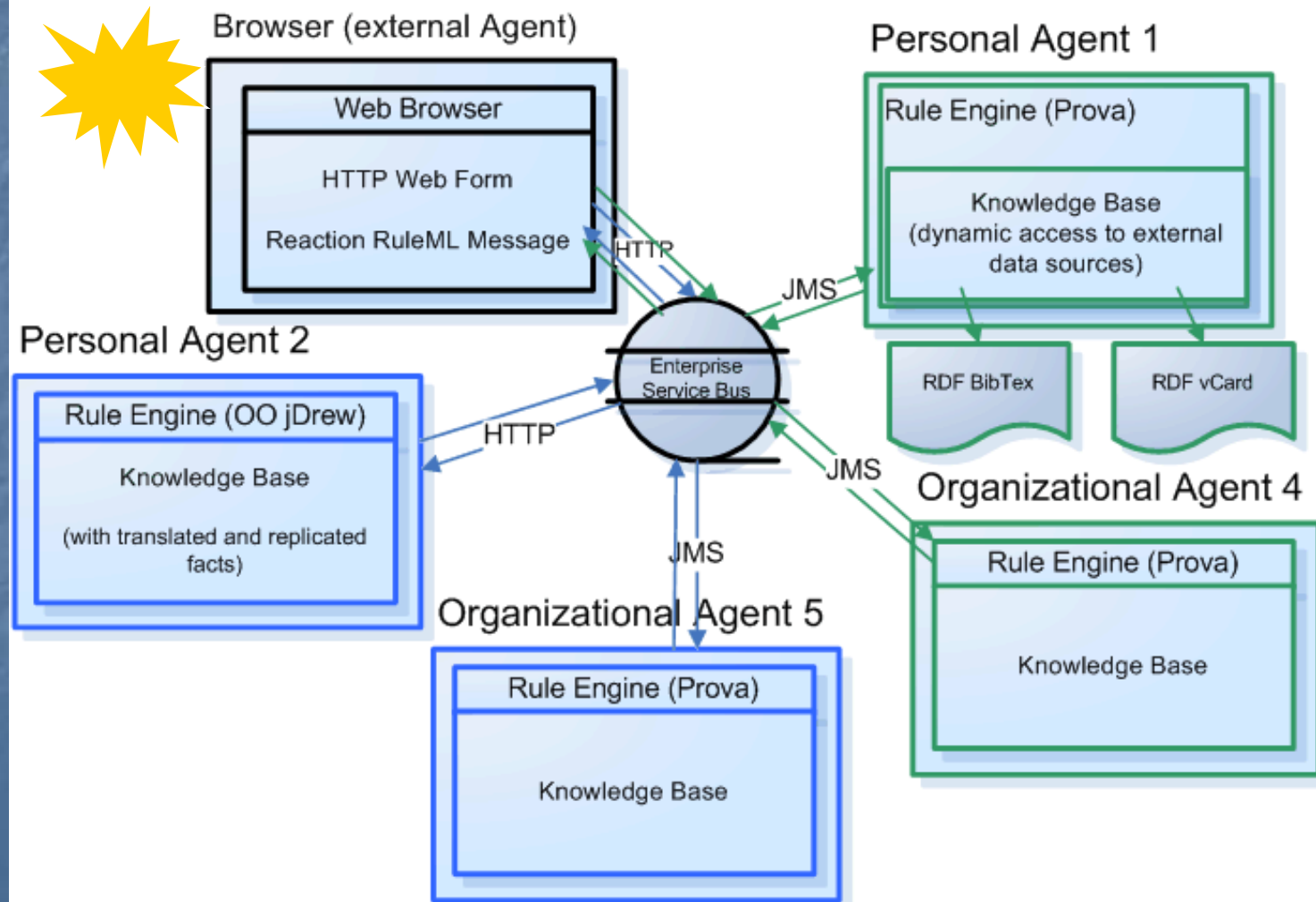
```
<RuleML xmlns="http://www.ruleml.org/0.91/xsd"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.ruleml.org/0.91/xsd
http://ibis.in.tum.de/research/ReactionRuleML/0.2/rr.xsd"
xmlns:ruleml2007="http://ibis.in.tum.de/projects/paw#">
  <Message mode="outbound" directive="query-sync">
    <oid>
      <Ind>RuleML-2009</Ind>
    </oid>
    <protocol>
      <Ind>esb</Ind>
    </protocol>
    <sender>
      <Ind>User</Ind>
    </sender>
    <content>
      <Atom>
        <Rel>getContact</Rel>
        <Ind>ruleml2009_GeneralChair</Ind>
        <Ind>update</Ind>
        <Var>Contact</Var>
      </Atom>
    </content>
  </Message>
</RuleML>
```



