An ontology for automated negotiation

Valentina Tamma
Department of Computer Science, University of Liverpool,
Liverpool L69 7ZF, UK
valli@csc.liv.ac.uk

Michael Wooldridge
Department of Computer Science, University of Liverpool,
Liverpool L69 7ZF, UK
mjw@csc.liv.ac.uk

Ian Dickinson
Hewlett-Packard Research Labs, Filton Road,
Bristol BS34 8QZ, UK
ian_dickinson@hp.com

ABSTRACT

This paper proposes a novel approach to negotiation, in which the negotiation protocol to adopt is not coded within the agents but it is expressed in terms of a common shared ontology that is shared by the agents in order to participate to a negotiation session. The negotiation ontology is defined in a way general enough to support a wide variety of market mechanisms, thus being particularly suitable for flexible applications such as electronic commerce. The paper describes the negotiation ontology and provides a walkthrough example describing how the proposed approach could be used to model protocols for auctions.[1]

1. INTRODUCTION

Research in automated negotiation to date has focused on the development of negotiation protocols and strategies specifically tailored to account for particular interactions among agents [17, 12, 11, 13]. Automated negotiation is particularly relevant in open environments such as the Internet, or, as it seems it will be, the semantic Web [4, 6, 9]. In this kind of environment fewer limitations are imposed on the agents and on the types of interaction they can be involved in. Thus, agents should be free to join and leave interactions at any time, and any agent willing to join in an interaction should conform to the "rules of encounter" that regulate that type of interaction.

Negotiation protocols regulate interactions among agents by representing the permitted rules of encounter. Usually protocols are coded *implicitly* within agents, as part of their code. However, in open environments this would be a limitation, since agents would be forced to either use one of the protocols they already know or else go off line in order to be reprogrammed with a new protocol. In this paper, we propose a different approach, where negotiation protocols are not hard-coded in agents, but instead when a new agent joins a pre existing interaction, the negotiation host advertises the type of protocol regulating the interaction and describes the protocol in terms of a *shared ontology* of negotiation. The negotiation ontology provides the basic vocabulary that an agent and a negotiation host must share in order to discuss the terms of the participation to the negotiation session. The idea is analogous to allowing agents inter-operation via a shared ontology which provides a formal and agreed upon definition of the terms that are to be used by the agents. The approach we present in this paper is currently implemented as part of an ongoing research project funded by HP Labs UK, which aims to provide ontological descriptions of negotiation services. In order to provide a proof of concept for the alternative approach to automated negotiation we present here, we are testing this approach in the market game scenario of the *trading agent competition*. The trading agent competition is a market game where multiple agents compete by assembling trips for their clients [22].

[1] This paper concentrates mainly on the ontological aspects of the proposed approach, while another paper, submitted to the AMEC 02 workshop, concentrates more on the negotiation process.

The remainder of this paper is organised as follows. Section 2 discusses automated negotiation in the context of e-commerce and describes the general approach we have devised to provide an ontological description of negotiation protocols. Then, Section 3 discusses the negotiation ontology and the ontological issues arising from modelling such a complex domain. Section 4 presents the application scenario that we are using for the proof of concept, and Section 5 presents a walkthrough the application scenario and shows how the negotiation ontology we present in this paper can be used to provide a general description of a negotiation protocol, so to support a wide variety of marketplaces. Finally, Section 6 draws conclusions and presents future work.

2. AN ONTOLOGICAL APPROACH TO AUTOMATED NEGOTIATION

Interest in automated negotiation in multiagent systems has been spurred to a great extent by the vision of software agents negotiating with other software agents to buy and sell goods and services on behalf of their owners in a future Internet-based global marketplace. Broadly, negotiation can be understood as the process of reaching agreement on one or more matters of common interest.

