Designing Responsive and Deliberative Automated Negotiators

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Abstract

In this paper we present a multi issue negotiation model which can be used for guiding agents during distributed problem solving. This model is composed of protocols which govern and manage agent interactions, and an agent architecture which represents decision mechanisms which assist agents during distributed problem solving processes.

keywords: Negotiation, Agent Architecture

Introduction

Automated agents are autonomous entities which decide for themselves what, when, and under what conditions their actions should be performed. Since agents have no direct control over others, they must persuade others to act in a particular manner. The type of persuasion we consider in this paper is negotiation which we define as *a process by which a joint decision is made by two or more parties. The parties first verbalise contradictory demands and then move towards agreements*,(Pruitt 1981). Furthermore, negotiating agents may populate different types of environments which require either a very simple and responsive decisions to be made (e.g. buying and selling of goods in an auction), or complex and deliberative problem solving activities (e.g. planning), or a combination of both. Therefore, we view negotiation decisions to be composed of responsive and/or deliberative components. The outcome of these decisions can result in either concession or search for new alternatives.

Traditionally, formal models of choice achieve coordination through specification of the negotiation space: the issues agents negotiate over, and their possible values that determine the set of alternative solutions. Negotiation is then considered as an optimisation problem, where given the utility function of the agents, the best solution is obtained. This methodology is often adopted in classical Game Theory. However, such formal models of choice often ignore *interactions*, and involve unrealistic assumptions (such as common knowledge and an unlimited computational ability). Interactions are viewed as unnecessary since rational and super-logical agents can reach agreements instantly given the common knowledge and unlimited computational power assumptions.

An alternative coordination methodology is the specification of the rule of interaction —*who* can say *what* and *when* (absence of any normative rule of behaviour may lead to unmanageable interactions). In this paper we follow this second approach, and ensure coordinated behaviour by defining our protocol as an extension of the normative rules of the Contract Net Protocol (Davis & Smith 1988).

In addition to a protocol of interaction, agents must be provided with the capability to represent and reason about, within their information and resource bounds, both their internal and their external world and with the capacity to interact according to the above protocol. It is this individual agent modelling which has been the central focus of the work reported in this paper. The design choices we have adopted for the negotiation model have been strongly influenced by two major application developments with which we have been involved. These are the ADEPT system for business process management, (Sierra, Faratin, & Jennings 1997), and the *Foundation of Intelligent Physical Agents* (FIPA) field trial of agent technology in the telecommunication domain, (FIPA97 1997). In this paper we focus exclusively on the latter scenario.

This paper extends our previous work, reported in (Faratin, Sierra, & Jennings 1998), on negotiation models in the following way. The agent architecture has been updated from a purely responsive mechanisms to include new higher level deliberative mechanisms, involving the generation of trade offs and the manipulation of the set of issues under negotiation. The negotiation protocol has been updated to account for these new mechanisms. More generally speaking, this paper advances the state of the art in negotiation by designing components of a negotiation architecture which allows agents to be both responsive and deliberative and thus participate in more varied types of negotiation processes.

The example scenario is introduced first, followed by the developed negotiation protocol. Next the individual agent architecture is expanded on which describe evaluation and offer generation mechanisms. The presented model is then compared with other developed models. Finally, we present the conclusions reached and future avenues of research.

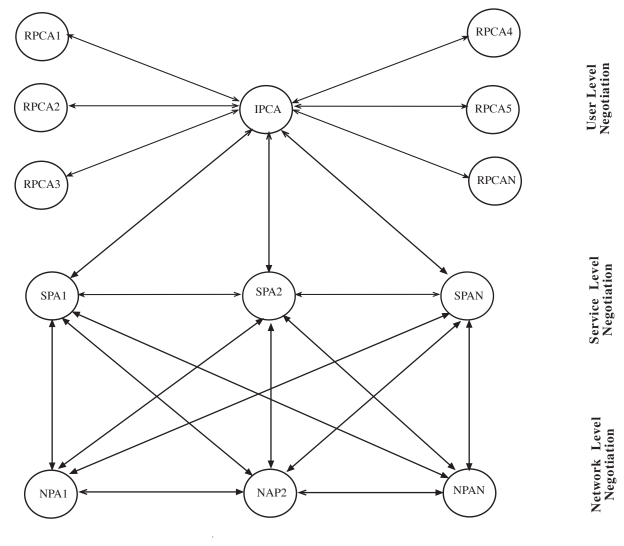

Figure 1: FIPAs VPN Provisioning Scenario.

