Multi-criteria negotiation on Multi-Agent Systems

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Abstract: Negotiation is a kind of decision making where two or more parties jointly search a space of solutions with the goal of reaching a consensus. This search usually is a single dimension process where the different agents, involved in the negotiation process, mutually adapt their price offers in order to reach their goals (to sell or to buy a good). However, this process is inflexible and often unrealistic because more than one single issue has to be negotiated in order to find out an adequate agreement. In this paper we introduce a multi-issue negotiation protocol for one-buyer-to-many-sellers interaction. The paper is also enhanced with an application example that illustrates the negotiation process and shows how it can be useful both as a product brokering and as a market brokering tool.

Keywords: Negotiation, Multi-issue negotiation, Electronic Commerce.

I - Introduction

Most of the well known negotiation protocols deal with a single dimension (usually the price). Moreover, Wellman [Wel99] also says that the preferences' reduction to the price single figure is what characterises the market. However, this seems to be a bit simplistic and unrealistic in the electronic commerce framework.

In this paper we are going to focus our attention on the kind of negotiation that takes place in an electronic market involving one buyer and many merchants that are potential sellers. In fact, we will use the traditional Consumer Buying Behaviour Model (CBB) that is also used and enhanced to accommodate the software agents concepts as it is done by [Gut98a]. CBB encompasses six main stages: Need Identification, Product Brokering, Merchant Brokering, Negotiation, Purchase and Delivery, and finally Service and Evaluation. Currently, Electronic Commerce agent mediated systems try to automate, at most, three of these stages (Product and Merchant Brokering as well as Negotiation). Here in this paper we are most concerned with the use of Software Agents for a rich (multi-dimensional) and flexible (adaptive) design of the Negotiation phase protocol. However, as we will see later, this negotiation protocol can also be seen as a product brokering stage once the buying agent can also use it as a market search process.

Negotiation is a kind of decision making where two or more parties jointly search a space of solutions with the goal of reaching a consensus [Ros94]. Some authors [Vul98] advocate the use of auction protocols for agent-mediated EC, arguing that they are widely recognised by economists [Moo92] as the most efficient way of resolving one-to-many negotiations.

Other authors point out the limitations of auctions' protocols and seek for more flexible negotiation models [Gut98b]. They stress out that online auctions are in fact less efficient and more hostile than it would be desired.

For example, the winner's curse, i.e. the winner pays more than the real value of the product, seems to be a consequence of auctions and, therefore, they propose more co-operative multi-attribute decision analysis tools and negotiation protocols using distributed constraint satisfaction policies to support it.

However, both lines of research are aware of the need of enhancing simple price-based auction mechanisms, transforming them into new protocols encompassing multi-dimensional issues to be negotiated among the market participants.

This kind of negotiation is no longer of a win-lose type (zero-sum game on the game theory taxonomy) and becomes one of the win-win type (non-zero sum game) allowing agents to co-operate when negotiating over multiple dimensions. Therefore, co-operative negotiations can be described as the decision making process of resolving a conflict involving two or more parties over multiple independent, but non-mutually exclusive goals [Lew97]. Another important point to take into account in which agents negotiation in the electronic commerce framework is concerned, is the need for real adaptive agents that can learn with past experience in several different ways in order to become more effective in the market. Interesting work in multi-issue negotiation is being carried out by Nick Jennings [Vul98; Sie97]. However, the focus of their work refers to one-to-one negotiation while our work is dedicated to one-to-many negotiation once this is the typical situation in on-line shopping.

II – Issues on Multi-criteria negotiation

It is not crucial whether we use multi-lateral negotiations or auction protocols for agent-mediated electronic commerce as far as we enhance the negotiation protocol capabilities with multi-attribute bids and appropriate evaluation functions. Moreover, and according to [Vul98] and [Moo92], once the only auction protocols relying on agents playing their dominant strategies are the English and the Vickrey auctions, it seems reasonable to try to accommodate the new co-operating negotiating facilities along the multi-dimensional buyers' preferences to the referred auction protocols. Vulkan and Jennings introduce an extension to the English auction protocol by which all the service provider agents have a preliminary negotiation stage ("pre-auction") to find out the best proposal which is, afterwards, proposed to the service seeking agents for negotiation (or take-it-or-leave-it). They claim that in doing so, they maximise the worst-case outcome for the buyers (always restricting the auctions to private and not common values, i.e. not allowing goods re-selling). However, the referred authors deal with the agents' preferences as if they were just quantitative parameters through the definition of constraints on parameters.