Research on automated negotiation in multiagent systems to date has focused on two issues [17, 13, 18]: the design of *protocols* and associated *strategies*. A negotiation protocol defines the "rules of encounter" between negotiation participants. For example, negotiation typically proceeds in a series of rounds, with agents either alternating or simultaneously taking it in turns to make proposals. A negotiation protocol also defines what constitutes an acceptable proposal (usually as a function of prior negotiation history), when agreement has been reached, and what the agreement deal is. An agent's key task is to employ a *negotiation strategy* that maximises its welfare: the strategy is essentially the agent's program, which defines how it behaves during negotiation. Although we recognise that devising a successful negotiation strategy is an important aspect when describing the agent's ability to negotiate, in this paper we disregard the problem of designing strategies while we concentrate on the problem of permitting agents to negotiate in a flexible way in open environments.

Automated negotiation relies on the idea that agents must use a shared protocol in order to resolve issues that can arise in the negotiation. In most contemporary multiagent negotiation scenarios, the protocol is fixed and implicitly assumed: an agent that engages in negotiation is assumed to know and agree to the protocol a priori. However, in order to fully exploit the potential of open environments like the Internet — and in future the Semantic Web — agents should not be forced to commit to a single negotiation protocol, *but should be able to choose the negotiation protocol which is most suitable to the type of interaction they participate in.*

In order to participate in the same marketplace agents need to have a shared understanding of the rules that describe what are the conditions under which the interaction between agents takes place, the deals that can be made and and the what sequences of offers are permitted [15]. In current approaches, agents either reach agreement on the negotiation protocol to use before they can actually start negotiating or the negotiation protocol is over imposed by a higher authority such as the *negotiation host* (who is responsible for the creation and enforcement of the rules governing participation [3]).

Some prototypical standards for negotiation have been proposed. For example, the FIPA agent communication language (ACL) provides a number of performatives (message types) explicitly intended to support negotiation [7]. An example is the `cfp` (call for proposals) performative, intended to support contract-net style task sharing via negotiation [19]. However, the FIPA performatives are intended to be used by agents *while negotiating*: they are not appropriate for defining the properties of negotiation protocols. In fact, there is currently no standard widely accepted for expressing different negotiation protocols.

With current approaches, therefore, agents interacting in the same marketplace must adopt the same negotiation protocol. These rules are usually hard-coded within the agent and clearly, this constitutes a limitation in open environments, such as those enabling electronic trading and the semantic web. These environments require a flexible type of interactions, in that agents should support a wide variety of negotiation forms. This is made possible only if few constraints are posed on the agent implementation.

We aim to find an approach that permits agents to negotiate with most of the negotiation mechanisms, and poses as fewer constraints on the agent implementation as possible, in order to ensure flexibility. To do so we have defined an ontology of negotiation protocols, based on the idea that there are some general concepts that are present in any negotiation protocol and that can help to classify them. The shared ontology of protocols defines the most general concepts that are used to describe a negotiation protocol and it is populated by the particular protocols available.

This ontology acts as a general framework that permits agents to reach agreement. Using a shared ontology of protocols makes it easier to compare the different negotiation protocols and to understand similarities and differences, thus facilitating the agreement on a single protocol. The negotiation ontology defines the basic terminology that permits agent to negotiate thus it can be used also to define the framework of the interaction.

The novelty of the approach is that it synthesises work in two important areas of agent research: ontologies and negotiation protocols. Negotiation protocols, although widely investigated in the theoretical multiagent systems literature, have been deployed to date only in experimental scenarios. No field-tested applications have been reported. We believe that such protocols are now at the stage where they can usefully be deployed, but a key obstacle to such deployment is the development of appropriate standards, and in particular, ontologies for negotiation. This kind of generic descriptions can be used as classification framework that permits the analysis of the negotiation protocols available, and to develop new ones. Moreover, the commitment to the same high level concepts about negotiation, can facilitate the communication of negotiation rules among the agents, thus permitting more flexible interactions.

