

# A Semantic Brokering System for the Tourism Domain

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**Abstract.** The tourism industry is a good candidate for taking up Semantic Web technology. In this paper we study the brokering and matchmaking problem in the tourism domain, that is, how a requester's requirements and preferences can be matched against a set of offerings collected by a broker. The proposed solution uses the Semantic Web standard of RDF to represent the offerings, and a deductive logical language for expressing the requirements and preferences. We motivate and explain the approach we propose, and report on a prototypical implementation exhibiting the described functionality in a multi-agent environment.

**Keywords:** Brokering, Rules, Ontologies, RDF Schema

## 1. Introduction

*E-Commerce* describes the revolution that is currently transforming the way business is conducted through the use of information technology, and in particular the World Wide Web. According to [21], in the 1<sup>st</sup> generation e-Commerce applications (current state), buyers and sellers are *humans* who typically browse through a catalogue of well-defined commodities (e.g. flights, books...) and make fixed price purchases usually by means of credit card transactions. Humans are in the loop at all stages of buying process something which is time consuming.

The 2<sup>nd</sup> generation of e-Commerce will be realized through the use of automated methods of information technology. Web users will be represented by *software agents*. According to [27], there is an increasing use of software agents for all the aspects of e-Commerce.

As software agents start to engage in e-commerce, new issues arise. Information must be organized in a way that is accessible by both humans and machines. Additionally, machines must be able to access, process and interpret the information in the same way. This vision is consistent with the *Semantic Web* initiative [9], which enriches the current Web through the use of machine-processable information about the meaning (semantics) of information content. This way, the meaning of displayed

information is accessible not only to humans, but becomes also accessible to software agents.

The key techniques of the Semantic Web are *semantic annotations (meta-data)*, such that Web information carries its meaning on its sleeve, and *ontologies* which organize terms in a conceptualization of a domain, thus connecting semantic annotations with each other and serving as a basis for interoperability.

The *tourism industry* is a most appropriate candidate for the early adoption of the latest e-Commerce technologies. According to [26], the area of tourism is highly dynamic and the need for Internet technologies is inevitable. Such early take-up of Internet technology by the tourism industry is due to a number of special characteristics:

- Its products are complex.
- A tourism product will perish if it is not sold in time.
- The tourism industry depends on complex value creation chains involving a large number of participants (travel agencies, tour operators, hotels, etc.).

However, the current Web poses a number of limitations to information processing, and the tasks of finding, extracting and interpreting the information are left to human users. The need for semantically connecting the dispersed and isolated pieces of information seems to be very crucial. In their work, Maedche and Staab ([26]) stress the need for (a) semantic search engines for tourism, (b) semantic-based electronic markets, and (c) (semantic) Web services for tourists.

The focus of the present work is on semantic-based electronic markets, according to this classification. Semantics-based electronic markets help both service providers and requesters to match their interests. The key operations in such markets are to:

- i. Identify appropriate services that satisfy user requirements.
- ii. Select the best service based on the user's preferences.

How to address these questions using Semantic Web technology is the main focus of the present work. The approach that we follow in this paper is based on the existence of a brokering service for tourism service providers, as a meta-service that provides a single point of contact (e.g. a tourism mall) for tourists. This centralized service gathers tourism service advertisements from travel agents that want to be found easily by their potential customers and offers a matchmaking service between travel package offers and tourist travel preferences.

The three basic roles that we identify are the *service requester* (or the buyer or the tourist), the *service provider* (or seller or travel agent), and the *broker*. The technical solution we provide is based on the following key ideas:

- The offerings or advertisements of tourism service providers are represented in a Semantic Web language (RDF).
- These advertisements are semantically enriched by the use of a domain ontology (in RDF Schema).
- The advertisements are communicated to the broker by their providers.
- The requirements and preferences of a potential customer are represented in a logical language, based on rules and priorities.
- The logical representation of preferences and requirements are communicated to the broker by the requester.
- The broker matches the preferences against the set of available advertisements. The outcomes are communicated back to the requester.

- The broker maintains a repository to permanently store the advertisements.
- All the above operations take place in a multi-agent environment based on the peer to peer paradigm.

The motivation for the broker to provide this mediation service is, of course, the profit: for each successful transaction the broker could charge either the buyer or the seller or both a small amount of money. The motivation for the tourist to request a tourist package deal through this brokering service, instead of searching directly at the various travel agents web sites/services is convenience: the user has just to visit a single web site/service, express his/her preferences just once using a single preference specification language, and get back the results in a unified format. Furthermore, the homogeneity of the advertisement format guarantees that the offers will be compared through a consistent set of metrics. Furthermore, the brokering service could offer better prices for its tourist customers because of special agreements with the travel agents. Finally, the motivation for the service provider to advertise (and actually sell) his/her products through the brokering service is enhanced product visibility by potential customers which could lead to more sales, at the expense of a small sale percentage.

In the following we will elaborate on the problem, the technical solution, and an implemented system displaying the described functionality. The remainder of the paper is organized as follows: Section 2 reviews the most important Semantic Web technologies used in our solution. Section 3 describes our solution to the brokering problem, including a rationale for the chosen technologies. Section 4 illustrates the approach using a concrete example. Section 5 describes the technical details of the system that implements the solution. Finally, section 6 reviews related work and section 7 concludes the paper and poses future research directions.

## **2. An Overview of the Used Technologies**

### **2.1 The Semantic Web Initiative**

The aim of the Semantic Web initiative is to advance the state of the current Web through the use of semantics. More specifically, it proposes to use *semantic annotations* to describe the meaning of certain parts of Web information. For example, the Web site of a hotel could be suitably annotated to distinguish between hotel name, location, category, number of rooms, available services etc. Such meta-data could facilitate the automated processing of the information on the Web site, thus making it accessible to machines and not primarily to human users, as it is the case today.

However, the question arises as to how the semantic annotations of different Web sites can be combined, if everyone uses terminologies of their own. The solution lies in the organization of vocabularies in so-called *ontologies*. References to such shared vocabularies allow interoperability between different Web resources and applications. For example, an ontology of hotel classifications in a given country could be used to relate the rating of certain hotels. And a geographic ontology could be used to determine that Crete is a Greek island and Heraklion a city on Crete. Such information would be crucial to establish a connection between a requester looking for accommodation on a Greek island, and a hotel advertisement specifying Heraklion as the hotel location.