FIPA's Negotiation Scenario

The scenario is based on the use of negotiation to coordinate the dynamic provisioning of resources for a Virtual Private Network (VPN) for end users.[1] This service is provided to the users by service and network providers. The scenario is made up of a number of agents which represent the users, service and network providers (see figure).

Users are represented by user agents which are collectively refered to as Personal Communication Agents, or PCAs. PCA agents are composed of *IPCA* and *RPCAs* (the Initiating Personal Communication Agent, representing the user who has the desire to initiate the meeting, and Receiving Personal Communication Agent/s, representing the party/parties whom are required to attend the meeting, respectively).The interactions between these PCA agents can be multilateral (involving one *IPCA* and multiple *RPCAs*) and are centred around negotiation over meeting scheduling, where each agent negotiates on behalf of their user with the goal to establish the most appropriate time and security level (see below) for the service requested by the *IPCA*. The set of issues which PCA agents negotiate over are: [*Service_Type*, *Security*, *Price*, *Start_Time*, *Duration*], where *Service_Type* denotes the choice of the service (eg. video, audio or mixture of both), *Price* is the share of the price the agents should pay for the service, *Start_Time* and *Duration*, the time the service will commence and its length respectively. The *Security* issue encodes the privacy of the meeting and is represented by both the method of security (e.g. in the order of value to PCAs, Entrust, Verisign or Mircosof) and the level of security method (again in the order of value, confidentiality, integrity and confidentiality).

However, *IPCA* and *RPCAs* requirements are constrained by what resources are available at the network domain level. For example, the network may be heavily loaded at the time the service is required by the *PCAs*. Since the network is only visible to *IPCA* through the Service Provider Agents (*SPAs*) the threads of *IPCA* and *RPCAs* negotiation are executed in parallel with negotiation between *IPCA* and *SPAs*, where the interactions between *IPCA* and *SPA* directly influences the meeting scheduling negotiations between *IPCA* and *RPCAs*. Furthermore, we assume only bilateral negotiation between *IPCA* and *SPAs*. However, each *SPA* agent can make agreements with *IPCA* for services and outsource these commitments by initiating negotiation with other *SPAs* for services. The set of issues in the negotiation between *IPCA* and *SPAs* is the same as the meeting scheduling negotiation thread between *IPCA* and *RPCAs* with the additional element *Participants* which is the list of users (represented by *RPCAs*) specified to be included in the requested service.

Either concurrently or after the service is provisioned between *IPCA* and *SPA* multiple threads of negotiation are initiated between the *SPA* and the Network Provider Agents, *NPAs*, which manage the infrastructure and low level aspects of the IP network. These threads of interaction are multilateral since each *NPA* manages only a subset of the IP network. Therefore the *SPA* must negotiate with a number of *NPAs* in order to secure resources for services it provides to *IPCA*. The set of issues in the thread of negotiation between *SPA* and *NPAs* is made up of the following elements: [*Quality_of_Service*, *Security*, *Participants*, *Price*, *Start_Time*, *Duration*], where *Quality_of_Service*, or *QoS*, represents the "goodness" of the service from an agent's perspective. *QoS* is often discussed as if it were composed of a number of sub issues such as, the *Bandwidth* (the capacity of the link), the *latency* (the delay imposed by the network on packets), the *jitter* (the maximum time deviation acceptable during transmission), the *availability* (percentage of the time over which the service is required) and *packetloss* (percentage of the total packets lost during the lifetime of the provisioned service). Therefore, the *QoS* issue is represented as a set of sub issues.

Features of the Scenario

Negotiation, in the scenario above exhibits the following characteristics:

- Agents negotiate over *services*. Services have a number of features/issues associated to them (e.g. its *Price*, *Duration* etc.), some of which can be dynamically introduced and retracted (eg. *QoS*), and successful negotiation involves resolution of these issues to the satisfaction of all parties involved.
- Since agents are autonomous, the factors which influence their negotiation stance and behaviour are

[1] A VPN refers to the use of a public network (such as the Internet) in a private manner.

private and not available to other parties. Thus agents do not know what utilities their opponents place on various outcomes, what reasoning models they employ, their opponent's constraints or whether an agreement is even possible at the outset (i.e. the participants may have non-intersecting ranges of acceptability).