3. NEGOTIATION ONTOLOGY

The negotiaton ontology we have developed builds on previous efforts to find commonalities across different negotiation protocols. From an analysis of the classification framework illustrated in [15], the generic software framework for automated negotiation developed at HP Labs [3], the work by Wurman and colleagues [23], and the London classification [1] we have identified the concepts and the relationships that are shared across most negotiation protocols. Figure 1 shows the negotiation ontology resulting from this merging process using an entity relationship model to represent concepts and relationships.

In particular, the London classification [1] identified the set of concepts that characterise most negotiation protocols, and thus is not only restricted to auctions. The concepts identified by the London classification that we have included in the ontology are:

- *People*: corresponds to the concept `Party` in the negotiation ontology shown in Figure 1;
- *Goods*: represented by `Object` in Figure 1;
- *Process*;

The London classification and the work by Lomuscio and colleagues [15] have provided us with the attributes used to describe the concepts. The work by Wurman and colleagues [23] inspired the ontology structure, by helping us to define the relationships linking the concepts. Finally, the work by Bartolini and colleagues [3] provided us with the notion of negotiation rules. It should be noticed that none of the previous efforts was an ontology as defined in [20]. The London

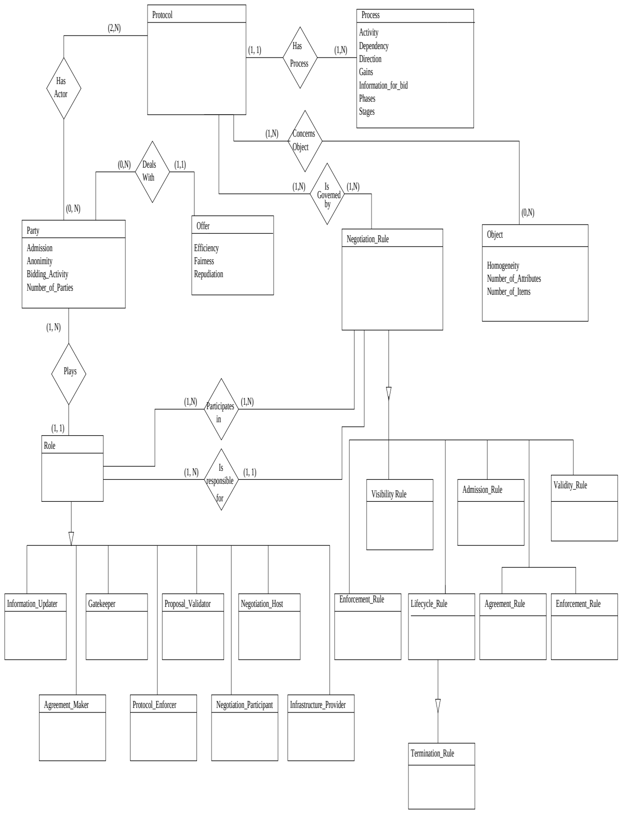

Figure 1: An ER model of the negotiation ontology

classification, the classification by Lomuscio and colleagues and the one by Wurman and colleagues were meant as a way to discover similarities among protocols and not to provide a general framework for *describing protocols*, which was the purpose of the work by Bartolini and colleagues. These previous efforts provided us with the basic concepts and relationship that need to be in a negotiation ontology, our additions to these were made bearing in mind the task of our ontology that is: *to provide the shared vocabulary permitting agents to negotiate in any kind of marketplace regardless of the negotiation mechanism that is used.* Furthermore, by merging a number of accepted classifications we reach the consensus needed in order to consider this a *shared* ontology.

The negotiation ontology bases the definition of its concepts on the executable version of the *Cyc Knowledge Base Upper Ontology* (OpenCyc v0.6b available at `http://opencyc.sourceforge.net/daml/cyc.daml`) which is the generic (or upper level) ontology, that is the ontology specifying concepts that are generic across many fields [21].

The most general concepts (shared across all possible applications and domains) are represented in the higher part of the hierarchy. By refining the concepts which compose the ontology hierarchy we describe groups of similar protocols, and we define the kind of features that are common to all of them.