<http://ruleml.org/RuleML-2009/RuleResponder/>
Query Selection: General Chair Contact

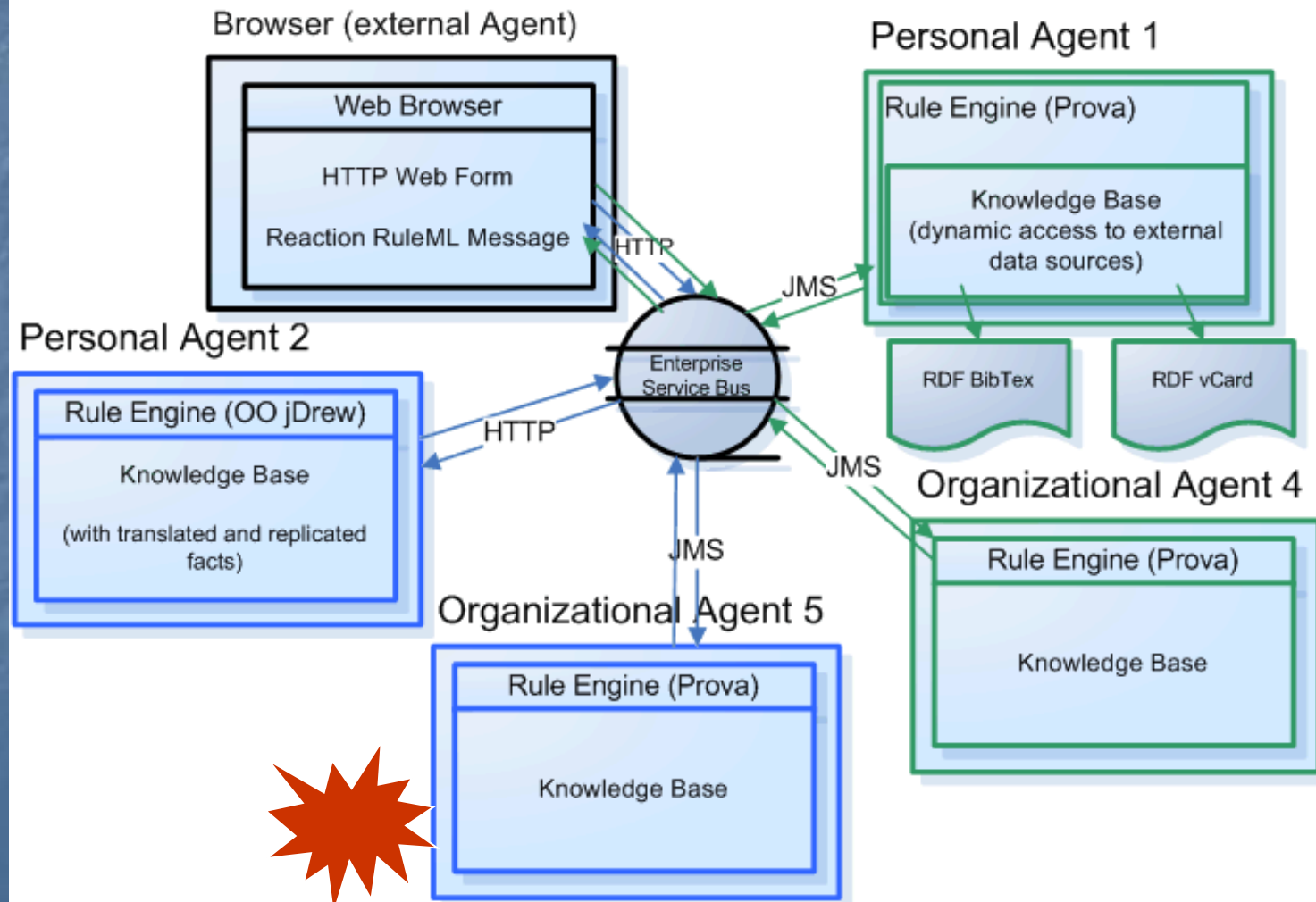
Architecture - Execution

Use Case 4 Use Case 5



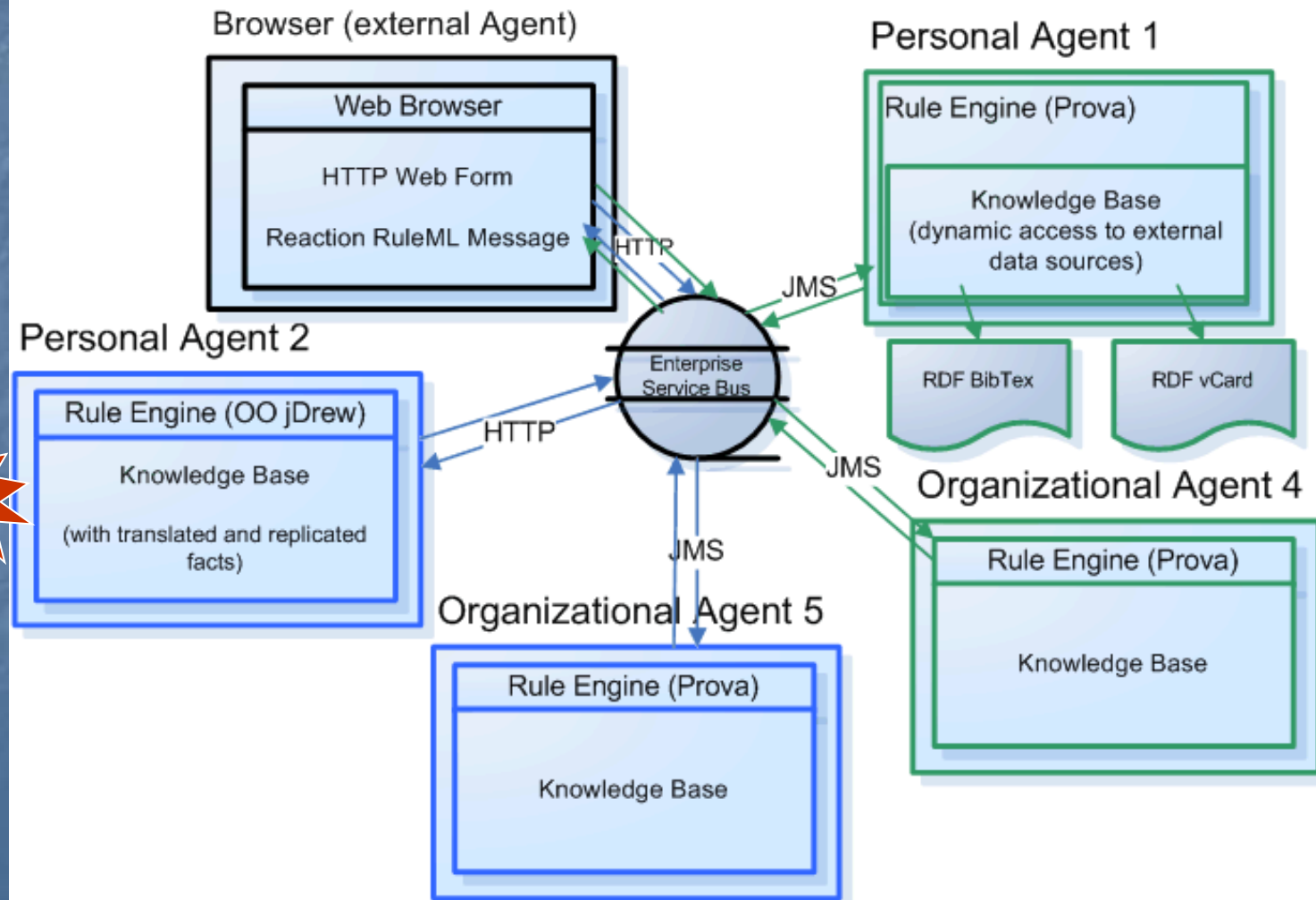
Architecture - Execution

Use Case 4 Use Case 5



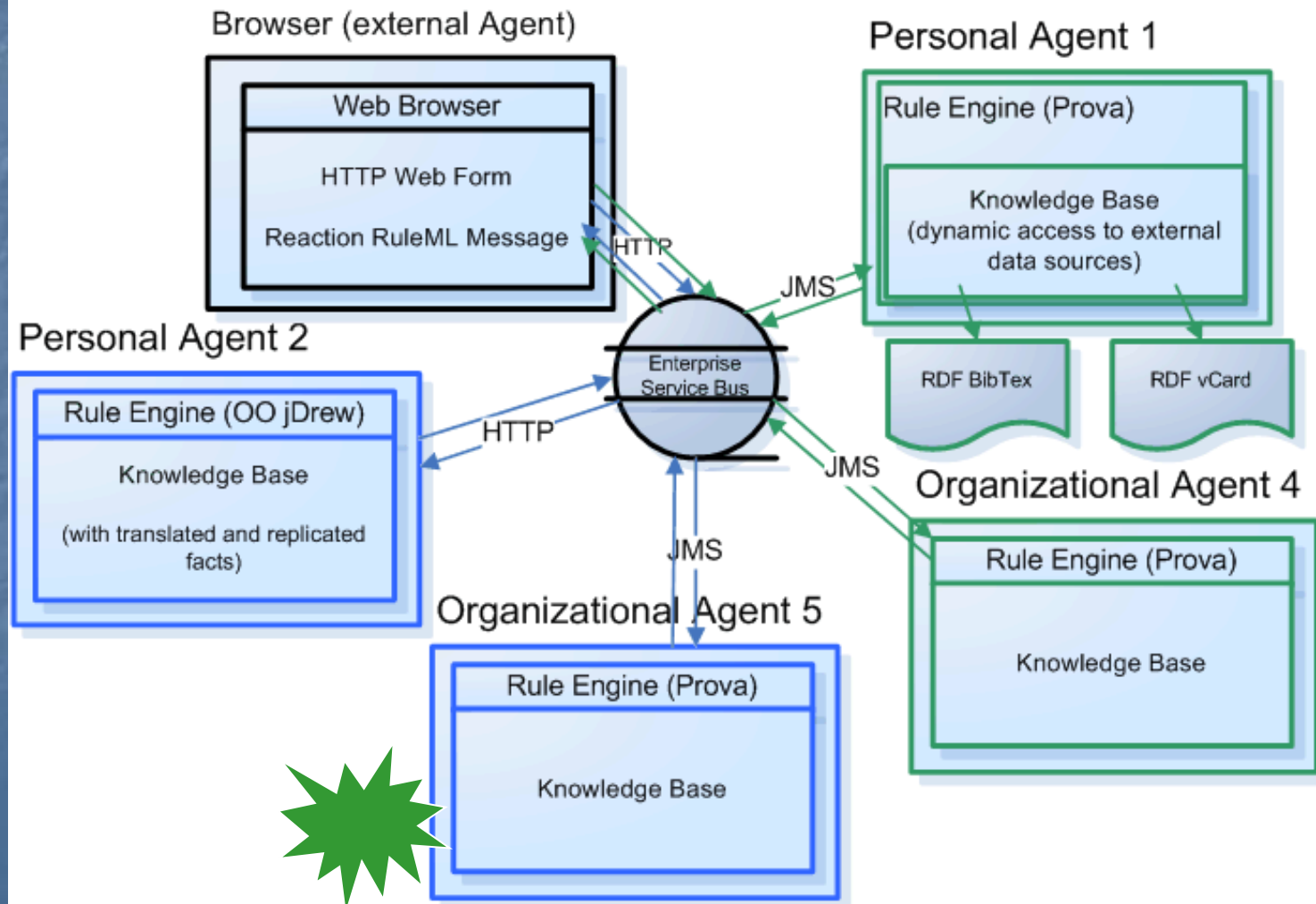
Architecture - Execution

Use Case 4 Use Case 5



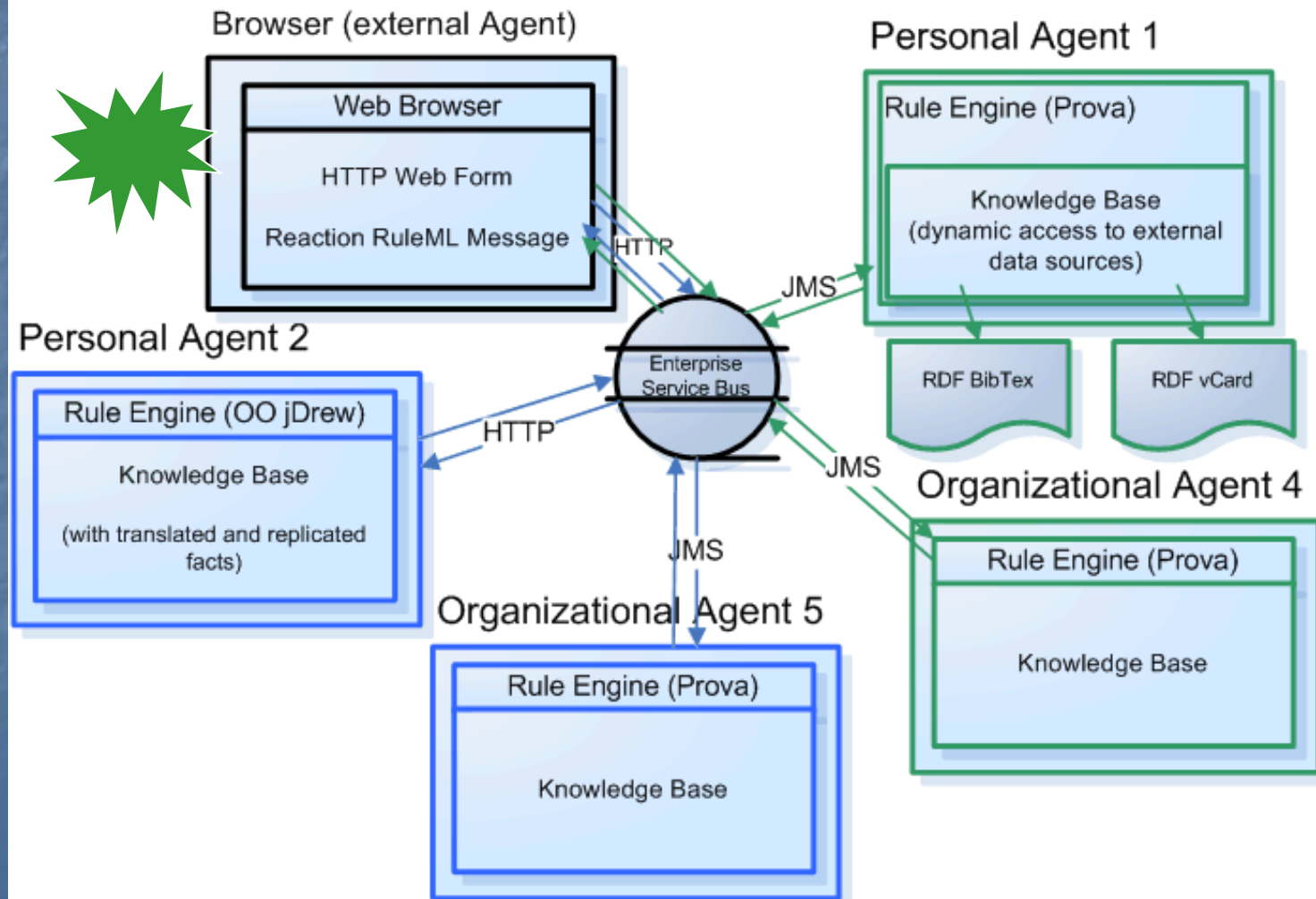