Multi-criteria negotiation is extremely useful in a large number of situations. Situations where more than one single parameter is simultaneously taking part in the same negotiation are common in real commercial scenarios where buyers are confronted with several different appealing proposals.

In single-criteria negotiation the value of a parameter is negotiated in such a way that the different negotiators try to defeat their opponents by offering a better proposal. The preferences of the buyer can be either implicit (the lower is the price the better for the buyer) or explicit with the buyer publicising its preference. This process can be done in a single round, where the competitors have one single chance to offer and no offer revision is allowed[1], or in multiple rounds where agents can revise their offers in face of the other competitors offers[2].

[1] Vickrey auction and First-price sealed bid auction are examples of single-round protocols.

[2] The English and the Dutch auctions are probably the most popular examples of multiple-round auctions [San96].

The first difficulty in multi-criteria negotiation is the buyers' preference definition. If we want to build a generic system, where no global, common knowledge is available, the buyer must make explicit his/her preferences in order to allow the potential sellers to calculate their best proposals taking also into account the buyer's point of view. While defining the buyer's preferences we must distinguish between discrete and continuous parameters. When the negotiation involves a discrete parameter it can be either a scalar or a non-scalar value. If it is a non-scalar value, the announcer (buyer agent) must specify either all the admissible values or a relationship over that parameter's domain values (higher than, lesser than, ...). Whenever the parameter's value is of a scalar type, the announcer can also specify intervals of admissible values. When dealing with continuous values, the announcer must specify specific values or intervals of acceptable values.

The second main difficulty in using multi-criteria negotiation is the mutual evaluation by both the buyer and sellers of each possible bid value. Because this evaluation must be done according to the buyer's criteria, the buyer must communicate his evaluation function to all the potential sellers. In order to allow the comparison of different possible bids including different parameters (due to different sellers' interests and possibilities) that cannot, in principle, be directly compared, the adopted solution is the weighting of the different possible values. In addition to the specification of the admitted values or intervals of values, buyer must also specify the weight he/her attaches to each possible value. When intervals of values are defined, an evaluation for each interval must also be specified. Alternatively, an initial and a final value for each interval can be defined. In this case, the evaluation of each intermediate value will be calculated by linear interpolation. For continuous or discrete scalar values the upper limit for the interval can be considered as infinite as well as the lower limit can be considered as minus infinite.

III – A new negotiation protocol

The new protocol for multi-criteria negotiation we are here presenting is a modified version of the well-known English auction. The buyer will start a negotiation session by announcing his request together with the list of the accepted values and correspondent evaluations. This announcement is then broadcast to all the potentially interested agents. These receiving agents (sellers) evaluate the request and find their best possible answer (bid). In this process, the sellers must weight two often antagonistic or, at least, not coincident interests – their own interest as sellers and the buyer's interest. In order to maximise their profits, the sellers will produce bids that are not their own best bid (according to their own evaluation function), but those which they believe would be the best from the buyer's point of view. The negotiation process will force the sellers to move from an ambitious perspective (trying to maximise their own utility instead of the one from the buyer) to a non ambitious one (reducing their own utility in order to increase the buyer's utility) as the negotiation progresses. The process of finding a maximum for the linear combination of two non-linear generic functions such as both the buyer's and sellers' evaluation functions, is a complex optimisation problem. Genetic algorithms could be used to find out the optimal bid value according to the current constraints. The best solution found by each seller will then be considered as its first bid. Once the buyer has received all the bids (or a predefined timeout has expired) the bids are ranked and the best bid is then selected. If the buyer, in face of the received bids, decides to change its own evaluation criteria, the evaluation parameters must be resent to all the sellers and the negotiation must be restarted. Otherwise, the best solution achieved is sent to all the sellers and a new negotiation round starts. In each round, the best bid is used as a reference bid. Only the best bids are accepted. If a seller sends out a bid with a lower buyer's evaluation, it is disqualified and eliminated from the seller's pool. If a seller has no chance to improve the best bid so far, its normal procedure is to quit the negotiation process explicitly by sending out to the buyer an adequate message. The negotiation process will finish when all but one seller quit or are disqualified.

