Deliberative Automated Negotiators Using Fuzzy Similarities

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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).

For negotiation 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 a normative protocol. It is this individual agent modelling which has been the central focus of the work reported in this paper.

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 by means of a fuzzy similarity measure. Due to the complexity of interactions and the nature and number of possible settlements, automated negotiators require problem solving mechanisms which are more sophisticated than simple response mechanisms. 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 deliberative component of the individual agent architecture is expanded on which describe evaluation and offer generation mechanisms. An example real world scenario is then introduced to clarify the concepts introduced in the model. Finally, we present the conclusions reached and future avenues of research.

Agent Negotiation Architecture

The main contribution of the research reported here is the use of fuzzy techniques for the specification of a negotiation architecture that structures the individual agent's reasoning throughout the problem solving. Negotiation is often characterised by the difficulty faced by agents in establishing crisp decisions. For example, preferences, comparison of contracts or evaluation of contracts may be vague. Thus, the use of fuzzy techniques appears very natural to extend a classical negotiation model. In this paper we'll see the use of fuzzy techniques to compare contracts exchanged between agents. More concretely we'll generate trade-offs as contracts that are 'similar' to contracts offered by opponents by means of a fuzzy similarity measure. Also, we'll use this measure to compute which issue to include in a negotiation process. Future work will include the modelling of fuzzy preferences, and the fuzzy qualitative modelling of weights or issues' importance.

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 mechanisms which assist an agent with evaluation of offers is described first, followed by two deliberative mechanisms and an example.

Evaluation Mechanism

The evaluation process involves computing the value/score of a proposal or a contract. When an agent a receives an offer x from b at time t, $x^t_{b\to a}$, 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:

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

where $w^a_{j_i}$ is the importance (or weight) of issue j_i such that $\sum_{1\le i\le n} w^a_{j_i} = 1$. Given that the set of negotiation issues can dynamically change, agents 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 $V_j^a : \mathcal{D}_j \to [0,1]$. For convenience, scores are bounded to the interval $[0,1]$ and the scoring functions are monotonous for quantitative issues. Note that our formulation assumes 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 whether to generate a new contract to propose back to the other agent.

Trade Off Mechanism

A trade off is where one party lowers its score on some issues and simultaneously demands more on other issues. Thus, a trade off is a search for a new contract to propose that is equally valuable to the previous offered contract, but which may benefit the other party.

This decision making mechanism is costly since it involves searching all, or a subset of, possible contracts with the same score as the previously offered contract and the selecting the a new contract to propose that is the "closest" to the opponent's last offer. The search is initiated by first generating new contracts that lie on what is called the iso-value (or indifference) curves (Raiffa 1982). Because all the potential contracts lie on the same iso-value curve the agent is indifferent between them. More formally, 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:*

$$iso_a(\theta) = \{x \mid V^a(x) = \theta\} \tag{2}$$

The selection of which contract to offer is then modelled as a "closeness function". The theory of fuzzy similarity can be used to model "closeness". The best trade off is the one that is the most similar contract on the iso-curve to the opponent's last offer, since it *may* be beneficial to the other party. This evaluation is uncertain since other party's evaluation is not known by the proposing agent. A trade off can now be defined as:

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

$$tradeoff_a(x,y) = \arg \max_{z \in iso_a(\theta)} \{Sim(z,y)\} \tag{3}$$

where the similarity, Sim, between two contracts is defined as a 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:*

$$Sim(x,y) = \sum_{j \in J} w_j^a Sim_j(x[j], y[j]) \tag{4}$$

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 that 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 $[0,1]$.