The refinement of a concept is obtained by restricting the values associated with the attributes describing the concepts, or by adding new attributes which associate with a concept additional, more specific features. For example, we defined the concept `Protocol` as characterised by the attribute `hasActor` whose minimum cardinality is 2, that is at least two agents need to be involved in a protocol. However, when defining the *English Auction Protocol* we have restricted the minimum cardinality to 3, since in an English auction need to be involved at least two agents and an auctioneer (who are all subconcepts of `Party`). Figure 2 shows the part of the negotiation ontology, represented in DAML+OIL [10], which models the value restriction.

```
 <daml:ObjectProperty rdf:ID="hasActor">
  <rdfs:comment>
  A number of agents (greater than 2) can
  partecipate to a protocol
  </rdfs:comment>
  <rdfs:domain rdf:resource="#Protocol"/>
  <rdfs:range rdf:resource="#Party"/>
  <daml:minCardinality>2</daml:minCardinality>
</daml:ObjectProperty>

<daml:Class rdf:about="#English-Auction">
  <rdfs:subClassOf rdf:resource="#Protocol"/>
  <rdfs:subClassOf>
    <daml:Restriction daml:minCardinality="3">
      <daml:onProperty rdf:resource:resource="#hasActor"/>
        <rdfs:comment>
          An English auction needs at least 2
          partecipants and 1 auctioneer
        </rdfs:comment>
      </daml:Restriction>
  </rdfs:subClassOf>
</daml:Class>
```

Figure 2: Value restriction on a concept property

Applicability rules and constraints are represented by axioms. Finally, the lower level concepts in the negotiation ontology specify the roles played by the agents involved in a negotiation process and the rules that describe the stages and the features of a protocol, such as which agents are permitted to see the offers, how a negotiation terminates, etc. The rules we have considered in the ontology are those identified by Bartolini and colleagues in [3], however, this set of rules is intended here only as an example, they are neither meant to be exhaustive nor they have been instanciated. They are intended to show a possible way of specialising the concept `Negotiation rule` defined in the ontology.

The advantages of this approach are of two kinds. The first type of advantage is flexibility. Negotiation protocols do not need to be coded in the agent, but can be learned dynamically by acquiring the ontology. The second type of advantage is that the ontology provides the terminology to reason in terms of negotiation protocols, their components, and the constraint regulating them.

In our ontology a negotiation protocol is defined in terms of the following concepts, each of them highlights a different aspect of a negotiation protocol:

- Negotiation protocol: This concept defines a generic protocol defining the "rules of encounter" that are followed by negotiation participants during a negotiation process. The rules describe the conditions defining the interactions between agents, the deals that can be made and the permitted sequences of offers [15];

- Party: this concept describes a single agent (be it human or electronic) or an organisation of agents which participate in a negotiation. Several agents can negotiate, and they can play different roles in the negotiation;
- Process: This concept describes the way to reach an agreement on some issue by modifying the attributes of the negotiation;
- Object: it describes the objects of the negotiation, that is the material or immaterial goods that are transferred once an agreement has been reached;
- Offer: this concept describes a possible combination of values associated to the negotiation attributes which represents an expression of will (for example to purchase a certain number of goods, to receive the goods by a certain date, or to pay a maximum price for the goods);
- Negotiation rule: The set of rules that govern a specific negotiation protocol. The generic protocol is parametric with respect to the negotiation rules that are applicable in the type of electronic market modelled by the protocol. In the ontology this means that we identify a number of negotiation rules, and the way in which they are specified defines a specific negotiation protocol.

Ad hoc relationships between concepts are also defined, they describe how the identified concepts interact to define the negotiation protocol domain. For example, a `Protocol` *Has actor* `Party` which models the fact that a number of agents interact in a negotiation protocol. A `Party` *Plays* `Role`, to model the fact that agents play different roles in the interaction. The concept `Role` is specified by the roles identified in [3].