- Since plans and execution of services/activities are real time and dependent on one another, the provisioning process should respect the time and resource levels of the agents—negotiation should be responsive to the time and resource levels of the agent. For example, if the environment can afford it (in terms of time, resources, etc.) then an agent may decide to engage in complex deliberation procedures involving a more refined search of the space of possible outcomes. For instance, *SPA* and *NPA* agents can engage in costly computation and selection procedures for contracts that manipulate or trade off the set of issues involved in negotiation. Alternatively, as the environment changes (deadline to reach an agreement is approaching fast, resource usage for negotiation has reached some critical level or the other agent is exhibiting a reluctance to change its offer, etc.) then one/both of the agents may begin to adopt a more responsive attitude towards their environment by conceding. Thus responsive behaviours are similar to reactive behaviours which consider environmental conditions and are simple and uncostly responses to the environment.

The Negotiation Protocol

Coordinated behaviour during negotiation is enforced through the normative rules of the negotiation protocol. We restrict ourselves to bi-lateral negotiations (however, multi-lateral negotiations can be shown to be equivalent to a series of bi-lateral negotiations (Binmore 1985)).

The protocol (see figure 2) starts by a dialogue to establish the conditions for negotiation (deadline, initial issues, etc.). Then, one of the agents makes an offer (transition from state 1 to state 2 or 3) for contract ϕ. After that, the other agent can make a counter-offer or a tradeoff —see section "Trade Off Mechanisms"— (moving to state 2 or 3 depending on who started), and the agent that started the negotiation can in turn make a new counter-offer or a new tradeoff (going back to state 2 or 3). Since information models of agents are not publicly known (that is, agents do not know the reservation values of the other party over the negotiation issues), offers maybe outside the mutual zone of agreement. Therefore, agents may iterate between states 2 and 3 taking turns to offer new contracts. In either of these two states, one of the agents may accept the last offer made by the opponent (moving to state 4) or withdraw from the negotiation (moving to state 5). Agents withdraw from the negotiation process when the deadline of negotiation has been reached.

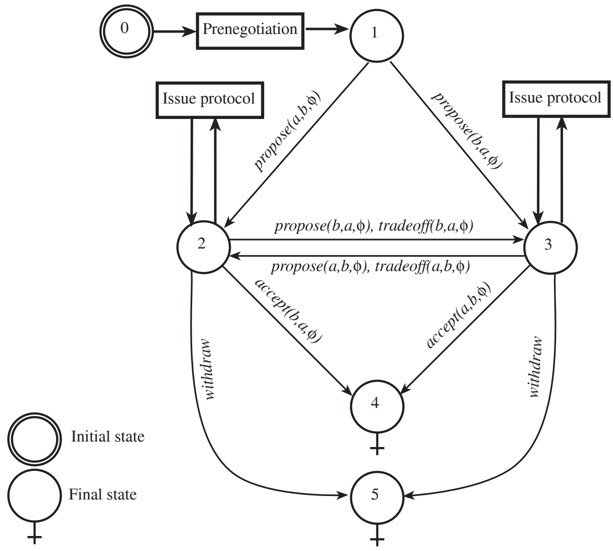

Figure 2: Negotiation protocol.

While at state 2 or 3 agents are permitted to start an ellucidatory dialogue to establish a new set of issues to negotiate over (see section "Issue Set Manipulation"). This protocol is a natural extension of the contract net protocol permitting iterated offer and counter-offer generation and permitting the modification of the set of issues under negotiation. Although we cannot guarantee termination or convergence in the general case, in practice the existence of time deadlines ensures that the protocol will terminate.

Agent Negotiation Architecture

The main contribution of the research reported here is the specification of a negotiation architecture that structures the individual agent's reasoning throughout the problem solving. Rational behaviour is assumed to consist of maximisation of some value function (Raiffa 1982). Given this rationality stance, the decisions faced by agents in negotiation are often a combination of: *offer generation decisions* (what initial offer should be generated, what counter offer should be given in situations where the opponent's offer is unacceptable), and *evaluatory decisions* (when negotiation should be abandoned, and when an agreement is reached). The solution to these decision problems is captured in the agent architecture. The components (or what is referred to as mechanisms) of the agent architecture which is responsible for generation of offers and counter offers are based on a distinction between mechanisms which are computationally uncostly and are responsive to the environment, and mechanisms which are relatively more costly because they engage in a more sophisticated search of the solution space.