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:*

$$Sim_j(x,y) = \bigwedge_{1 \le i \le m} (h_i(x) \leftrightarrow h_i(y)) \tag{5}$$

where $\{h_1, \ldots, h_m\}$ is a set of comparison criteria with $h_i : D_j \to [0,1]$, and $\leftrightarrow$ is 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

Our other deliberation mechanism is issue set manipulation. Negotiation processes are directed and centred around the resolution of conflicts over a set of issues J. It is 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. However, elements of $J^{\neg core}$ can be altered dynamically. Agents can add or remove issues into $J^{\neg core}$ as they search for new possible and up to now unconsidered solutions.

If J^t is the set of issues being used at time t (where $J^t = \{j_1, \ldots, j_n\}$), $J - J^t$ is the set of issues not being used at time t, and $x^t = (x[j_1], \ldots, x[j_n])$ is $a's$ current offer to b at time t, then issue set manipulation is defined through two operators: *add* and *remove*.

The *add* operator assists the agent in selecting an issue j' from $J - J^t$, and an associated value $x[j']$, that gives the highest score to the agent.

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

$$add(J^t) = \arg \max_{j \in J - J^t} \{ \max_{x[j] \in D_j} V^a(x^t.x[j])\} \tag{6}$$

where . stands for concatenation.

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

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

$$remove(J^t) = \arg \max_{j_i \in J^t - J^{core}} \{V^a(x)\} \tag{7}$$

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

The *remove* operator can also be defined in terms of the aforementioned similarity function. 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:*

$$remove(J^t) = \arg\max_{j_i \in J^t - J^{core}} \{sim((x[j_1], \ldots, x[j_{i-1}], x[j_{i+1}], \ldots, x[j_n]), (y[j_1], \ldots, y[j_{i-1}], y[j_{i+1}], \ldots, y[j_n]))\} \quad (8)$$

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 that maximises some measure — such as the contract score. However, a search of the tree of possible operators to find the optimum set of issues may be computationally expensive. To overcome this problem we intend to implement anytime algorithms and use the negotiation time limits to compute a, possibly sub-optimal, solution. Another computational requirement of these mechanisms is the need for an agent to dynamically recompute the issue weights. We define the re-computation of weights by first specifying the importance of the added issue, I_j, *with respect* to the average importance of other issues. Then:

Definition 8 *The weight of added issue j, w_j, is defined as:*

$$w_j = \frac{I_j}{(n-1)+I_j}$$
$$w_i^{'} = (1-w_j)w_i \quad \forall i \in \{i_1, \ldots, i_n\}, i \neq j \quad (9)$$

where w_j is the importance of the issue j, n is the new number of issues, w_i is the old weight for issue i and $w_i^{'}$ is its new weight after the inclusion of issue j. Recomputation of weights when an issue is removed in turn is defined simply as re-normalising the remaining weights:

Definition 9 *The weight of the remaining issues i after an issue j has been removed is defined as:*

$$w_i^{'} = \frac{1}{1-w_j} w_i \quad (10)$$

An Illustrative Example

The concepts and processes outlined above will be described using an example involving negotiation between the European Union (EU) and Morocco over fishing rights off the coast of Morocco. Negotiation between these parties involves reaching agreements over access rights as well as fishing conditions which Morocco affords EU fishing boats off its coastline.

Issue	*Reservation*	*Weight*
Zone	$\{All, Central, Boundaries\}$	0.2
Quantity	$[20, 2]$	0.35
Ships	$[30, 5]$	0.2
Price	$[100, 5]$	0.25

Figure 1: Core Negotiation Parameters for EU

Issue	*Reservation*	*Weight*
Zone	$\{Boundaries, Central, All\}$	0.3
Quantity	$[1, 10]$	0.2
Ships	$[1, 10]$	0.1
Price	$[50, 200]$	0.4

Figure 2: Core Negotiation Parameters for Morocco

Negotiation Parameters

Figures 1 and 2 detail the "core" set of issues involved in negotiation for EU and Morocco respectively. Reservation values specify the ranges of acceptable values for an issue and the weight of the issue signifies the level of importance of that issue.