Architecture - Execution

Use Case 4 Use Case 5



Architecture - Execution

Use Case 4 Use Case 5



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Rule Responder

Use this text form to send a query in Reaction RuleML format to the RuleML-2009 Organizational Agent:

```

<RuleML xmlns=
  "http://www.ruleml.org/0.91/xsd"
  xmlns:xsi=
  "http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation=
  "http://www.ruleml.org/0.91/xsd
  http://ibis.in.tum.de/research/
  ReactionRuleML/0.2/rr.xsd"
  xmlns:ruleml2007=
  "http://ibis.in.tum.de/projects/paw#">
  <Message mode="outbound"
  directive="query-sync">
    <oid>
      <Ind>RuleML-2009</Ind>
    </oid>
    <protocol>
      <Ind>esb</Ind>
    </protocol>
    <sender>
      <Ind>User</Ind>
    </sender>
    <content>
      <Atom>
        <Rel>getContact</Rel>
        <Ind>ruleml2009_GeneralChair</Ind>
        <Ind>update</Ind>
        <Var>Contact</Var>
      </Atom>
    </content>
  </Message>
</RuleML>

```

Send Message

Query Selection

The drop-down boxes show sample queries you -- as an External Agent -- can send to the RuleML-2009 Organizational Agent. These examples can also act as initial templates that you can edit to create your own queries.