The development of the Semantic Web proceeds in steps, each step building a layer on top of another. The layered design is shown in Fig. 1, which is outlined below.

- At the bottom layer we find *XML* [10], a language that lets one write structured Web documents with a user-defined vocabulary. XML is particularly suitable for sending documents across the Web, thus supporting syntactic interoperability.
- *RDF* is a basic data model for writing simple statements about Web objects (resources). The RDF data model does not rely on XML, but RDF has an XML-based syntax. Therefore it is located on top of the XML layer.
- *RDF Schema* provides modeling primitives for organizing Web objects into hierarchies. RDF Schema is based on RDF. RDF Schema can be viewed as a primitive language for writing ontologies.
- But there is a need for more powerful *ontology languages* that expand RDF Schema and allow the representation of more complex relationships between Web objects. Ontology languages, such as OWL, are built on the top of RDF and RDF Schema.
- The *logic layer* is used to enhance the ontology language further, and to allow writing application-specific declarative knowledge.
- The *proof layer* involves the actual deductive process, as well as the representation of proofs in Web languages and proof validation.
- Finally *trust* will emerge through the use of digital signatures, and other kind of knowledge, based on recommendations by agents we trust, or rating and certification agencies and consumer bodies.

For an easy yet comprehensive introduction to the Semantic Web see [4].

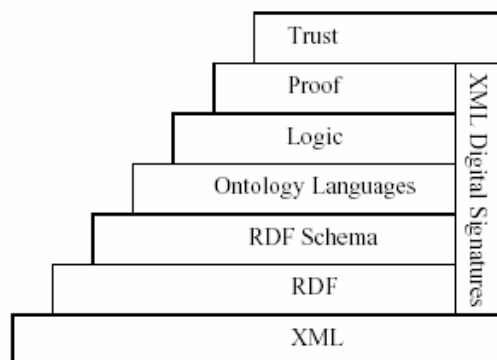


Fig. 1 The Semantic Web Tower

## 2.2 RDF Basic Features

RDF [5] stands for Resource Description Framework and its purpose is to describe resources on the Web. RDF is designed to be read by computers. The basic RDF data model consists of three fundamental concepts: *resource*, *property* and *statements*.

Resources are the central concept of RDF and are used to describe individual objects of any kind, for example Web pages, people, hotels, flights etc. Every

resource has a URI, a Universal Resource Identifier, which can be a Web address or some other kind of unique identifier.

Properties express specific aspects, characteristics, attributes, or relations between resources. For example, properties might be the number of rooms in a hotel, proximity to the beach etc.

Finally statements are composed of a specific resource, together with a named property and the *value* of that property for that resource. The value can be a resource in turn; for example, the manager of Agapi Beach hotel is Alexis Zorbas. Alternatively, the value can be a *literal*, a primitive term that is not evaluated by an RDF processor. For example, the number of rooms of Agapi Beach is 117.

A statement consists of three parts (subject, predicate, object) and is often referred to as a triple. A triple of the form (x, P, y) corresponds to the logical formula P(x, y), where the binary predicate P relates the object x to the object y; this representation is used in our system for translating RDF statements into a logical language ready to be processed automatically in conjunction with rules.

Another possible representation is the graph-based. The graph is directed with labeled nodes and arcs. The arcs are directed from the resource (the subject of the statement) to the value (the object of the statement); see Figure 2. This kind of graph is known as a *semantic net* in the artificial intelligence community.

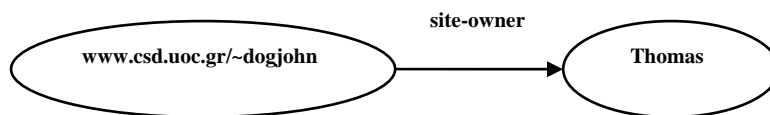


Fig. 2 Graph-Based Representation of RDF Statement

Lastly, there is a third representation based on XML. This representation is compatible with the layered design of the Semantic Web, and facilitates exchange of RDF information among applications.

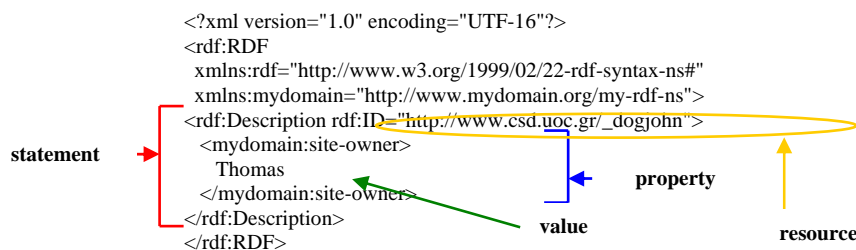


Fig. 3 XML-Based Representation of an RDF Statement

## 2.3 RDF Schema Basic Features

RDF is domain-independent, in that no assumptions about a particular domain of use are made. It is up to the users to define their own terminology in a schema language called RDF Schema (RDFS) [11]. In doing so, they actually define a simple ontology, a conceptual model of the domain at hand. The basic features of RDF Schema are the following.

In RDF, Web resources are individual objects. In RDFS, objects sharing similar characteristics are put together to form *classes*. Examples for classes are hotels, airlines, employees, rooms, excursions etc. Individuals belonging to a class are often

referred to as *instances* of that class. For example, John Smith could be an instance of the class of employees of a particular hotel.

Binary *properties* are used to establish connections between classes. For example, a property *works\_for* establishes a connection between employees and companies. Properties apply to individual objects (instances of the classes involved) to form RDF statements, as seen above.

The application of predicates can be restricted through the use of *domain and range restrictions*. For example, we can restrict the property *works\_for* to apply only to employees (domain restriction), and to have as value only companies (range restriction). This way, nonsensical statements due to user errors, for example that Crete works for Agapi Beach, can be automatically detected.

Classes can be put together in hierarchies through the *subclass relationship*: a class C is a subclass of a class D if every instance of C is also an instance of D. For example, the class of island destinations is a subclass of all destinations: every instance of an island destination (e.g. Crete) is also a destination.

The hierarchical organization of classes is important due to the notion of *inheritance*: once a class C has been declared a subclass of D, every known instance of C is *automatically* classified also as instance of D. This has far-reaching implications for matching customer preferences to service offerings. For example, a customer may wish to make holidays on an Indonesian island. On the other hand, the hotel Noosa Beach advertises its location to be Bali. It is not necessary (nor is it realistic) for the hotel to add information that it is located in Indonesia and on an island; instead, this information is inferred by the ontology automatically.