A protocol is also governed by a number of negotiation rules, this aspect is modelled by means of the relationship (`Protocol` *Is governed by* `Negotiation Rule`), where the concept `Negotiation Rule` is specified by the different types of rules identified in [3].

It should be noticed at this point that the higher level concepts of the negotiation ontology are not connected by an *IS A* relationship, since they are not taxonomic in nature, as already observed by Wurman and colleagues in [23]. All the other concepts in the ontology are organised according to a proper *IS A* relationship [14]. The conceptual model [16] of the negotiation ontology is the most expressive if we compare it to the expressive power spectrum in [14]. The conceptual model we use includes concepts (defined in terms of attributes), which are organised according to a strict is a hierarchy and are linked by relationships defined *ad hoc*. It also includes instances (the specific negotiation protocols), and its concepts are constrained by axioms (some of which are represented as *structural constraints* in Figure 1).

In building the negotiation ontology we have used an ontology editor that is independent of specific representation formalisms (WebOde [2]) and has been translated in XML [24] and DAML+OIL [10].

The approach we illustrate in this paper can be thought to complement the one by Bartolini and colleagues [3]. Both approaches define a general framework for negotiation protocols which is based on the definition of a number of generic negotiation rules. In their approach they assume that agents share a *negotiation template* which defines the parameters of the negotiation, and the space of the possible proposals. The negotiation rules define the interactions among the agents. They are currently working on a platform independent specification of templates, proposals and rules in DAML+OIL [10].

In our approach the negotiation ontology defined above is an explicit and formal specification of the consensual knowledge of the agents [20]; it defines the negotiation template formally and explicitly and makes explicit the rules governing the negotiation by *defining them in terms that are shared among all agents.* Moreover, agents can only partially commit to the negotiation ontology by defining mapping functions between their internal knowledge and the negotiation ontology (see Section 5); in this way they comply to the "negotiation template" only for interaction purposes.
From this viewpoint we complement the work by Bartolini and colleagues; in fact the negotiation ontology has been designed as a *shared ontology* for negotiation, and thus is independent not only of the agent platform, but also of the conceptualisation of the negotiation domain the agents adopt in their internal knowledge. Thus, *agents can still maintain their conceptualisation of the negotiation domain while committing to the shared ontologies only when they need to interact.* This is becomes extremely important to ensure that agents can negotiate using a variety of protocols and are able to interact in a truly open environment.

4. THE TRADING AGENT COMPETITION

The trading agent competition is a series of events that aims to publicise research issues arising in automated trading. The competition takes place in the market domain and is designed to face trading agents with difficult problems concerning bidding strategies, market prediction and resource allocation.

Trading agents have to acquire travel goods in three different markets in the travel shopping domain: flights, hotels, and entertainment tickets. Different trading rules govern the markets, which are organised as three distinct types of auctions.

In the competition each competing agent aims to assemble a travel package, which consists of:

- a round-trip flight;
- a hotel reservation;
- tickets to some of the entertainment events such as: alligator wrestling, amusement park, and museum.

A run of the game is called an instance. Several instances of the game are played during each round of the competition in order to evaluate each agent's average performance and to smooth the variations in client preferences.

In the next section we describe how the ontology based approach to automated negotiation relies on the negotiation ontology defined in Section 3. We consider the application scenario of the trading agent competition, which restricts the search space of all the possible negotiation protocols to auctions only. However, we believe that the negotiation ontology describes concept that are general enough to be applicable to any type of negotiation protocol.

5. A WALKTHROUGH EXAMPLE

In order to provide an example of automated negotiation that makes use of the approach to automated negotiation presented in Section 2 we have considered the application scenario of the trading agent competition, which we have simplified in order to use it a scenario for our approach. This example is intended only to illustrate how the approach makes use of the negotiation ontology, and it does not consider any real implementation details.