General Chair Contact

15 October 2009

We are please to announce that Ontotext have become a gold level sponsor
[Ontotext web site](#)

15 October 2009

RuleML 2009 proceedings now available at Springer
[read more ...](#)

4 September 2009

Preliminary program announced
[read more ...](#)

RuleML 2009 Sponsors

Gold Sponsor



Silver Sponsors



```

<?xml version="1.0" encoding="UTF-8" ?>
- <RuleML xmlns="http://www.ruleml.org/0.91/xsd"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://www.ruleml.org/0.91/xsd
  http://ibis.in.tum.de/research/ReactionRuleML/0.2/rr.xsd">
- <Message mode="outbound" directive="answer">
  - <oid>
    <Ind>RuleResponder@iitfrdextdev01.iit-iti.priv213</Ind>
    </oid>
  - <protocol>
    <Ind>esb</Ind>
    </protocol>
  - <sender>
    <Ind>RuleResponder</Ind>
    </sender>
  - <content>
    - <Atom>
      <Rel>getContact</Rel>
      <Ind>ruleml2009_GeneralChair</Ind>
      <Ind>update</Ind>
    - <Expr>
      <Fun>person</Fun>
    - <Expr>
      <Fun>symposiumChair</Fun>
      <Ind>ruleML_2009</Ind>
      <Ind>general</Ind>
    </Expr>
    - <Expr>
      <Fun>foafname</Fun>
    - <Expr>
      <Fun>firstName</Fun>
      <Ind>Adrian</Ind>
    </Expr>
    - <Expr>
      <Fun>lastName</Fun>
      <Ind>Paschke</Ind>
    </Expr>
    </Expr>
  - <Expr>
    <Fun>foaftitle</Fun>
  - <Expr>
    <Fun>title</Fun>
    <Ind>Dr</Ind>
  </Expr>
  </Expr>
  - <Expr>
    <Fun>foafmbox</Fun>
  - <Expr>
    <Fun>email</Fun>
    <Ind>adrianDOTpaschkeATgmxDOTde</Ind>
  </Expr>
  </Expr>
  - <Expr>
    <Fun>exphones</Fun>
  - <Expr>
    <Fun>telephoneNumbers</Fun>
  - <Expr>
    <Fun>office</Fun>
    <Ind>4935146340074</Ind>
  </Expr>
  <Fun>cellPhone</Fun>
  </Expr>
  </Expr>
  </Atom>
  </content>
</Message>
</RuleML>

```

Sample Message to Publicity Chair PA (I)

```
<content>
  <Atom>
    <Rel>sponsor</Rel>
    <Expr>
      <Fun>contact</Fun>
      <Ind>Mark</Ind>
      <Ind>JBoss</Ind>
    </Expr>
    <Ind type="integer">500</Ind>
    <Expr>
      <Fun>results</Fun>
      <Var>Level</Var>
      <Var>Benefits</Var>
      <Var>DeadlineResults</Var>
    </Expr>
    <Expr>
      <Fun>performative</Fun>
      <Var>Action</Var>
    </Expr>
  </Atom>
</content>
```



<http://www.ruleml.org/RuleML-2009/RuleResponder>
Query Selection: Publicity Chair Sponsoring

English Description:

Mark from JBoss would like to sponsor RuleML-2009 with \$**500**. What level, benefits, and deadline results will this provide, and what kind of action should be taken?

```
- <content>
- <Atom>
  <Rel>sponsor</Rel>
- <Expr>
  <Fun>contact</Fun>
  <Ind>Mark</Ind>
  <Ind>JBoss</Ind>
</Expr>
<Ind type="integer">500</Ind>
- <Expr>
  <Fun>results</Fun>
  <Ind>bronze</Ind>
- <Expr>
  <Fun>benefits</Fun>
- <Expr>
  <Fun>logo</Fun>
- <Expr>
  <Fun>on</Fun>
  <Ind>site</Ind>
</Expr>
</Expr>
- <Expr>
  <Fun>acknowledgement</Fun>
- <Expr>
  <Fun>in</Fun>
  <Ind>proceedings</Ind>
</Expr>
</Expr>
- <Expr>
  <Fun>passed</Fun>
  <Ind>deadline</Ind>
</Expr>
</Expr>
- <Expr>
  <Fun>performative</Fun>
  <Ind>email</Ind>
</Expr>
</Atom>
</content>
```


Publicity Chair PA

Knowledge Base: Rules

% Rule stored in the Publicity Chair's PA:

```
sponsor(contact[?Name,?Organization],  
        ?Amount:integer,  
        results[?Level,?Benefits,?DeadlineResults],  
        performative[?Action]) :-
```

```
requestSponsoringLevel(?Amount:integer,?Level),  
requestBenefits(?Level,?Benefits),  
checkDeadline(?DeadlineResults),  
checkAction(?Action,?Level,?Amount:integer).
```



Yellow:
Query
other rules

Publicity Chair PA

Knowledge Base: 1st & 2nd Rule Premise

requestSponsoringLevel(?Amount:integer,?Level),

% Satisfied by presponsor, bronze, ..., emerald rule:

...