## 2.4 Rules and Priorities on the Semantic Web

At present, the highest layer that has reached sufficient maturity is the ontology layer in the form of the description logic based language OWL [20]. The next step in the development of the Semantic Web will be the logic and proof layers, and *rule systems* appear to lie in the mainstream of such activities. Moreover, rule systems can also be utilized in ontology languages. So, in general rule systems can play a twofold role in the Semantic Web initiative: (a) they can serve as extensions of, or alternatives to, description logic based ontology languages; and (b) they can be used to develop declarative systems on top of (using) ontologies. Reasons why rule systems are expected to play a key role in the further development of the Semantic Web include the following:

- Seen as subsets of predicate logic, monotonic rule systems (Horn logic) and description logics are orthogonal; thus rules provide additional expressive power to ontology languages.
- Efficient reasoning support exists to support rule languages.
- Rules are well known in practice, and are reasonably well integrated in mainstream information technology, such as knowledge bases, etc.

Possible interactions between description logics and monotonic rule systems were studied in [19]. However, these works don't exploit features such as negation, rules with exceptions and conflicting rules. Based on that work and on previous work on hybrid reasoning [24] it appears that the best one can do at present is to take the intersection of the expressive power of Horn logic and description logics; one way to view this intersection is the Horn-definable subset of OWL.

In our work we follow a different approach, by adding rules "on top" of web ontologies. However, as it is argued in [6], putting rules and description logics

together poses many problems, and may be overkill, both computationally and linguistically. Another possibility is to start with RDF/RDFS, and extend it by adding rules. Furthermore, we make use of a feature called *conflicts among rules*. Generally speaking, the main sources of such conflicts are:

- Default inheritance within ontologies.
- Ontology merging.
- Rules with exceptions as a natural representation of business rules.
- Reasoning with incomplete information.

### 2.4.1 Basics of Defeasible Logics

*Defeasible reasoning* is a simple rule-based approach to reasoning with incomplete and inconsistent information. It can represent facts, rules, and priorities among rules. This reasoning family comprises defeasible logics [2] and Courteous Logic Programs [17]. The main advantage of this approach is the combination of two desirable features: enhanced representational capabilities allowing one to reason with incomplete and contradictory information, coupled with low computational complexity compared to mainstream nonmonotonic reasoning. The main features of this approach are:

- Defeasible logics are rule-based, without disjunction.
- Classical negation is used in the heads and bodies of rules, but negation-as-failure is not used in the object language (it can easily be simulated, if necessary [3]).
- Rules may support conflicting conclusions.
- The logics are skeptical in the sense that conflicting rules do not fire. Thus consistency is preserved.
- Priorities on rules may be used to resolve some conflicts among rules.
- The logics take a pragmatic view and have low computational complexity.

There are two kinds of rules (fuller versions of defeasible logics include also defeaters): *Strict rules* are denoted by  $A \rightarrow p$ , and are interpreted in the classical sense: whenever the premises are indisputable then so is the conclusion. An example of a strict rule is “*Professors are faculty members*”. Written formally:  $professor(X) \rightarrow faculty(X)$ . Inference from strict rules only is called *definite inference*. Strict rules are intended to define relationships that are definitional in nature, for example ontological knowledge.

*Defeasible rules* are denoted by  $A \Rightarrow p$ , and can be defeated by contrary evidence. An example of such a rule is  $faculty(X) \Rightarrow tenured(X)$  which reads as follows: “*Professors are typically tenured*”.

A *superiority relation* on  $R$  is an acyclic relation  $>$  on  $R$  (that is, the transitive closure of  $>$  is irreflexive). When  $r_1 > r_2$ , then  $r_1$  is called *superior* to  $r_2$ , and  $r_2$  *inferior* to  $r_1$ . This expresses that  $r_1$  may override  $r_2$ . For example, given the rules

$$\begin{aligned} r: & professor(X) \Rightarrow tenured(X) \\ r': & visiting(X) \Rightarrow \neg tenured(X) \end{aligned}$$

which contradict one another, no conclusive decision can be made about whether a visiting professor is tenured. But if we introduce a superiority relation  $>$  with  $r' > r$ , then we can indeed conclude that he/she cannot be tenured.

A formal definition of the proof theory is found in [2]. A model theoretic semantics is found in [29], and argumentation semantics is discussed in [14].

### 3. Proposed Solution

#### 3.1 Agent Discovery and Service Providing Architectures

*Agent discovery* is a way of advertising, managing and finding information about agents' services and capabilities. We can distinguish two different categories of agent discovery mechanisms, centralized and distributed.

When it comes to centralized solutions for agent discovery, or “middle agents” according to [38], three different kinds of agents prevail. They are called *matchmakers* or Yellow Pages Services, *facilitators* and *brokers* respectively. We borrow the next two figures from their work.

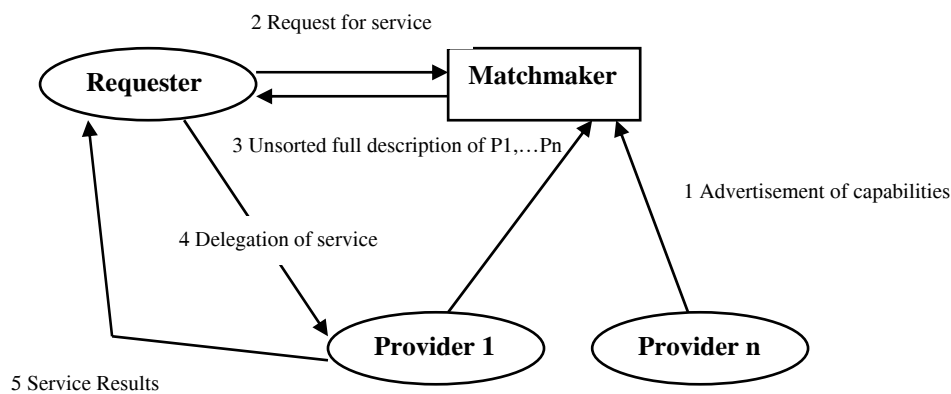


Fig. 4 Matchmaker Architecture

When it comes to matchmakers, different service providers advertise their capabilities (1) and the matchmaker puts them into a repository. When the matchmaker is asked for a particular service by a service requester (2), it returns information about all the available service providers (3). It now depends on the requester which provider it will choose (4) for the required service. Lastly, the provider serves the request and returns the results (5). It is assumed that the “address” of a matchmaker is well-known.