The mechanisms which assist an agent with evaluation of offers is described first, followed by the developed generation mechanisms in sections "Responsive

Mechanisms" and "Deliberative Mechanisms" respectively. Since the novelty of the work reported here are the deliberative mechanisms, the reader is referred to (Faratin, Sierra, & Jennings 1998) for an indepth explanation of evaluatory and responsive mechanisms.

Evaluation Mechanisms

Evaluation of a contract consists of computing the value/score of the contract. When an agent a receives an offer x from b at time t, $x^t_{b\rightarrow a}$, over a set of issues J, $(x = (x[j_1], \ldots, x[j_n])$ where $j_i \in J)$, it rates the overall contract value using the following weighted linear additive scoring function:

$$V^a(x) = \sum_{1\leq i\leq n} w^a_{j_i} V^a_{j_i}(x[j_i])$$

where $w^a_{j_i}$ is the importance (or weight) of issue j_i such that $\sum_{1\leq i\leq n} w^a_{j_i} = 1$. Given that the changing of the set of issues during negotiation is permitted, agents will need to dynamically change the values of the weights. The score of value $x[j]$ for agent a, given the domain of acceptable values $\mathcal{D}_j$, is modelled as a scoring function $V^a_j : \mathcal{D}_j \rightarrow [0,1]$. For convenience, scores are bounded to the interval $[0,1]$, and the scoring functions are monotonous for quantitative issues. Note that in the above formulation we assume scores of issues are independent. Given the score of the offered contract, the contract evaluation function will determine whether to accept or reject the contract or generate a new contract to propose back to the other agent. The mechanisms which generate new contracts are presented in the sections below.

Responsive Mechanisms

Responsive mechanisms model reactive behaviours to a number of environmental factors. The underlying rationale and motivation for the design of these mechanisms has been the need to model responsive behaviours to growing environmental needs. For example, if *IPCA* has committed lots of resources over its negotiation with *SPA* and time of the required video service with other *RPCAs* is soon, then simple and less costly decision mechanisms which can result in concession may be more preferred by *IPCA*.

Responsive mechanisms generate offers by linearly combining simple decay functions, called *tactics*. Tactics generate values for issues using only a single environmental criteria. We have designed three families of tactics:

- **Time-dependent tactics** These tactics model increasing levels of concession as the deadline for the negotiation approaches.
- **Resource-dependent tactics** These tactics model increasing levels of concession with diminishing levels of resources, such as time.
- **Behaviour-dependent tactics** Concession here is based on the concessions of the other negotiating party.

However, to determine the best course of action agents may need to consider and assess more than just one environmental condition. Since each tactic generates a value for an issue using only a single criterion, the concept of *strategy* is introduced to model the modification, over time, of tactic weights as the criteria change their relative importance in response to environmental changes.

Deliberative Mechanisms

Agents need to be both responsive *and* deliberative. Below we formally model two deliberative mechanisms: *trade offs* and *issue set manipulations*.

Trade Off Mechanisms A trade off is informally defined as the mechanism where one party lowers its score on some issues and simultaneously demands more on other issues. For example, for the *IPCA*, offering a lower *Price* for a later *Start_Time* of a service maybe equivalent in value (depending on the weights of the two issues) to offering a higher *Price* for an earlier *Start_Time* of a service. However, this change in offer *may* benefit the *SPA* agent.[2] Thus, a trade off is a search for a contract that is equally valuable to the previous offered contract, but which may benefit the other party.

This decision mechanism is more costly than the responsive mechanisms because it involves searching all or a subset of possible contracts with the same score as the previously offered contract (hence there is no loss in contract utility) and selection of the contract which is the "closest" to the opponent's last contract offer.

Search is initiated by first generating new contracts that lie on what is called the iso-value (or indifference) curves (Raiffa 1982). Because all newly generated contracts lie on the same iso-value curve then agents are indifferent between any two given contracts on this curve. An iso-curve is defined as:

Definition 1 *Given a scoring value θ, the iso-curve set at degree θ for agent a is defined as:*

$$iso_a(\theta) = \{x \mid V^a(x) = \theta\}$$

The selection of which contract to offer is then modelled as a "closeness function". Theory of fuzzy similarity is used in order to model "closeness". The best tradeoff then would be the most similar contract on the iso-curve. More formally, tradeoff is defined as:

Definition 2 *Given an offer from agent a to b, x, and a subsequent offer from agent b to a, y, with $\theta = V^a(x)$, trade off for agent a with respect to y is defined as:*

