Decentralized strategy for supporting multi-agent negotiation of several aspects of different products

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***Abstract*—In virtual markets based on multi-agent systems, clients and providers delegate the responsibility of buying or selling a product or service to software agents. In this sense, decentralized negotiation strategies in multi-agent systems are the key to allow that agents to reach agreements. However, in environments where there is not any mediator, to reach consensus is not warranted. In this work, we propose a decentralized strategy of negotiation in order to two or more agents may negotiate as a group at the same time several characteristics of several products. We apply this proposal in a virtual market simulating *ChileCompra*, where provider agents generate coalitions to satisfy tenders requesting several products or services.**

Keywords: multi-agent system, negotiation, coalition, virtual market.

I. Introduction

In multi-agent systems, agents interact collaboratively in order to solve a problem. In virtual markets, agents represent their users' interests about different products and/or services that are present in the context of negotiation. Thus, humans or other systems will delegate tasks to agents that run automatically. During the negotiation process, the agents seek consensus and form a coalition with other agents in order to maximize the utility of their constituents.

In the literature, it has been proposed centralized (or mediated) and decentralized (non mediated) trading strategies. On the one hand, in mediated strategies, an external agent or observer monitors that the "best" agreements be achieved. On the other hand, in non mediated negotiations, the parties involved negotiate and reach, or do not reach agreements by exchanging messages without a mediator. These negotiation strategies may also be classified according the number of features, aspects or properties that may be negotiated where multi-aspect is more complex to solve.

Lai and Sycara [1] proposed a strategy for *negotiation without mediation* between two agents considering several aspects. Subsequently, Zheng et al. [2] modified this proposal including *multiple aspects* in a multi-agent context (with more than two agents) because in many real situations, it is required to include simultaneously several products or services in the process of negotiation (it requires that agents have a joint vision of the elements and aspects in order to make informed decisions). For example, an agent might be willing to lower the price of product A always when it can raise the price of product B.

In this paper, we extend the negotiating strategy proposed by Zheng et al [2] to allow the inclusion of multiple elements (products or services) to be treated at the same time, where each agent may be involved in different aspects of them. To illustrate this proposal, a case study is presented in the context of a virtual market, specifically for the purpose of being applied to the electronic market *MercadoPublico*[1] of *ChileCompra*[2].

The remainder of this paper is organized as follows: Section II highlights some of the most relevant articles on negotiation between agents, Section III exposes the main concepts of virtual markets, Section IV presents our proposed negotiation strategy, in Section V presents a case study, and finally in Section VI we conclude the work and provide future work.

II. State of the Art

In *centralized or mediated negotiations*, we highlight the work of Chalamish and Kraus [3], where an external agent (i) gets the negotiation preferences and analyzes them, (ii) supervises the negotiation and proposes impartially offers to the implied agents trying to solve their conflicts. In contrast, in *decentralized or non mediated negotiation* agents negotiate and exchange information between them directly. Most of the strategies proposed for *decentralized or non mediated negotiation* are restricted to negotiation between two opponent agents (for instance a seller and a buyer) and only one negotiable feature/property/aspect (for instance, the price of the product).

In *multi-aspect negotiation* we have two kind of proposals. On the one hand, those which are based on game theory and on the other hand, those which use the artificial intelligence paradigm. The proposals based on game theory start from the premise that an agent knows beforehand the opponent preferences and moreover, they assume that these preferences are lineal utility functions (for instance the proposals of Kalai [4] or Lang and Rosenthal [5]). However, this is unrealistic. Typically, in trading market the known information between the parts is incomplete, where the utility functions are privates and more sophisticated. In artificial intelligence based techniques, it has been proposed that agents should adapt their strategies according the elapsed negotiation time (this idea was first used by Faratin et al. [6]).

The first works of Nash [7] and Farantin et al. [8] considered the inclusion of several aspects in *decentralized*

[1]https://www.mercadopublico.cl/
[2]http://www.chilecompra.cl/

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negotiation, where a total or partial knowledge about the preferences of the opponent agent is assumed, besides of the use of simple utility functions. Buffet and Spencer [9] proposed a negotiation strategy of *multi-aspects* that used bayesian techniques, but applicable only to some kinds of agents, and therefore, not generalizable. Wu et al. [10] considered the negotiation between more than two agents in a context of *multi-aspect* negotiation, where agents do not know beforehand the opponents' preferences. In this last work, authors showed how the negotiation about two aspects is made between three agents.

Lai and Sycara [1] proposed a *non mediated negotiation* strategy to support the negotiation of several aspects of two opponent agents. This work presented a *concession strategy* where agents decrease their utility proportionally to the elapsed negotiation time. Moreover, in this proposal the utility function was private and strictly concave. Authors proposed to build *indifference curves*, which were obtained varying the utility function's parameters without varying its utility value. When an agent wants to make an offer, it selects the point of the *indifference curve* with the minimum distance to the offer given by the last opponent in the previous period. Zheng et al. [2] extended this proposal for more than two agents negotiating without mediator. Authors proposed as strategy for generating offers, a *sequential projection*. This strategy consists of (i) a *concession step* in which agents reduce their utility until they do not reach the reserved utility (which it is their minimum acceptable utility) and (ii) a step for *generating the offer*, where the agents use the last two previous opponents' offers and its own last two previous offers in order to generate a new offer that preserves its utility between its allowed margins. Authors demonstrate that if the feasibility space is not empty, then the method converges to an acceptable agreement between the agents in a finite time.