requestSponsoringLevel(?Amount:integer,?Level) :-

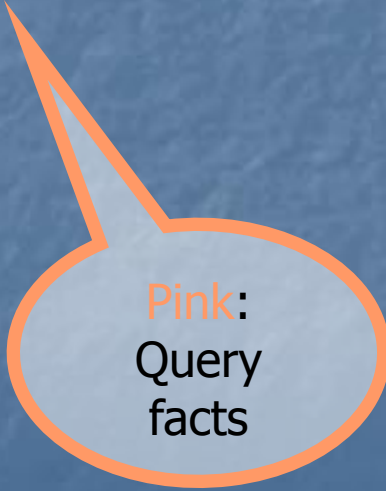
sponsoringLevel(rank5,?Level,us\$[?EmeraldAmount:integer]),
greaterThanOrEqualTo(?Amount:integer,
?EmeraldAmount:integer).

requestBenefits(?Level,?Benefits),

% Satisfied by rule:

requestBenefits(?Level,?Benefits) :-

benefits(?Level,?Benefits).



Pink:
Query
facts

Publicity Chair PA

Knowledge Base: 3rd & 4th Rule Premise

checkDeadline(?DeadlineResults),

% Satisfied by rule:

checkDeadline(passed[deadline]):-

date(?X:integer),

deadline(sponsoring,?D:integer),

greaterThan(?X:integer,?D:integer).

checkAction(?Action,?Level,?Amount:integer).

% Satisfied by rule:

checkAction(?Action,?Level,?Amount:integer) :-

actionPerformed(?Action,?Level,?Amount:integer).

*What happens if we now provide a \$5000 sponsorship?
... see next slide ...*

Sample Message to Publicity Chair PA (II)

- <content>
- <Atom>
- <Rel>sponsor</Rel>
- <Expr>
- <Fun>contact</Fun>
- <Ind>Mary</Ind>
- <Ind>Super</Ind>
- </Expr>
- <Ind type="integer">**5000**</Ind>
- <Expr>
- <Fun>results</Fun>
- <Var>Level</Var>
- <Var>Benefits</Var>
- <Var>DeadlineResults</Var>
- </Expr>
- <Expr>
- <Fun>performative</Fun>
- <Var>Action</Var>
- </Expr>
- </Atom>
- </content>



<http://www.ruleml.org/RuleML-2009/RuleResponder>

Query Selection: Publicity Chair Sponsoring *(edited)*

English Description:

Mark from JBoss would like to sponsor RuleML-2009 with \$**5000**. What level, benefits, and deadline results will this provide, and what kind of action should be taken?

```

- <content>
- <Atom>
  <Rel> sponsor </Rel>
- <Expr>
  <Fun> contact </Fun>
  <Ind> Mark </Ind>
  <Ind> JBoss </Ind>
</Expr>
<Ind type="integer"> 5000 </Ind>
- <Expr>
  <Fun> results </Fun>
  <Ind> platinum </Ind>
- <Expr>
  <Fun> benefits </Fun>
- <Expr>
  <Fun> logo </Fun>
- <Expr>
  <Fun> on </Fun>
  <Ind> site </Ind>
</Expr>
</Expr>
- <Expr>
  <Fun> acknowledgement </Fun>
- <Expr>
  <Fun> in </Fun>
  <Ind> proceedings </Ind>
</Expr>
</Expr>
- <Expr>
  <Fun> option </Fun>
- <Expr>
  <Fun> sponsor </Fun>
  <Ind> student </Ind>
</Expr>
</Expr>
- <Expr>
  <Fun> free </Fun>
  <Ind> registration </Ind>
- <Expr>
  <Fun> amount </Fun>
  <Ind> 2 </Ind>
</Expr>
</Expr>

```

```

- <Expr>
  <Fun> logo </Fun>
- <Expr>
  <Fun> in </Fun>
  <Ind> proceedings </Ind>
</Expr>
</Expr>
- <Expr>
  <Fun> option </Fun>
  <Ind> demo </Ind>
</Expr>
</Expr>
- <Expr>
  <Fun> name </Fun>
- <Expr>
  <Fun> all </Fun>
- <Expr>
  <Fun> advance </Fun>
  <Ind> publicity </Ind>
</Expr>
</Expr>
</Expr>
- <Expr>
  <Fun> distribution </Fun>
- <Expr>
  <Fun> brochures </Fun>
- <Expr>
  <Fun> all </Fun>
  <Ind> participants </Ind>
</Expr>
</Expr>
</Expr>
</Expr>
- <Expr>
  <Fun> passed </Fun>
  <Ind> deadline </Ind>
</Expr>
</Expr>
</Expr>
- <Expr>
  <Fun> performative </Fun>
  <Ind> phone </Ind>
</Expr>
</Atom>
</content>

```

Program Chair PA (RuleML-2010)

- Contains knowledge about tracks of RuleML-2010
 - Track title, Track topics, Track chairs
- Answers queries for finding a relevant track for a paper
 - Uses a paper's keywords within (the strings of) the track titles and topics
 - Rule-based heuristic scoring functions

Program Chair PA: Find Relevant Tracks

<Message ...>

Query

...