The evaluation function used both by buyers and sellers is the following:

$$E(v) = \sum_{i=1}^{n} w_i . c(v_i) \tag{1}$$

$$c(v_i) = \begin{cases} \text{if } p_i \text{ discrete} \rightarrow T[v_i] \\ \text{if } p_i \text{ continuous} \rightarrow \dfrac{v_i - \min_i}{\max_i - \min_i} . (T[\max_i] - T[\min_i]) + T[\min_i] \end{cases} \tag{2}$$

where:

n – number of parameters (i from 1 to n)	$T[v_I]$ – score defined by the user to value v_i of parameter i
p_I – type of parameter I	Max_i – maximum value of parameter i
w_I – weight defined by the user to parameter I	Min_I – minimum value of parameter I

In the formula above, the evaluation function $E(v_i)$ is a linear combination of the n parameters evaluation values represented as $c(v_I)$ and weighted by means of w_I. The function $c(v_I)$ represents the score defined for the value c_I. If the parameter is discrete, such a result is a list of values, one for each possible value of the input parameter. If the parameter is continuous, the evaluation value is calculated by linear interpolation between the value ($T[min_i]$) corresponding to the minimum acceptable value for the parameter i (min_i) and the value ($T[max_i]$) corresponding to the maximum (max_i) acceptable value for the parameter i as defined by the user. The weights w_i are somehow redundant because the user could define different weights by correctly setting the evaluations $T[v_i]$. However, the explicit definition of the weights was considered to be much more understandable and natural for the user.

IV – A negotiation example

In order to illustrate the concepts and protocol presented before, an application example is now introduced. The negotiation protocol is completely generic and can be applied to any (or almost any) field. To make it easy the reading of this paper, the automotive market - a scenario that is familiar for many of us - was chosen. A situation where a user wants to buy a new car was simulated and the new protocol for negotiation is now applied, explained and discussed.

After the user has selected a car in the category of "family car" he gets a pre-defined evaluation function that was created in order to correspond to the usual preferences of the typical family car's buyer. However, the user can also freely customise his profile if he has different preferences. In this example, the weights considered in the evaluation function range from 0 to 100 and the values range from 0 to 20. However, any other scale can be used because only relative comparisons of those values are made. The absolute value of the classifications is irrelevant. The weights referred above reflect the importance the user gives to each parameter. Classifications define the importance the user gives to each one of the discrete parameters' values or to each one of the limits of each continuous parameter domain. Classifications can also be used to express a low or a high importance to each parameter. By associating high classifications to the different values of a parameter (ex. 16-20) the user can also give it a higher importance in the final classification than what would be the case if using low classifications (ex. 6-10). This kind of redundancy was introduced in order to achieve a more natural representation of the user's preferences.

	Brand			Number of doors				Price		ABS		AIRGBAG Driver		AIRGBAG Pass		Alarm		AC		Power steering	
Weight	100			20				100		20		20		20		5		50		30	
Type	D			D				C		D		D		D		D		D		D	
Value	Beta	Gamma	Delta	2	3	4	5	2000	6000	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
Score	7	10	10	9	10	14	15	15	5	15	10	15	5	15	5	15	10	15	5	15	5

	Power windows		Metalic painting		Alloy wheels		Sunroof		Radio		Urban consumption		Capacity (cc)		Max. Power		Maximum Speed		Aceleration		Baggage capacity	
Weight	10		15		0		5		10		60		40		70		30		60		70	
Type	D		D		D		D		D		C		C		C		C		C		C	
Value	Y	N	Y	N	Y	N	Y	N	Y	N	4	12	1000	2000	50	150	150	250	5	25	200	1000
Score	15	5	12	10	11	10	14	12	8	6	20	2	15	16	5	15	10	12	20	0	5	20

Table 1 – User's preferences.