Facilitators operate in a slightly different way. Initially, providers advertise their capabilities (1). After requesters have located a facilitator they pass on their preferences along with the delegation of a service (2). The facilitator, in turn, picks one of the providers to delegate the requested service (3). The provider then returns the result (4) and the facilitator returns it to the requester (5).

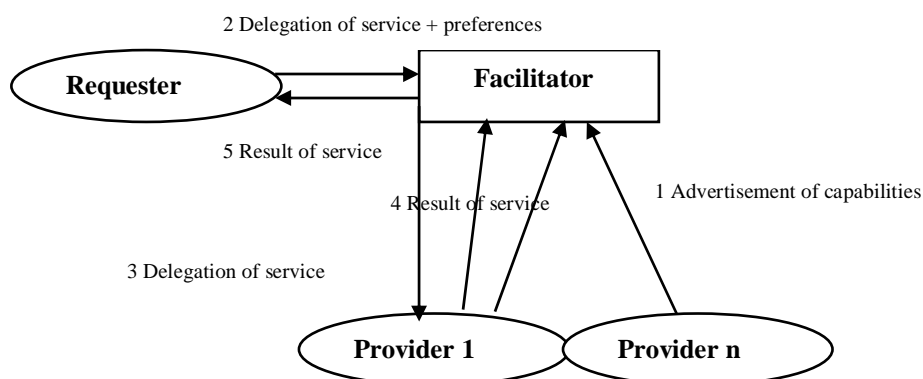


Fig. 5 Facilitator-Broker Architecture



A variation of this architecture could be that the middle agent itself performs the serving of a request using services and information from other agents in conjunction with his own services. In the latter case the middle agent is called “broker”. We use this variation for our implementation. However, we would like to stress that our technology can easily be adapted to realize any of the above architectures; we have chosen to implement the broker architecture to demonstrate the feasibility of the overall approach.

### 3.2 General Approach

The three basic roles that we identify in our brokering system are the *Service Requester* (or the Buyer), the *Service Provider* (or Seller), and the *Broker*. Another agent, called Directory Facilitator (D.F.) plays a secondary role and is the yellow pages service (or Matchmaker), which agents use to find each other and register what protocols they use, what ontologies they use, etc. The technical solution we provide is based on the following key ideas:

- Service requesters, service providers and brokers are represented by software agents that run on the JADE multi-agent platform.
- The requirements of the service requester are represented in defeasible logic, using rules and priorities. These requirements include both indispensable requirements that must be met for a service to be acceptable (for example, air-conditioning is required), and soft requirements (preferences) that can be used to select among the potentially acceptable offerings. These requirements are communicated to the broker agent by the requester agent. This communication initiates a brokering activity.
- The offerings or advertisements are represented in a certain semi-structured format using the Semantic Web standard language RDF for describing Web resources. The provider agents communicate the offerings to the broker agent.
- The terminology shared by providers, requesters and brokers is organized in an ontology using the Semantic Web standard of RDF Schema.
- The broker is also a software agent and has special knowledge both for the declarative language and the advertisement format. It also has the ability to perform semantic checks to the information it receives.
- When the broker receives a request it matches the request to the advertisements by running the request specification against the available offerings, making use of information provided by the shared ontology, as required. Then the requester’s preferences are applied to select the most suitable offering(s) which are then presented to the requester.
- For the persistent storage of advertisements, an RDF repository, and particularly ICS-FORTH RDF Suite [1], is used.

### 3.3 Description of Offerings

The offerings are described in RDF, the standard Semantic Web language for representing factual statements. This choice (a) supports interoperability among agents and applications, and (b) facilitates the easy publication, collection and combination in decentralized dynamic settings. The offerings are enriched through reference to shared ontologies, e.g. of the tourism domain or geographical terms. The benefits of ontologies for matching requester requirements to offerings were stated previously. We assume that this ontology is expressed in RDF Schema. We have chosen this language over the use of OWL because at present it is not clear how the

deductive capabilities of OWL and rule systems can be combined; it is one of the main research lines in the Semantic Web community. We could certainly use most features of OWL Lite, given that they can be expressed using rules [19].

### 3.4 Description of Requests and Preferences

The requirements and preferences of the requester are described in a logical language. Before choosing one or several languages for the specification of requests it is important to establish a set of criteria that such languages need to satisfy. The criteria presented below are inspired from those formulated by [22] in the context of techniques for information modeling. They encompass several well-known principles of language design.

Firstly, a language for specifying requirements and preferences needs to be *formal*, in the sense that its syntax and its semantics should be precisely defined. This ensures that the requirements and preferences can be interpreted unambiguously (both by machines and humans) and that they are both *predictable* and *explainable*.

Secondly, the language should be *conceptual*. This, following the well-known *Conceptualization Principle* of [16], effectively means that it should allow its users to focus only and exclusively on aspects related to requirements, without having to deal with any aspects related to their realization or implementation. Examples of conceptually irrelevant aspects in the context that we consider are: physical data organization and access, platform heterogeneity (e.g. message-passing formats), and book-keeping (e.g. message queue management).

Thirdly, in order to ease the interpretation of strategies and to facilitate their documentation, the language should be *comprehensible*. Comprehensibility can be achieved by offering a graphical representation, by ensuring that the formal and intuitive meanings are as much in line as possible, and by offering structuring mechanisms (e.g. decomposition). These structuring mechanisms often lead to *modularity*, which in our setting means that a slight modification to a strategy should concern only a specific part of its specification. Closely related to its comprehensibility, the language that we aim should be suitable, that is, it should offer concepts close to those involved in requirements and preferences.

As we are interested in the automation of the brokering process, the requirements description language should be *executable*, and its execution should exhibit acceptable performances even for complex requirements (i.e. the execution performances should be *scalable*). Finally, the language that we aim should be sufficiently *expressive*, that is it should be able to precisely capture a wide spectrum of requirements.

We have chosen defeasible logic to represent requesters' requirements and preferences because it satisfies the above criteria. In particular,

- It is a formal language with well-understood meaning ([2] presents a proof theory, [29] its model semantics, and [14] its argumentation semantics), thus it is also predictable and explainable.
- It is designed to be executable; implementations are described in [30]. It is also scalable, as demonstrated in the same paper, where it was shown that 100,000 rules can be processed efficiently. This is so because the computational complexity of defeasible logic is low [28].
- It is expressive, as demonstrated by the use of rules in various areas of information technology. In fact, among the logical systems, it is rule-based systems that have been best integrated in mainstream IT.