The issue *Zone* represents the sectors of the coastal regions where fishing is permitted by Morocco. The values of this issue are qualitatively subdivided into regions, where fishing fleets can fish anywhere (all), or the central regions of the area (central) or on the outskirts of the region (boundaries). *Quantity*, the most important issue for EU, represents the total tonnage of fish (in units of millions) the shipping fleet is permitted to catch. Like *Zone*, *Ships* is a qualitative issue which represents the number of the ships allowed to fish within *Zone*. Finally, *Price*, the most important issue for Morocco, is the amount of money the EU will pay Morocco for the right to fish within *Zone*.

Non-core issue types, which EU or Morocco can include into negotiation respectively, and their respective parameters, are given in figures 3 and 4. *Trade* represents the amount of discount (in percentage) Morocco can obtain through the sale of fish caught by EU to Morocco. *Seasons*, the least important non-core issue to Morocco, qualitatively represents the seasons where Morocco can afford EU fishing rights in its territorial waters —W, A, Sp, Su, represent winter, autumn, spring and summer respectively. Finally, *Fish* represents the type of fish Morocco will permit EU boats to catch and ranges from Tuna to Octopus and Cuttlefish.

Finally, how agents value the contracts proposed to them is given by the value function. For the purpose of exposition, the value of the offer x for quantitative

Issue	*Reservation*	*Weight*
Trade	$[10, 80]$	0.2
Seasons	$\{Su, Sp, A, W\}$	0.4
Fish	$\{Tuna, Octopus, Cuttlefish\}$	0.4

Figure 3: Non Core Negotiation Parameters for EU

Issue	*Reservation*	*Weight*
Trade	$[90, 15]$	0.4
Season	$\{W, A, Sp, Su\}$	0.1
Fish	$\{Tuna, Octopus, Cuttlefish\}$	0.3

Figure 4: Non Core Negotiation Parameters for Morocco

issues i is modelled as a simple linear function, defined as:

$$V(x_i) = \begin{cases} \frac{x_i - min_i}{max_i - min_i} & \text{if increasing} \\ 1 - \frac{x_i - min_i}{max_i - min_i} & \text{if decreasing} \end{cases} \quad (11)$$

Because the values of issues $\{Quantity, Ships\}$ increase with increasing levels of the offer, these issues are increasing in value for EU (and conversely decreasing for Morocco). Alternatively, the values of issues $\{Price, Trade\}$ decrease with increasing levels of the offer and therefore decrease in value for EU (but increase for Morocco). The value functions for qualitative issues $\{Zone, Ships, Season, Fish\}$ are discrete in nature and is represented in figure 5 for both EU and Morocco.

Issue Trade-Off Negotiation

Assume EU begins the negotiation, offering Morocco a contract which allows EU to fish in all zones, for 15 tones, using 18 ships for a price of 55 units, $[All, 15, 18, 55]$. Using equation (1), the qualitative scores in figure 5, and equation (11), EU scores the value for this contract to be 0.7705. Further assume that Morocco evaluates this contract to be unacceptable and therefore counter-proposes with the contract $[Boundaries, 8, 4, 100]$.

	EU	
Issue	*Reservation*	*Score*
Zone	$\{All, Central, Boundaries\}$	$\{1, 0.6, 0.1\}$
Ships	$[30, 5]$	$0.04/ship$
Season	$\{W, A, Sp, Su\}$	$[0.2, 0.6, 0.8, 1]$
Fish	$\{Tuna, Octopus, Cuttlefish\}$	$[1, 0.8, 0.1]$
	Morocco	
Issue	*Reservation*	*Score*
Zone	$\{All, Central, Boundaries\}$	$\{0.1, 0.6, 1\}$
Ships	$[30, 5]$	$0.11/ship$
Season	$\{W, A, Sp, Su\}$	$[1, 0.8, 0.6, 0.2]$
Fish	$\{Tuna, Octopus, Cuttlefish\}$	$[0.1, 0.8, 1]$