[2] This evaluation is uncertain since information models are private—*IPCA* does not know the valuation methodology or the importance *SPA* attaches to the issues in negotiation.

$$tradeoff_a(x,y) = \arg_z \max_{z \in iso_a(\theta)} \{Sim(z,y)\}$$

Similarity between two contracts is defined as weighted combination of the similarity of the issues:

Definition 3 *The similarity between two contracts x and y over the set of issues J is defined as:*

$$Sim(x,y) = \sum_{j \in J} w_j^a Sim_j(x[j], y[j])$$

With, $\sum_{j \in J} w_j^a = 1$. Sim_j is the similarity function for issue j.

Following the results from (Valverde 1985), a similarity function, that is, a function which satisfies the axioms of reflexivity, symmetry, and t-norm transitivity, can always be defined as a conjunction (modelled as the infimum) of appropriate fuzzy equivalence relations induced by a set of criteria functions h_i. A criteria function is a function that maps from a given domain into values in $[0,1]$. For example, a function that models the criteria of whether a price is low, $lowprice : Price \to [0,1]$, could be:

$$lowprice(x) = \begin{cases} 1 & \text{x} < £10 \\ \frac{£20 - x}{£10} & £10 < \text{x} < £20 \\ 0 & x \geq £20 \end{cases}$$

Hence the similarity between two values for issue j, $Sim_j(x,y)$ is defined as:

Definition 4 *Given a domain of values D_j, the similarity between two values $x, y \in D_j$ is defined as:*

$$Sim_j(x,y) = \min_{1 \leq i \leq m} (h_i(x) \leftrightarrow h_i(y))$$

where $\{h_1, \dots, h_m\}$ is a set of comparison criteria with $h_i : D_j \to [0,1]$, and $\leftrightarrow$ being an equivalence operator.

Simple examples of the equivalence operator, $\leftrightarrow$, are $h(x) \leftrightarrow h(y) = 1 - \mid h(x) - h(y) \mid$ or $h(x) \leftrightarrow h(y) = min(h(y)/h(x), h(x)/h(y))$.

Issue Set Mechanisms Another deliberation methodology we have designed is the issue set manipulation mechanism. Negotiation processes are directed and centred around the resolution of conflicts over a set of issues J. This set may consist of just one or more issues (distributed and integrative bargaining respectively). For simplification the ontology of the set of possible negotiation issues J, is assumed to be a shared knowledge amongst all the agents. It is further assumed that agents begin negotiation with a prespecified set of "core" issues, $J^{core} \subseteq J$, and possibly other mutually agreed non core set members, $J^{\neg core} \subseteq J$. Alterations to J^{core} is not permitted since some features such as the *Price* of services are mandatory. However, elements of $J^{\neg core}$ negotiation set can be altered dynamically. Agents can add or remove issues into $J^{\neg core}$ as search for new possible and up to now unconsidered solutions. In the scenario above agents negotiate over core issues. The negotiation between *SPA* and *NPA* agents however consist of offers over none core issues. For example, a *SPA* agent may begin *QoS* negotiation with a *NPA* agent, specifying only *Bandwidth*. However, later on *NPA* may decide to include into *QoS* negotiation a *packetloss* issue with a high value if *SPA* has demanded a high capacity *Bandwidth*. Alternatively, *SPA* may later on remove the *Bandwidth* issue from *QoS* negotiation with *NPA* if *IPCA* has changed its demand from a high quality video service to a standard audio service.

If J^t is the set of issues being used at time t (where $J^t = \{j_1, \dots, j_n\}$), and $J - J^t$ is the set of issues not being used at time t, and $x^t = (x[j_1], \dots, x[j_n])$ is a's current offer to b at time t, then issue set manipulations is defined through two operators: *add* and *remove* which agents can apply to the set J^t. The *add* operator assists the agent in selecting an issue j' from $J - J^t$, and an associated value $x[j']$, which gives the highest score to the agent.

Definition 5 *The best issue to add to the set J^t is defined as:*

$$add(J^t) = \arg_j \max_{j \in J - J^t} \{ \max_{x[j] \in D_j} V^a(x^t.x[j]) \}$$

where . stands for concatenation.

An issue's score evaluation is also used to define the *remove* operator in a similar fashion to the *add* operator. Thus, this operator assists the agent in selecting the best issue, to remove from the current negotiation set J^t with the highest score.