- Finally, it is suitable for expressing requirements and preferences in our setting. This is so, because it supports the natural representation of important features:
  - Rules with exceptions are a useful feature in our problem. For example, a general rule may specify acceptable offerings, while more specific rules may describe cases in which the general rule should not apply and the offering should not be accepted. We will elaborate on this point in the next section when we consider a concrete example.
  - Priorities are an integral part of defeasible logic, and are useful for expressing user preferences for selecting the most appropriate offerings from the set of the acceptable offerings.

## 4. A Concrete Example of Travel Packages Brokering

### 4.1 Used Ontologies and Data

As we have justified the selection of the used technologies, we provide a complete scenario. We define an ontology in RDFS to model concepts and their relationships in the domain of travel industry. Part of the RDFS ontology is depicted in Fig. 6.

```

<?xml version="1.0" ?>
<!DOCTYPE rdf:RDF [<!ENTITY xsd "http://www.w3.org/2001/XMLSchema#">]>
<rdf:RDF
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#">
  <rdfs:Class rdf:ID="Itinerary">
    <rdfs:comment>The class of travel packages offered by travel agents</rdfs:comment>
  </rdfs:Class>
  <rdfs:Class rdf:ID="TravelAgent">
    <rdfs:comment>The class of the travel agents. </rdfs:comment>
  </rdfs:Class>
  <rdfs:Class rdf:ID="Service">
    <rdfs:comment>The class of services included into a travel package</rdfs:comment>
  </rdfs:Class>
  <rdfs:Class rdf:ID="LocalTransportation">
    <rdfs:comment>All available means of transportation at the holiday place
  </rdfs:comment>
    <rdfs:subClassOf rdf:resource="#Service"/>
  </rdfs:Class>
  <rdfs:Class rdf:ID="CarRentalCompany">
    <rdfs:comment>The class of Car rental companies.</rdfs:comment>
    <rdfs:subClassOf rdf:resource="#LocalTransportation"/>
  </rdfs:Class>
  <rdfs:Class rdf:ID="Resort">
    <rdfs:comment>The class of available places to live during holiday.</rdfs:comment>
  </rdfs:Class>
  ...
  <rdf:Property rdf:ID="offeredBy">
    <rdfs:comment>Relates particular itineraries to travel agents</rdfs:comment>
    <rdfs:domain rdf:resource="#Itinerary"/>
    <rdfs:range rdf:resource="#TravelAgent"/>
  </rdf:Property>
  <rdf:Property rdf:ID="includesService">
    <rdfs:comment>It relates a service to a particular itinerary</rdfs:comment>
    <rdfs:domain rdf:resource="#Itinerary"/>
    <rdfs:range rdf:resource="#Service"/>
  </rdf:Property>
  <rdf:Property rdf:ID="parking">
    <rdfs:comment>A boolean indicator for the existence of parking</rdfs:comment>
    <rdfs:domain rdf:resource="#Resort"/>
    <rdfs:range rdf:resource="&xsd:boolean"/>
  </rdf:Property>
  ...
</rdf:RDF>

```

Fig. 6 Part of the Tourism Domain Ontology

We also define a few initial instances of the ontology regarding descriptions about hotels, islands, travel agents, means of transport, airline companies etc. Part of the initial instances are depicted in Fig. 7. The terms which are used for the definition of the instances are reference to the RDFS ontology. For example Creta Mare Royal is of type “Hotel”.

```
<?xml version="1.0"?>
<!DOCTYPE rdf:RDF [
<!ENTITY xsd "http://www.w3.org/2001/XMLSchema#">
<!ENTITY schema "http://www.csd.uoc.gr/~dogjohn/ontology/TravelOntology.rdfs#">
<!ENTITY inst "http://www.csd.uoc.gr/~dogjohn/data/TravelOntologyInstances.rdf#">]
>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
xmlns:instances="&inst;"
xmlns:schema="&schema;">
<rdf:Description rdf:about="CretaMareRoyal">
<rdf:type rdf:resource="&schema;Hotel" />
<schema:resortID rdf:datatype="&xsd:string">1</schema:resortID>
<schema:hotelName rdf:datatype="&xsd:string">Creta Mare Royal</schema:hotelName>
<schema:hotelStars rdf:datatype="&xsd:integer">6</schema:hotelStars>
<schema:hotelCategory rdf:datatype="&xsd:string">Business</schema:hotelCategory>
<schema:parking rdf:datatype="&xsd:boolean">true</schema:parking>
<schema:swimmingPool rdf:datatype="&xsd:boolean">true</schema:swimmingPool>
<schema:breakfast rdf:datatype="&xsd:boolean">true</schema:breakfast>
<schema:distanceFromSea rdf:datatype="&xsd:integer">10</schema:distanceFromSea>
</rdf:Description>
</rdf:RDF>
```

Fig. 7 Part of the Travel Ontology Instances

## 4.2 Expression of Offers

Every travel agent company, which is a potential service provider, can publish an offer to the broker. After publication, the offer is considered as an advertisement. The advertisement regards a complete travel package and its format is depicted in Fig. 8. The example advertisement is submitted by travel agent “Zorpidis S.A” and regards a travel package for two persons for the island of Crete. It includes a hotel, local transportation service (a car) and tickets for the ferry, and costs 1000 money units.

```
<?xml version="1.0"?>
<!DOCTYPE rdf:RDF [
<!ENTITY xsd "http://www.w3.org/2001/XMLSchema#">
<!ENTITY schema "http://www.csd.uoc.gr/~dogjohn/ontology/TravelOntology.rdfs#">
<!ENTITY inst "http://www.csd.uoc.gr/~dogjohn/data/TravelOntologyInstances.rdf#">]
>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
xmlns:instances="&inst;"
xmlns:schema="&schema;">
<rdf:Description rdf:about="IT1">
<rdf:type rdf:resource="&schema;Itinerary" />
<schema:from rdf:datatype="&xsd:string">Thessaloniki</schema:from>
<schema:to rdf:datatype="&xsd:string">Crete</schema:to>
<schema:departureDate rdf:datatype="&xsd:string">3/8/2004</schema:departureDate>
<schema:returnDate rdf:datatype="&xsd:string">15/8/2004</schema:returnDate>
<schema:persons rdf:datatype="&xsd:integer">2</schema:persons>
<schema:price rdf:datatype="&xsd:integer">1000</schema:price>
<schema:offeredBy rdf:resource="&inst;ZORP" />
<schema:includesResort rdf:resource="&inst;CretaMareRoyal" />
<schema:includesTransportation rdf:resource="&inst;Minoan" />
<schema:includesService rdf:resource="&inst;AVIS" />
<schema:forPlace rdf:resource="&inst;Crete" />
</rdf:Description>
</rdf:RDF>
```