In the scenario of the example, the trading agent competition, agents participate to three different auctions which concern flight, hotel accommodation, and entertainment events and the negotiation mechanisms of each auction is not supposed to be known in advance. Therefore agents should be designed in a way such that they can adapt to the specific market mechanism they encounter during the competition. In the case of the trading agent competition, agents participating to the competition should be able to negotiate in all three types of auctions. Therefore, in the approach we propose agents comply to the negotiation ontology, which means that the agents are either able to import and use the negotiation ontology, or mappings are defined between the agent internal knowledge and the concepts in the negotiation ontology. Ideally these mappings should be *translations* [5], that is they should preserve the semantics of the concepts, however, *transformations* [5] (mappings that do not preserve the semantics) are permitted. Transformations permit to relate concepts in the ontology to the ones in the agent's conceptualisation which are most similar, typically a *hypernym* or a *hyponym*. In this way the agent's conceptualisation of the domain does not need to match completely the one of the negotiation ontology, but it has to be a "close approximation".

By using this kind of approach agents share only the concepts in the negotiation ontology, which are very general and make as few claims as possible about the world, thus respecting the minimal ontological commitment principle for knowledge sharing [8].

Agents engaged in a negotiation process need to have two types of knowledge:

- Knowledge concerning the domain of interest: that is the concepts which represent the objects that are negotiated and the parameters of the negotiation; in the example of the trading agent competition the domains of interest are three and they are the *travel*, *accommodation*, and *entertainment* domains.
- Knowledge concerning the negotiation: that is what are the roles involved in the negotiation and what are the permitted interactions.

In order to ensure the maximum level of flexibility in open environments, an agent should be able to shop in any kind of marketplace regardless of the goods that are traded and of the negotiation mechanism that is used. In the situation defined by the trading agent competition this means that the agents knowledge on the domains concerning the negotiated goods should not be internal to the agent but it should be consensual among the agent participating to the negotiation. Typically this is achieved by committing to an ontology of the domain of interest which is shared among all negotiating agents. By applying the approach presented in Section 2 we achieve also the independence from a specific negotiation protocol which is used in an auction.

Let us suppose to have an agent which has to trade in the three markets of the trading agent competition. That is, the agent has to participate to three different auctions whose protocols are not known in advance. For each auction the agent requests *admission* to the negotiation host. In order to be admitted to the auction, the agent has to commit to the vocabulary used in the auction (the terminology concerning the domain) and to the negotiation protocol that is used in the auction (the set of rules regulating the negotiation). While the commitment to the domain terminology can be partial (i.e., the agents need only to commit on those terms they use during the negotiation), commitment to the protocol has to be complete. In the example below we assume that the agents are all using the same domain ontology.

Once the negotiation host has received a request of admission from one agent, it needs to check whether the agent fulfills the requirements for participating to the marketplace. If the agent can participate to the auction, the negotiation host advertises the URL of the ontology that is adopted to describe the negotiation protocol used in the auction, which in this example we assume to be the ontology presented in Section 3. The advertisement consists of the specification of the rules determining the protocol defined in terms of the negotiation ontology defined in Section 3, that is they are *strict subclasses of* the rules defined in the top level negotiation ontology. Let us suppose that one of the auctions is an English auction, and that the domain is entertainment. The protocol will be defined in DAML+OIL [10] as partially illustrated in Figure 3 (we have not included the complete definition for reasons of space). The concept `Protocol` in the ontology is defined in terms of other concepts such as `Object`, which will be specified according to the specific rules of the protocol adopted, and the same will happen to all the other concepts which are related to `Protocol`. This means that the properties associated with these concepts will be filled with the values describing an the protocol.