The preferences on the above tables will be used both by the sellers to evaluate their offers from the buyer's point-of-view and by the buyer to evaluate the different bids. The first line on table 1 is the *type* of each parameter. It can be either *discrete* (D) or *continuous* (C). If the type is continuous, the different accepted values for the parameter are given and, below it, the correspondent classification is also given. If the parameter is continuous, the two limit values (minimum and maximum) are defined and the classification for these two limits is presented. The evaluation function will use linear interpolation to evaluate intermediate values. The evaluation scale used was between 0 (minimum) and 20 (maximum). However, it is important to stress out that the scale used is irrelevant because the evaluation function will be used only for the sake of comparison between the different bids. This classification criterion will be appended to the announcement.

Values in table 1 reflect the evaluation criteria of the buyer. Likewise, the different sellers will also have their own evaluation function to calculate the value of each possible bid. As well as the buyer's goal is to get the product that maximises his evaluation, the seller's goal will be to find out both the product and selling conditions that will maximise its satisfaction and simultaneously convince the buyer. The evaluation function of the sellers can be based on parameters that are distinct from those of the buyer. For simplicity, we have used, in this example, the same evaluation function for all the sellers. However, each seller may also use a completely different function with different parameters and corresponding classification. The evaluation function for the different sellers is presented on table 2.

	ABS		AIRGBAG Driver		AIRGBAG Pass		Alarm		AC		Power steering		Power windows	
Weight	20		20		20		20		20		20		20	
Type	D		D		D		D		D		D		D	
Value	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
Score	10	15	10	15	10	15	10	15	10	15	10	15	10	15

	Metalic painting		Alloy wheels		Sunroof		Stock		Model age		Max. Discount	
Weight	20		20		20		80		50		100	
Type	D		D		D		C		C		C	
Value	Y	N	Y	N	Y	N	0	100	0	6	0	25
Score	10	12	10	12	10	15	0	20	10	20	20	16

D – discrete parameter C – continuous parameter

Table 2 – Sellers evaluation function.

Comparing the previous table with table 1 it can be seen that only some evaluation parameters are common to both tables. New parameters like *Stock* (reflecting the number of units in seller's stock), *Model age* (how long is the car's model available in the market) and *Discount* (the percentage of discount relative to the ideal price) were now introduced. Those new parameters as well as the absence of some of the previously defined ones, and the different given values for the common parameters reflect the different perspectives the buyer and the sellers have on the same product. Of course, sellers evaluation function is private to each seller and it is never revealed to the buyer or to any other seller.

Sellers, knowing both functions, can evaluate the products they want to sell, from both perspectives. To go on with our example, we will now consider three different sellers *Beta, Gamma* and *Delta* with different products to sell that can be of interest to the buyer who have made the previous announcement (see next table).