Figure 8. Expression of an Advertisement in RDF

### 4.3 Formalization of Requirements and Preferences

On the other hand, every customer who is a potential service requester can express his requirements and preferences to the broker. Consider the following example: “Antonis, a busy businessman, has the following preferences about his holiday travel package: First of all, he wants to depart from Athens and he considers that the hotel at the place of vacation must offer breakfast. In addition, he would like either the existence of a swimming pool at the hotel to relax all the day, or a car equipped with A/C, to make daily excursions at the island. However, Antonis believes that if there is no parking area at the hotel, the car is useless, because he adds to him extra effort and fatigue. Lastly, if the tickets for his transportation to the island are not included in the travel package, he is not willing to accept it...”. This verbal description of Antonis’s hard requirements about acceptable offers can be modeled through the following defeasible logic rules, depicted in Fig. 9. More rules and priorities could be used to express selection preferences among acceptable offerings.

```

$$\begin{aligned} r_1: & \text{from}(X, \text{athens}), \text{includesResort}(X, Y), \text{breakfast}(Y, \text{true}) \Rightarrow \text{accept}(X) \\ r_2: & \text{from}(X, \text{athens}), \text{includesResort}(X, Y), \text{swimmingPool}(Y, \text{true}) \Rightarrow \text{accept}(X) \\ r_3: & \text{from}(X, \text{athens}), \text{includesService}(X, Z), \text{hasVehicle}(Z, W), \\ & \text{vehicleAC}(W, \text{true}) \Rightarrow \text{accept}(X) \\ r_4: & \text{includesResort}(X, Y), \text{parking}(Y, \text{false}) \Rightarrow \sim\text{accept}(X) \\ r_5: & \sim\text{includesTransportation}(X, Z) \Rightarrow \sim\text{accept}(X) \\ & r_4 > r_3, r_1 > r_4, r_2 > r_4, r_5 > r_1, r_5 > r_2, r_5 > r_3 \end{aligned}$$

```

Figure 9. Expression of User’s Requirements in Defeasible Logic

## 5. Brokering System Implementation

### 5.1 Multi-Agent Framework

The agent framework we used for the development of our system is JADE [8], [23]. JADE is an open-source middleware for the development of distributed multi-agent applications. It is Java-based and compliant with the FIPA specifications [13]. It provides libraries for agent discovery, communication and interaction, based on FIPA standards

From the functional point of view, JADE provides the basic services necessary to distributed peer-to-peer [34] applications in the fixed and mobile environment. JADE allows each agent to dynamically discover other agents and to communicate with them according to the peer-to-peer paradigm. From the application point of view, each agent is identified by a unique name and provides a set of services. It can register and modify its services and/or search for agents providing given services, it can control its life cycle and, in particular, communicate with all other peers.

### 5.2 System Architecture and Modules

The architecture of the broker consists of five main modules: (a) reasoning module, (b) control module, (c) semantic and syntactic validator, (d) RDF Suite module, and (e) rule-query-RDF loader module. Reasoning and control modules consist of other sub-modules as one can see in Fig.10 which depicts the overall system architecture. The other three modules are stand-alone. Finally, the control module is responsible for the coordination of all the other modules.

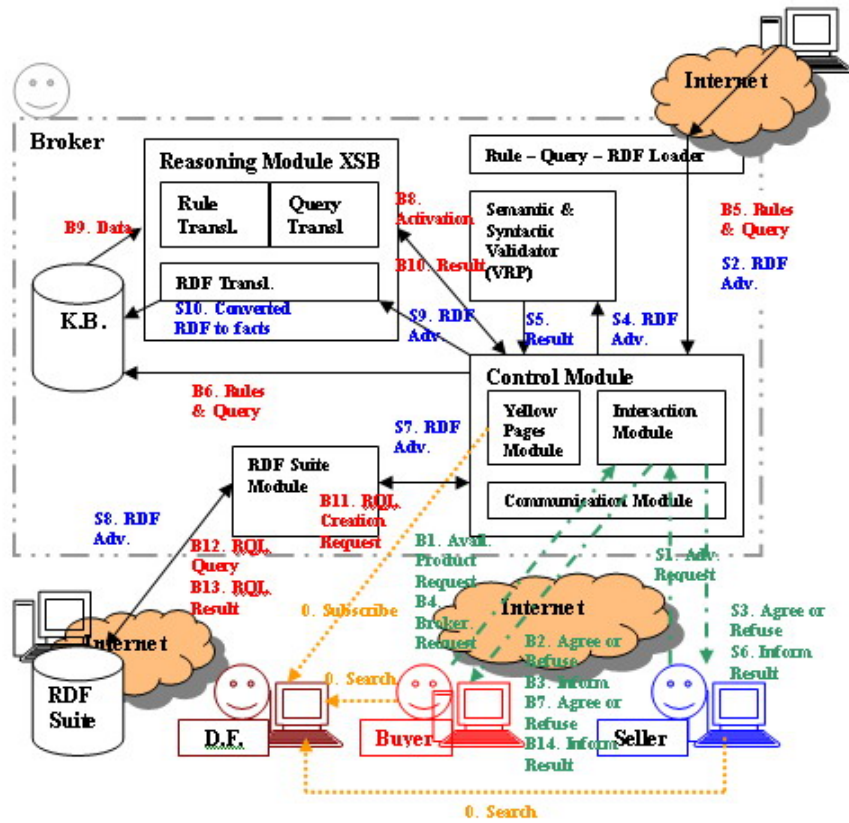


Fig. 10. The Brokering System Architecture

### RDF Translator

The role of the RDF translator is to transform the RDF statements into logical facts, and the RDFS statements into logical facts and rules. This transformation allows the RDF/S information to be processed by the rules provided by the Service Requester (representing the requester's requirements and preferences). For RDF data, the SWI-Prolog RDF parser is used to transform them into an intermediate format, representing triples as *rdf(Subject, Predicate, Object)*. Some additional processing (i) transforms the facts further into the format *Predicate(Subject, Object)*; (ii) cuts the namespaces and the "comment" elements of the RDF files, except for resources that refer to the RDF Schema, for which namespace information is retained.