For example, in the case of an English auction for the entertainment domain the `NumberOfItems` will be "Multiple" (in the hypothesis that multiple entertainment tickets are negotiated in the same negotiation process) whereas if the English auction concerns the flight domain, then `NumberOfItems` is set to "Single" (since only one flight per negotiation process can be negotiated). The concepts are all specified associating values with the properties of concepts, which is achieved by the restrictions illustrated in Figure 4 and that should be advertised by the negotiation host. Finally, the rules are specified. In order for the agent to be able to

```
<daml:Class rdf:about="#English-Auction">
  <rdfs:subClassOf rdf:resource="#Protocol"/>
  <rdfs:subClassOf>
    <daml:Restriction daml:minCardinality="3">
      <daml:onProperty rdf:resource:resource="#hasActor"/>
        <rdfs:comment>
          An English auction needs at least 2
          partecipants and 1 auctioneer
        </rdfs:comment>
      </daml:Restriction>
    <daml:Restriction>
      <daml:onProperty rdf:resource="#hasObject"/>
      <toClass rdf:resource="#Protocol">
    </daml:Restriction>
  </rdfs:subClassOf>
</daml:Class>

<daml:Class rdf:ID="Object-English-Auction">
  <rdf:subClassOf rdf:resource="#Object"/>
  <rdf:subClassOf>
    <daml:Restriction daml:Cardinality="1">
      <daml:onProperty rdf:resource="#Attribute">
    </daml:Restriction>
  </rdfs:subClassOf>
</daml:Class>
```

Figure 3: Part of the English auction protocol definition

```
<daml:Class rdf:ID="Flight-Object-English-Auction">
  <rdf:subClassOf rdf:resource="#Object"/>
  <rdf:subClassOf>
    <daml:Restriction>
      <daml:onProperty rdf:resource="#NumberOfItems"/>
      <daml:hasValue rdf:resource="#single"/>
    </daml:Restriction>
  </rdf:subClassOf>
</daml:class>

<daml:Class rdf:ID="Entertainment-Object-English-Auction">
  <rdf:subClassOf rdf:resource="#Object"/>
  <rdf:subClassOf>
    <daml:Restriction>
      <daml:onProperty rdf:resource="#NumberOfItems"/>
      <daml:hasValue rdf:resource="#multiple"/>
    </daml:Restriction>
  </rdf:subClassOf>
</daml:class>
```

Figure 4: The restrictions on the number of items negotiated

```
daml:Class rdf:ID=``Agreement-Formation-Rule-
                     In-English-Auction''>
  <rdfs:subClassOf
   rdf:resource=''#AgreementFormationRule''/>
/daml:Class>

<daml:ObjectProperty rdf:ID="hasRoleInput">
  <rdfs:domain rdf:resource="#Agreement-Formation-Rule-
                             In-English-Auction"/>
  <rdfs:range rdf:resource="#Party"/>
  <daml:minCardinality>2</daml:minCardinality>
</daml:ObjectProperty>

<daml:ObjectProperty rdf:ID="hasAttributeInput">
  <rdfs:domain rdf:resource="#Agreement-Formation-Rule-
                             In-English-Auction"/>
  <rdfs:range rdf:resource="#price"/>
  <daml:Cardinality>1</daml:Cardinality>
</daml:ObjectProperty>

<daml:ObjectProperty rdf:ID="hasRule">
  <rdfs:domain rdf:resource="#Agreement-Formation-Rule-
                             In-English-Auction"/>
  <rdfs:range rdf:resource="#Process"/>
  <daml:Cardinality>1</daml:Cardinality>
</daml:ObjectProperty>

<daml:DatatypeProperty rdf:ID="price">
  <rdf:type rdf:resource="#Object"/>
  <rdfs:range rdf:resource="http://www.w3.org/2000/10/
                           XMLSchema#nonNegativeInteger"/>
</daml:DatatypeProperty>
```

Figure 5: The concept describing how to reach agreement in an English auction

understand the rules, these should be defined in terms of the concepts modelled in the negotiation ontology. For instance, the negotiation ontology defines, among the others, the rule describing the conditions under which an agreement can be made (*agreement formation rule*). Thus, the negotiation host advertises the agreement formation rule, which should be an instance of the one shown in Figure 5. Being an instance, all the "variables" (here represented by classes) should be instanciated in order for the rule to be applicable. The specific rule should be also expressed in a language which is executable. For example, we could represent rules in a rule engine such as the Java Expert System Shell (Jess). In this case the ontology could be interpreted from DAML+OIL and fed into Jess to permit users to query the knowledge modelled in the ontology. An alternative approach which is currently under development would be to use the DAML+OIL API to hook into Jess.