Figure 5: Qualitative Values for EU & Morocco

Issue	*Criteria Function*
Zone	$[1, 0.5, 0]$
Quantity	$0.4/Ship$
Ships	$Offer - min/max - min$
Price	$1 - (Offer - min/max - min)$

Figure 6: Comparison Criteria for EU

EU decides to offer Morocco a contract which is a trade-off over some issues and possibly more acceptable to Morocco. A contract trade-off for EU begins by generating all/subset of contracts that lie on the indifference curve (using equation 3). Three such points are:

$$[Central, 15, 18, 24.6], [All, 13, 18, 19.2], [All, 15, 17, 51.7]$$

where EU has traded-off $Zone$ for $Price$ in the first contract (fishing in central zone only but paying less to Morocco), $Quantity$ for $Price$ in the second (reduced tonnage for less payment) and $Ships$ for $Price$ in the third (reduced number of ships and less payments). Note, since these are indifference contract points the value of each of these contracts is the same as EUs first offer, namely 0.7705.

Figure 6 shows the comparison criteria that EU uses for computing the similarity (using equation 5) between each iso-contract issue and the corresponding issue in Morocco's last offer, namely $[Boundaries, 8, 4, 100]$. $Offer$, in figure 6, refers to the number of ships Morroco or EU make to one another. The equivalence operator for comparing two values of the criteria, used in equation 5, is $1- \mid h(x) - h(y) \mid$.

Given the above iso-contracts and criteria functions, the most similar iso-contract to Morocco's last offer is then computed, using equation 4, to be $0.45, 0.38$ and 0.43 for the iso-contracts $[Central, 15, 18, 24.6], [All, 13, 18, 19.2], [All, 15, 17, 51.7]$ respectively. Therefore, EU offers Morocco $[Central, 15, 18, 24.6]$ since this is the closest EU iso contract to Morocco's last offer.

Issue Inclusion Negotiation

Assume now that Morocco evaluates, using equation 1, EUs first offer ($[Central, 15, 18, 24.6]$) to be unacceptable, and decides to include an issue into the core negotiation set. Using equation 9, and the importance levels of non-core issues in table 4, the new set of weights after individually adding $Trade$, $Season$ and $Fish$ into the existing set of issues are, $[0.27, 0.18, 0.09, 0.36, 0.09]$, $[0.29, 0.2, 0.1, 0.39, 0.02]$ and $[0.28, 0.19, 0.09, 0.37, 0.07]$ respectively. The final step in deciding which issue to include into the core negotiation set is achieved by individually adding each non-core issue into the core set and then, using the updated weights, computing the value for the new contract (equation 6). The contract whose overall value is the greatest is then selected. In this case the inclusion of $Trade$, $Season$ and $Fish$ generates contracts with overall contract value of 0.56, 0.52, and 0.55 respectively. Therefore, Morocco begins a sub-dialogue with EU to include the issue $Trade$ into the original dialogue. If EU accepts the inclusion of this issue then Morocco will offer the contract $[Boundaries, 8, 4, 100, 90]$, allowing EU to fish within the boundaries of the Morocco coastline, for 8 tonnage of fish, using 4 ships, and a payment of 100 units. Finally, Morocco also demands a trade agreement with EU for the EU sale of fish to Morocco at a 90% discount rate.

Related Work

The central focus of the work reported here, has been the use of fuzzy techniques for the design of a negotiation agent architecture for structured interactions in real environments. 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 we do not assume agents are cooperative and negotiation is an iterative process involving more than two interchanges of offers. 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. Other systems such as KASBAH have attempted to actually engineer a real world application (Chavez & Maes 1996). However, negotiation in KASBAH is between semi-autonomous agents which negotiate 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.

Conclusions

This paper has presented a distributed negotiation model which coordinates agent interactions. Mechanisms have been proposed for finding solutions using fuzzy logic and based on realistic assumptions that 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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