In addition, for processing RDF Schema information, the following rules capturing the semantics of RDF Schema constructs are created:

- A:  $C(X) :- \text{rdf:type}(X, C).$
- B:  $C(X) :- \text{rdfs:subClassOf}(Sc, C), Sc(X).$
- C:  $P(X, Y) :- \text{rdfs:subPropertyOf}(Sp, P), Sp(X, Y).$
- D:  $D(X) :- \text{rdfs:domain}(P, D), P(X, Z).$
- E:  $R(Z) :- \text{rdfs:range}(P, R), P(X, Z).$

Let us consider rule B that captures the meaning of the subclass relation of RDFS. A class  $Sc$  is subclass of a class  $C$  when all instances of  $Sc$  are also instances of  $C$ . Stated another way, if  $X$  is an instance of  $Sc$  then it is also instance of  $C$ . That is exactly what rule B says. All the above rules are created at compile-time, i.e. before the actual querying takes place. Therefore, although the above rules at first sight seem second-order because they contain variables in place of predicate names, they are actually first-order rules, i.e. predicate names are constant at run-time.

### **Semantic-Syntactic Validator**

This module is an embedded version of [37], a parser for validating RDF descriptions. Upon receipt of an advertisement, the RDF description, which corresponds to that advertisement, is checked by this module. Among others, the tests performed are: class hierarchy loops, property hierarchy loops, domain/range of subproperties, source/target resources of properties and types of resources. This module is “called” by the control module and returns either the RDF description, in case the latter is error free, or an error message. For the implementation of this module we used the API of VRP.

### **Interaction and Communication Modules**

The communication module is responsible for sensing the network and notifying the control module when an external event (e.g. a request message) occurs. In order to decide the course of action based on the incoming message’s type, the broker agent extracts the message from the queue and examines its type, i.e. whether it is a “Broker Request”, ”Advertise Request” message etc. Accordingly it activates the interaction module. The interaction module consists of different interaction protocols that extend the standard FIPA Request interaction protocol. For the implementation of these modules, we used the API of JADE framework.

### **RDF Suite Module**

The RDF Suite module is responsible for all the actions related with the handling of the advertisements and the domain ontology. The most important functions of this module are:

- Initial upload of RDFS ontology and RDF instances into the RDF repository.
- Update of the RDF repository with RDF descriptions that are received from the service providers and correspond to product or service advertisements.
- Preparation of RQL queries and forwarding to the RDF Suite.
- Receipt of RQL queries’ results.

The RDF Suite module implements a client socket, which connects to a server socket and passes an RQL query or retrieves the results. At this point we must say, that although RSSDB and VRP work well in MS Windows and their Java API can be easily used, there is a problem with RQL that operates only in UNIX. The server socket, which creates a UNIX pipe to RSSDB, solves this problem. For the implementation of this module we used the API of RSSDB and the API of Java for File Management and Networking.

### **Rule-Query-RDF Loader**

The role of this module is to download the files, which contain the rules and the query of the user, in defeasible logic format. It also downloads the appropriate RDF descriptions, which correspond to service providers’ advertisements. It also implements methods for file handling. For the implementation of this module we used the API of Java for File Management and the API for Networking.

### **Reasoning Module**

The role of the Reasoning Module is to apply the queries to files, which contain the facts and the rules, and to evaluate the answer. When the Service Requester makes a query, the Reasoning Module compiles the files containing the facts and the rules, and applies the query to the compiled files. The answer of the query is sent to the Control Module of the system. XSB Prolog is used as the compiler and reasoning module for our system. We made this choice, as we needed a logic programming system

supporting well-founded semantics. XSB Prolog offers this functionality through its *not* operator.

### **Rule Parser & Translator**

The Rule Parser is responsible for checking the validity of the defeasible rules, which are submitted by the Service Requester. The rules are considered to be valid, if they follow the standard syntax of defeasible logic, as described in [2]. If there are syntax errors, the system informs the user about these errors, and does not proceed to the translation. Otherwise, the parser creates a symbol table, which includes all the rules and priority information, and passes this table to the Translator.

The Rule Translator is responsible for transforming the rules submitted by the Service Requester using the syntax of defeasible logic, into Prolog rules that emulate the semantics of defeasible logic. The method we use for translating defeasible theories into logical programs is described in detail in [5].

The logical program that derives from this procedure will be later combined with the logical facts that represent the RDF triples, and will be used to evaluate the queries of the Service Requester.

### **Query Translator**

In order to apply a query to the Prolog files, which contain the rules and the facts, it must be priorly transformed into a valid Prolog query. This task is performed by the Query Translator. There is a standard format for the queries that the Service Requester can make:

*D x* : which are the literals (atoms or their negation) x which are provable according to the rules provided by the Service Requester.

The literals ‘x’ represent the conclusions of the rules, which are submitted by the Service requester. ‘x’ can be for example of the form ‘*accept\_hotel(X)*’. In this case a query of the form ‘*D accept\_hotel(X)*’, is intended to find those literals X satisfying the conclusion ‘*accept\_hotel(X)*’.

## **5.3 System Interactions**

We describe the sequence of actions, separately for the buyer (B label) and the seller (S label). Initially Buyer, Seller and Broker agents, subscribe to Directory Facilitator or D.F. agent. These actions are depicted by the dashed lines (step 0). They provide information such as the ontologies they are committed to, the interaction protocols they use, the content language they use etc.

A *seller* initializes an interaction by issuing an “Advertise” request (step S1). The broker extracts the field “RDFInfoAtWeb” from the received message and tries to download the corresponding advertisement from the web, which is an RDF description with information about the advertised product or service (step S2). If the document exists, broker informs the seller that he agrees to perform the requested action (step S3). Subsequently the broker checks the RDF advertisement semantically and syntactically, using the Semantic and Syntactic validator module (step S4). The result is returned to the control module of broker (step S5), and if the advertisement is valid, according to the domain ontology, seller is informed that the requested action was performed. Otherwise an error message is posted (step S6). Broker then performs a twofold action. He firstly feeds the RDF Suite module with the advertisement (step S7), which in turn stores it to the RDF Suite repository (step S8) and secondly sends the advertisement to the RDF translator module of the Inference engine to add it in the



subsumption hierarchy (step S9). Finally the knowledge base is updated with the new facts which were previously extracted from the RDF advertisement (step S10).