<content>

<Atom>

<Rel>findTracks</Rel>

<Ind type="string">

defeasibility; rule exceptions

</Ind>

<Var>ScoredTrack</Var>

</Atom>

</content>

</Message>

<Expr>

<Fun>track</Fun>

<Ind type="string">

Rules and Norms

</Ind>

<Expr>

<Fun>relevance</Fun>

<Ind type="real">10017</Ind>

</Expr>

</Expr>

Answer

May 20, 2010
RuleML-2010 deadlines
are extended

Read more...

Navigation

The Symposium

Who Will Attend
Highlights
Keynote Speakers and
Invited Demos
Boxed Lunch Panel
Accepted Papers
Program Committee
Proceedings
Program
Registration
Venue
Sponsors and Partners
Sponsorship
Rule Responder Q&A
Business Rule Forum

Authors

Objectives
Topics
RuleML-2010 Challenge
Submission Guidelines
RuleML 2010 Call for

Topics

Conference Theme

This year, we particularly welcome submissions that address applications of Web rule technologies for business and information systems. We invite you to share your ideas, results, and experiences: as an industry practitioner, rule system provider, technical expert and developer, rule user or researcher, exploring foundations, developing systems and applications, or using rule-based systems. We invite high-quality submissions related to (but not limited to) one or more of the following topics:

Track Topics

...

CfP

Rules and Norms

- Methodologies for modeling regulations using both ontologies and rules
- Defeasibility and norms: modeling rule exceptions and priority relations among rules
- The relationship between rules and legal argumentation schemes
- Rule language requirements for the "isomorphic" modeling of legislation
- Rule based inference mechanism for legal reasoning
- E-contracting and automated negotiations with rule-based declarative strategies

...

Conclusion (I)

- Rule Responder was implemented & tested for various use cases (<http://responder.ruleml.org>) and deployed for RuleML-2008/.../2010 [Q&A](#)
- Its organizational agents delegate external queries to topic-assigned personal agents
- It couples rule engines [Prova](#) & [OO jDREW](#) & [DR-Device](#) (& [Euler](#)) via Mule middleware and [RuleML 0.91](#) XML interchange format
 - Without a Reaction Rule Dialect, W3C RIF could not be used for behavioral Responder logic

Conclusion (II)

- Current system is reusable on all levels: Symposium Planner, Rule Responder, (D-)POSL, RuleML, OO jDREW, DR-Device, Prova, and Mule
- RuleML Responder Technical Group jointly with [Adrian Paschke](#), [Alexander Kozlenkov](#), Ben Craig, Taylor Osmun, Derek Smith, Irfan ul Haq, Omair Shafiq, Mahsa Kiani, [Nick Bassiliades](#), Stratos Kontopoulos, and Kalliopi Kravari
- Integrated another 'partner engine', [Euler](#), for recent use cases, e.g. in [WellnessRules2](#) and [PatientSupporter](#) (generating RuleML/XML queries from menus for POSL and N3). More upcoming

Future Work (I)

- Communication between Personal Agent and Human Owner
 - The PA may need to interact with its Human Owner
 - Formal interaction between PAs and their owners can employ Reaction RuleML emails (SMTP)
 - Semi-formal interaction could use Controlled English
- Query Decomposition
 - Queries decomposed into subqueries, delegated to multiple PAs, and partial answers re-integrated
 - Applications in information (data and knowledge) integration

Future Work (II)

- Centralized, Distributed-Hierarchical (here), and Distributed-Networked (future) query answering
- Centralized: Avoids all communication overhead
- Distributed: More fault-tolerant and typically faster
 - Alternative agents when an agent becomes defunct
 - Hierarchical: OA may sometime become a bottleneck
 - Networked: Peer-to-peer exchange between PAs
- From centralized to distributed knowledge maintenance
 - Easier to keep distributed rules up-to-date
- Discussed in [Technical Report](#) by Ben Craig and explored in PhD project by Mahsa Kiani