If we translate the ontology into Java and feed it to Jess, the agreement formation rule could be expressed as in Figure 6 [3]. The terms `BUYER` and `SELLER`, should be defined in terms of the negotiation ontology, more precisely they should be defined as instances of the ontology concept `Party`, and both `RES-PRICE` and `PRICE` should be instances of the ontology concept `Price`.

We are currently exploring the possibility to model the rules as processes, thus defining them in terms of input, output, states and events changing the states.

6. CONCLUSIONS AND FUTURE WORK

In this paper we have presented an ontological approach to automated negotiation, particularly when this takes place

```
(defrule agreement-formation-rule)
(active-proposal}
    (proposal-id ?PID)
    (submitter ?BUYER)
    (role Buyer)
    (price ?PRICE))
(active-proposal
    (proposal-id ?PID)
    (submitter ?SELLER)
    (role Seller)
    (price ?RES-PRICE)
(test
    (> PRICE RES-PRICE))
=> (assert
   (agreeement}
      (buyer ?BUYER)
      (seller ?SELLER)
      (price ?PRICE)))
```

Figure 6: The agreement formation rule expressed in Jess

in open environments such as the Internet, or, the Semantic Web [4, 6, 9]. In this kind of environment fewer limitations should be imposed on the agents and on the types of interaction they can be involved in. Ideally, agents should be able to join and leave interactions at any time, and any agent intending to join in an interaction should conform to the specific negotiation protocol which regulate that type of interaction.

In our approach protocols are not coded within agents, since this would be a limitation. A new agent joining a pre existing interaction, should acquire the negotiation protocol governing that interaction from the negotiation host, who advertises the type of protocol used. In order to permit interoperability, the protocol is defined in terms of a *shared ontology* of negotiation which provides the basic vocabulary that agents must share in order to discuss the terms of the participation to the negotiation session.

The novelty of the approach is twofold, in fact it it synthesises work in both ontologies and negotiation, which are important areas of agent research.

The negotiation ontology that we have illustrated in Section 3 is intended to capture similarities between the different negotiation mechanisms. This kind of generic descriptions can be used as classification framework that permits the analysis of the negotiation protocols available, and to develop new ones. But also, by committing to the same high level concepts, the communication among of negotiation rules among the agents is facilitated, thus improving flexibility.

Negotiation protocols, although widely investigated in the multiagent systems literature, have been deployed to date only in experimental scenarios. We believe that such protocols are now at the stage where they can usefully be deployed, but a key obstacle to such deployment is the development of appropriate standards, and in particular, ontologies for negotiation.

The approach we have presented in this paper is still at a very early stage, and there are a number of issues that need to be further investigated. One is how to model something like a protocol in an ontology. The idea of using rules to model the interactions among agents is the most straightforward, however we are need to investigate whether this is sufficient to permit the interaction or whether a different type of knowledge should be included in the ontology. An alternative approach would be to model the protocol as processes, where specific events cause a change of state. This approach would require the inclusion of a number of concepts in the ontology, such as event, state, etc. as well as a theory of time and the knowledge necessary to draw temporal conclusions from this theory.

Another aspect which we have disregarded in the paper but which we are planning to investigate is *negotiation strategies*. We do realise that permitting agents to understand the "rules of encounter" of a new protocol does not mean that the agent has gained the ability to successfully apply these rules. More investigation is needed on how the agent could develop the most appropriate negotiation strategy once it has acquired a new protocol.

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