Definition 6 *The best issue to remove from the set J^t (from a's perspective), is defined as:*

$$remove(J^t) = \arg_{j_i} \max_{j_i \in J^t - J^{core}} \{V^a(x)\}$$

with $x = (x^t[j_1], \dots, x^t[j_{i-1}], x^t[j_{i+1}], x^t[j_n])$

The *remove* operator can also be defined in terms of the similarity function defined above in section "Trade Off Mechanisms". This type of similarity based *remove* operator selects from two given offers x, from agent a to b, and y, from agent b to a, which issue to remove in order to maximise the similarity between x and y. Therefore, this mechanism can be considered as more cooperative. We define this similarity based *remove* operator as:

Definition 7 *The best issue to remove from a's perspective from the set J^t is defined as:*

$$remove(J^t) = \arg_{j_i} \max_{j_i \in J^t - J^{core}} \{sim((x[j_1], \dots, x[j_{i-1}], x[j_{i+1}], \dots, x[j_n]), (y[j_1], \dots, y[j_{i-1}], y[j_{i+1}], \dots, y[j_n]))\}$$

It is not possible to define a similarity based *add* operator since the introduction of an issue does not permit an agent to make comparisons with the opponent's last offer, simply because there is no value offered over that issue. Agents deliberate over how to combine these *add* and *remove* operators in a manner which maximises some measure —such as the contract score. However, a search of the tree of possible operators to find the optimum set of issues maybe computationally expensive and requires approximate and anytime algorithms. Another computational requirement of these mechanisms is the need for an agent to dynamically recompute the issue weights.

The protocol for establishing a new set of negotiating issues is isomorphic to the negotiation protocol described in figure 2. The pre-negotiation phase is omitted (since the current set of issues have already been agreed). ϕ is replaced by a new set of issues S, and primitives *propose* and *tradeoff* are replaced by *newset* —a request for a new set of issues to be included in to the negotiation. Each negotiating agent can start a dialogue over a new set of issues S (state 1 to 2 or 3). Each agent can then either propose a new set (transition from state 2 to 3, depending on who started the dialogue), accept the other's proposed set (state 4) or withdraw and continue with the original set (state 5).

Related Work

Negotiation has been studied in a number of related disciplines. However, the central focus of the work reported here, has been the design of a negotiation agent architecture for structured interactions in real environments over services. Our work is closely related to the Contract Net protocol (Davis & Smith 1988), where a protocol is used for modelling interactions. However, unlike the CNP protocol we do not assume agents are cooperative. Furthermore, because of privacy of information models search for acceptable solutions maybe more elaborate than the CNP's two messages —negotiation is an iterative process. In addition to this, CNP is a theory of system architecture and is silent with respect to the individual agent architecture and consequently, like game theory, is inadequate for agent design since any agent architecture is as good as another as long as they obey the CNP protocol. The proposed model in this paper not only specifies a negotiation protocol used for iterative interaction modelling but also provides both responsive and deliberative mechanisms which agents can implement and execute according to their own requirements.

Iterative negotiation, over multiple issues and agents, is modelled by the PERSUADER system through the concepts of argumentation and mediation (Sycara 1989). However, negotiation, as defined in this paper, is a *mutual* selection of outcome and precludes any intervention by outside parties. Furthermore, persuasion mechanisms operate on the beliefs of agents with the aim of changing one or both parties beliefs. This is not the case for negotiation —it is not necessary for the agents to have similar beliefs at the end of negotiation.

Other systems such as KASBAH have attempted to actually engineer a real world application (Chavez & Maes 1996). KASBAH models time, actions and strategies involved in negotiation. However, negotiation in KASBAH is over a single issue and agents are semi-autonomous —the system models only a subset of the decision making which is involved in negotiation and the user makes all the other decisions. Furthermore, the decisions that are delegated to the agents (called strategies in KASBAH) is severely limited to only three and even their selection is not autonomous. The model presented in this paper handles multiple issues and is designed for fully autonomous agents.

Conclusions

This paper has presented a distributed negotiation model which coordinates both agent interactions and individual agent decisions. Protocols have been defined which structure interactions and model the iterated nature of reaching agreements. Mechanisms have been proposed for finding solutions which are based on realistic assumptions, are practical and model the complex nature of negotiation.

The direction for future research will be primarily focused at empirical evaluation of the developed model to determine its properties.

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