Brand	Model	Doors	Normal price	ABS	AIRBAG Cond	AIRBAG Pass	Alarm	Air cond	Power steering	Power windows	Metalic painting	Alloy weels	Sunroof	Radio	Urban consumption	Capacity (cc)	Max. Power	Max. Speed	Aceleration	Baggage capacity
Beta	Betamax SR	3	3098	n	s	n	n	n	s	s	n	s	s	n	9.3	1370	103	185	11.9	320
	Betamax AIRBP MP SR	3	3170	n	s	s	n	n	s	s	s	s	s	n	9.3	1370	103	185	11.9	320
	BetamaxAC AIRBP	3	3461	n	s	s	n	s	s	s	n	s	n	n	9.3	1370	103	185	11.9	320
	Betamax AC AIRBP MP	3	3491	n	s	s	n	s	s	s	s	s	n	n	9.3	1370	103	185	11.9	320
	Betamax AC SR AIRBP MP	3	3566	n	s	s	n	s	s	s	s	s	s	n	9.3	1370	103	185	11.9	320
Gamma	Gamex EL	5	3073	n	n	n	n	n	s	s	n	n	n	s	9.2	1370	80	170	13.9	380
	Gamex EL AIRBC AC	5	3505	s	s	n	n	s	s	s	n	n	n	s	9.2	1370	80	170	13.9	380
	Gamex EL AIRBC AIRBP AC	5	3545	s	s	s	n	s	s	s	n	n	n	s	9.2	1370	80	170	13.9	380
	Gamex EL MP	5	3113	n	n	n	n	n	s	s	s	n	n	s	9.2	1370	80	170	13.9	380
	Gamex EL AC MP	5	3338	n	n	n	n	s	s	s	s	n	n	s	9.2	1370	80	170	13.9	380
	Gamex EL AIRBC AIRBP AC MP	5	3585	s	s	s	n	s	s	s	s	n	n	s	9.2	1370	80	170	13.9	380
Delta	Delux	5	3085	n	s	n	n	n	s	s	n	n	n	n	10.1	1392	75	169	14.4	380
	Delux ABS	5	3185	s	s	n	n	n	s	s	n	n	n	n	10.1	1392	75	169	14.4	380
	Delux ABS AIRBP AC	5	3418	s	s	s	n	s	s	s	n	n	n	n	10.1	1392	75	169	14.4	380
	Delux ABS AIRBP AC AW	5	3533	s	s	s	n	s	s	s	s	s	n	n	10.1	1392	75	169	14.4	380

Table 3 – Sellers products description.

After having received the announcement, the seller will send out a bid that optimises its own criteria. If there are more than one possible solution with equal value to the seller, he will decide for the one that is more valuable to the buyer. Once the different bids received from all the sellers, the buyer selects the best proposal and communicates the evaluation of that proposal to all the sellers. In each negotiation round all the bids must have a higher evaluation than the best bid of the previous one plus some pre-defined threshold (in this example 0.1) unless it is their last bid. In this case any increment to the previous best one is accepted. In the next table, the buyer and seller evaluations are depicted. The minimal and maximal evaluations are due to the price factor. In this example price is the single parameter that can be continuously modified inside pre-defined limits by the seller (set by the ideal price and maximum discount). Because the price has a direct influence in both the buyer and seller evaluations, when a car is proposed at its higher price, the maximum evaluation for the seller and the minimum for the buyer will be obtained. When the minimum price is offered we will get the maximum for the buyer and the minimum for the seller. Any value between these two situations is possible depending on the percentage of discount adopted. A situation where a seller chooses to make a discount instead of moving to another product, occurs in the third negotiation round of the example below. Of course that this table can only be calculated on the vendor's side. The buyer has no idea about what maximum discount the seller is able to do. Only negotiation can force the seller to reduce its price moving from a zero discount offer to a reduced price offer. Anyway, the seller will always make the offer with a higher evaluation to himself. The price reduction will only be adopted if it is the best solution to the seller accordingly to its evaluation function.

Brand	Model	Seller max evaluation	Seller min evaluation	Buyer max evaluation	Buyer min evaluation
Beta	Betamax SR	13.27	10.60	10.14	9.99
	Betamax AIRBP MP SR	13.13	10.47	10.44	10.28
	BetamaxAC AIRBP	12.16	9.49	10.98	10.80
	Betamax AC AIRBP MP	12.24	9.58	11.01	10.83
	Betamax AC SR AIRBP MP	11.95	9.28	11.00	10.82
Gamma	Gamex EL	12.84	10.17	10.17	10.01
	Gamex EL AIRBC AC	12.46	9.79	11.13	10.95
	Gamex EL AIRBC AIRBP AC	12.55	9.89	11.39	11.21
	Gamex EL MP	12.68	10.01	10.20	10.04
	Gamex EL AC MP	12.81	10.15	10.81	10.64
	Gamex EL AIRBC AIRBP AC MP	11.97	9.30	11.42	11.24
Delta	Delux	13.52	11.74	10.10	10.00
	Delux ABS	13.37	11.59	10.21	10.10
	Delux ABS AIRBP AC	12.43	10.65	11.09	10.97
	Delux ABS AIRBP AC AW	12.11	10.33	11.10	10.98

Table 4 – Buyer and sellers evaluations.