A *buyer* sends an “Available Products” request to the broker (step B1). Broker informs buyer if he agrees or not to perform the action (step B2) and in turn he sends to buyer a message with the available categories of products (step B3). Buyer then issues a “Brokering” request, for a particular category of products (step B4). Broker downloads from the web the Rules which capture the preferences of the buyer and are expressed in defeasible logic. He also downloads the submitted query which is also expressed in defeasible logic (step B5). Subsequently the rules and the query are stored in the knowledge base by the broker (step B6). Broker informs the buyer if he agrees or not to perform the requested action, according to the validity of the rules and the query (step B7). The check is performed by the Reasoning module but is out of the scope of this paper. Broker in turn activates the reasoning module (step B8), which uses the stored data in the knowledge base (step B9) and performs the reasoning process. The result is the set of the ID’s of the matched RDF descriptions (step B10). Afterwards, the RDF Suite module of the broker creates dynamically an RQL query (step B11) which is passed to the RDF Suite repository for the retrieval of all the resources which correspond to the IDs of the result set (step B12). The result of the query is returned to the broker (step B13). Finally, the broker encapsulates the received information to an ACL message and sends it back to the buyer (step B14).

## 6. Related Work

InfoSleuth [31] is an agent-based information discovery and retrieval system that adopts “broker agents” to perform the syntactic and semantic matchmaking. The broker uses a rule-based reasoning engine, implemented in LDL, to determine which agents have advertised services that match those requested in the query. The brokering is realized in two levels. Syntactic brokering is the process of matching request, on the basis of the syntax of incoming messages and used ACLs or Content Languages. Semantic brokering is the process of matching requests on the basis of the requested capabilities or offered services. An agent’s knowledge is expressed independently of syntax, based on shared common service ontology.

Trastour et al. [36] enumerate the requirements for a language to express service descriptions in the context of a matchmaking service. They propose the use of RDF/RDFS for the matchmaking process. Each advertisement, either for service request, or for service offering is represented as an RDF resource. Properties from this resource characterize the type of requested or offered service. The advertisements are stored into a repository and the matching of advertisements is reduced to matching of RDF graphs. The authors implemented a matching algorithm.

Li and Horrocks [25] assess the requirements for a service description language and ontology, and argue that DAML+OIL and DAML-S common service ontology, fulfil these requirements. This argument is supported by their design and implementation of a prototype matchmaker which uses a description logic reasoner to match service advertisements and requests based on the semantics of ontology-based service descriptions. Similar is the work of [33]. They also use DAML-S to describe the advertisements along with the request and afterwards they use a matching algorithm.

Chen et al. [12] propose an architecture for an agent that, although not explicitly stated, could be used for semantic brokering. The iAgent they propose consists of

inference, control and communication layer. As they say, a typical inference engine makes inference according to static facts and rules. As an alternative they propose that the facts are extracted from semantic mark-up documents that are written in DAML+OIL. The fact translator module of the iAgent, converts all the DAML+OIL documents into prolog format. As a result, although DAML+OIL is description logic, which is not suitable for complex queries, iAgent finally uses a Horn-based logic engine (SWI-Prolog) for inferencing.

## 7. Conclusions and Future Work

In this paper we studied the brokering and matchmaking problem in the tourism domain, that is, how a requester's requirements and preferences can be matched against a set of offerings collected by a broker. The proposed solution uses the Semantic Web standard of RDF to represent the offerings, and a deductive logical language for expressing the requirements and preferences. We motivated and explained the approach we propose, and reported on a prototypical implementation exhibiting the described functionality in a multi-agent environment.

Our approach has obvious *advantages* compared to other approaches. Particularly, (a) we do not provide a fixed algorithm for brokering but it is the user who specifies the algorithm on the basis of its preferences. (b) The architecture we provide is highly reusable. The system can be applied in any domain only with the addition of a new ontology and new rules which capture the preferences. (c) Using JADE, we exploit the advantages of peer-to-peer systems (i.e. travel agencies and broker as peers) and also make use of FIPA standards for agent communication and discovery. (d) We use a highly expressive language for preferences specification with interesting features, such as conflicting rules and priorities of rules. (e) We use RDF for the expression of advertisements. This choice supports interoperability among agents and applications and facilitates the easy publication, collection and combination in decentralized dynamic settings. (f) We allow for permanent storing of advertisements with the use of the RDF Suite repository. The main *drawbacks* of the current implementation are: (a) The advertisements cannot be removed automatically when they expire. (b) The syntax of the defeasible logic may appear too complex for many users, and should be supported by, possibly graphical, authoring tools.

The architecture we proposed is based on the assumption that all tourist service advertisements have the same format, i.e. that there is a shared tourism ontology. This is not a very unrealistic assumption, since many business communities have already conceded into common ontologies. However, even if different travel agents use different ontologies, ontology translation techniques could be used to map different ontologies onto the common ontology supported by the brokering service. The ontology translation service could be offered by the brokering service for several popular tourism ontologies. However, if a travel agent uses a minor and/or personal ontology, then it should be his/her responsibility to provide translation to the common ontology, should he/she wants to take advantage of the brokering services offered.

In the future we intend to extend the described work in various directions: (i) Add advertisement removal functionality, which will be activated, when the advertisement has expired. (ii) Implement graphical user interfaces for the integrated system. Someone will be able to load the files, which correspond to the rules of negotiation strategy and brokering preferences respectively, using a file manager. He will be also able to adjust negotiation protocol parameters and monitor the progress of the brokering and negotiation procedure. (iii) Integrate the current brokering system with the negotiation system proposed in [35]. In our current implementation, a service

requester agent is able to find potential products or services and potential service providers. We intend to extend our system to support direct involvement of the service requester in negotiation with the service provider for the resulted product, as soon as the brokering stage has been completed.

Finally, as a long-term goal we intend to extend the semantic brokering approach presented in this paper to brokering for general purpose semantic web services, providing matchmaking between Web Service advertisements and requests described in OWL-S. Of course, first of all we must carefully define which of the features of OWL are captured by defeasible logic and can be used, and which cannot.

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