In the previous table, the "Bidder's max evaluation" column corresponds to the seller's evaluation of each car at its maximum price and the "Bidder's min evaluation" column corresponds to the seller's evaluation at each car minimum price. In a similar way the “Buyer’s max evaluation” is the buyer’s evaluation at the minimum possible price and the “Buyer’s min evaluation” column the buyer evaluation at the maximum possible price. This table is private to the sellers because buyers do not know the minimum prices. The table is used to know the range of values each bid (car) can have from the buyer's perspective, whenever the price (the only continuous parameter that the sellers can control in this example) is modified.

Let us now see how negotiation evolves from the announcement stage to the final assignment. The first step in the negotiation process is the announcement made by the buyer with the intention of buying a car and containing its evaluation function as described in table 1. In their first bid, the different vendors will send out the bid that presents the best evaluation for themselves. As we can confirm looking to table 4, company *Beta* decides to bid with car *Betamax c/TA* (13.27 to *Beta*, 9.99 to the buyer), *Gamma* with *Gamex EL* (12.84 to *Gamma*, 10.01 to the buyer) and *Delta* with *Delux* (13.52 to *Delta*, 10.00 to the buyer). Therefore, *Gamma EL* is the best offer and 10.11 is the price beat in the round (10.01 plus 0.1). In the second round *Gamma* does not bid because it has the best proposal. *Beta* then proposes *Betamax* with passenger AIRBAG, open roof and metallic painting (13.13 to *Beta,* 10.28 to the buyer). *Delta* proposes *Deluxe* with ABS and a 2% discount in order to achieve an acceptable evaluation by the buyer (13.01 to *Delta*, 10.12 to the buyer). In the third round *Alfa* is leading. *Gamma* proposes now *Gamex EL* with air conditioned and metallic painting (12.81 to *Gamma*, 10.64 to the buyer) and *Delta* the *Deluxe* with ABS, passenger AIRBAG and the air conditioned (12.43 to *Delta*, 10.97 to the buyer). In the fourth round *Beta* is in serious difficulties to beat the third round best and does its best proposing *Betamax* with passenger AIRBAG, air conditioned, metallic painting and the lowest possible price (9.58 to *Beta*, 11.01 to the buyer). *Gamma* bids with *Gamex EL* with double AIRBAG and air conditioned (12.55 to *Gamma*, 11.21 to the buyer). This last offer is unbeatable by the other sellers and both quit in the sixth and last negotiation round leaving *Gamma* as the negotiation winner.

VI - Conclusions and future work

In this paper we have presented what we believe to be an adequate protocol for multi-issue, multi-vendor negotiation process. Inspired by the English-Auction, the protocol now proposed supports multi-round negotiation of multi-issue evaluated transactions allowing the buyer agent to automatically find out the best of the proposed bids according to the buyer's interests. This solution is very well suited to the retail electronic market, once it promotes the buyer's pro-activity more effectively than the usual in current electronic auction systems. Instead of being up to the seller to promote the auction for selling goods (or services) we are here proposing that the buyers can do it by launching buying announcements to which the sellers try to answer by making the best possible bids. Moreover, instead of negotiating just the price, as it is typical in most of the current systems, a large number of different issues that characterise the products should be negotiated. This means that if the buyer does not have a precise idea about what it really wants, and he is receptive to proposals including different features of a specific good (as it is often the case in real-life trading) he can specify large acceptance margins for the future bids and, through negotiation, to find out the most suitable product available in the market. Of course that broader parameter domains (due to relaxation) usually means more negotiation rounds and, as a consequence, more time consumption as well as more communication.

A limitation of the actual implementation is the restriction of the bids’ evaluation functions to linear functions. The introduction of Genetic Algorithms in the offer search process will allow the use of evaluation functions without any restrictions. Another important further development will be the inclusion of an advanced protocol to support agents' coalitions formation. The introduction of mechanisms for coalition formation and intra-coalition negotiation identical to those presented in [Oli97] but now adapted to the multi-criteria negotiation, will be one of the next steps in the development of our multi-issue negotiation protocol.

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