III. Virtual Market formalization

Let consider a multi-agent system comprised by M agents, where $M \geq 2$ and the $i-th$ agent is represented by A_i. Let N be the number of elements (goods or services), where each element E_j ($j = 1..N$) has K_j features/attributes/properties. A *tenderer agent* (AL) is who sends a tender, which is comprised of a request of a set of goods/products (for instance, a tender requesting 300 syringes and 40 kilos of cotton). A tenderer has a utility function (u_L) for evaluating offers from providers (who may apply separately or as alliances). As equation (1) shows, this utility function is comprised by criteria such as the total price of the tender, and by each product, the provider reputation, the quantity of goods/services or coverage percentage of the tender, experience, or time response.

$$U_L(\mathbf{x}) = \left[\sum_{j=1}^{N} \sum_{k=1}^{K_j} W_{Ljk} (1 - \nu(x_j^{(k)}))^3 \right]^{1/3} \tag{1}$$

where $U_L(x)$ is the utility of the offer $\mathbf{x}$ for the tenderer. K_j is the quantity of attributes by each element E_j. W_{Ljk} is the weight assigned by the tenderer to the attribute k of the element E_j. $\nu(z)$ is the evaluation of the aspect z by the tenderer, where $0 \leq \nu(z) \leq 1$.

A *provider agent* (AP) can provide several and different elements (goods/services). This kind of agents negotiates to create a convenient and cooperative alliance and in this way, is able to cover a major percentage of the tenders. They negotiate aspects such as the quantity of product they will provide and at which price. Therefore, provider agents have by each tender, reserved and desired prices and quantities, which are the negotiable aspects.

The utility function of the provider agents U_{P_i} is defined by the following equation:

$$U_{P_i}(\mathbf{x}) = \left[\sum_{j=1}^{N} \sum_{k=1}^{K_j} W_{ijk} \mu(x_j^{(k)})^3 \right]^{1/3} \tag{2}$$

where W_{ijk} is the weight assigned by the agent i to the aspect k of the element E_j; and $x_j^{(k)}$ is the value of the aspect k of the element E_j in the proposal $\mathbf{x}$. $\mu(z)$ is the evaluation of the provider agent to the aspect z ($0 \leq \mu(z) \leq 1$).

Figure 1 shows an example of the utility function where two aspects are under consideration. For this example, the wights 0.2 and 0.8 are established for the aspect 1 and aspect 2, respectively.

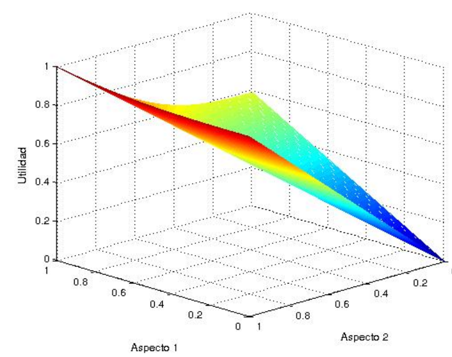

Fig. 1. Utility function with two aspects

Different from the proposal of Zheng et al. [2], provider agents compute the change of utility with respect to the tenderer agent with equation (3), that is the only utility function which is public

$$\triangle U_{ir}(t) = \min_{r} \mid U_L(\mathbf{x}_r(t-1)) - U_L(\mathbf{x}_r(t-2)) \mid \tag{3}$$

where $\triangle U_{ir}(t)$, is the minimum perceived change by the agent A_i respect to the offers of the rest of the agents r. $\mathbf{x}_r(t-1)$ is the last offer of the agent r; $\mathbf{x}_r(t-2)$ is the next to last of the proposals of the agent r; y $U_L(\mathbf{x})$ is the utility of the tenderer agent for the offer $\mathbf{x}$.

It is important to notice that not necessarily all the offers include proposals for all the aspects.

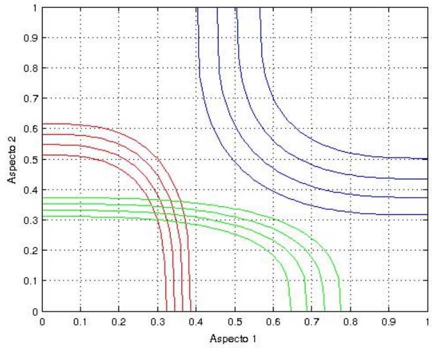

Fig. 2. Final indifference curves for three agents.

IV. A DECENTRALIZED MULTI-AGENT MULTI-PRODUCT AND MULTI-ASPECT NEGOTIATION STRATEGY

Different to the works of Lai and Sycara [1] or Zheng et al. [2], we define the grade of participation of an agent by each aspect of each product. Let W_{ijk} be the grade of participation of the agent A_i in the negotiation of the aspect $E_j^{(k)}$, whose domain values are defined as $\Omega = [0, 1]$, where

$$\sum_{i=1}^{M} W_{ijk} = 1 \qquad \forall j \in [1, \ldots, N], k \in [1, \ldots, K_j]$$

	E_1		E_j		E_N
	$E_1^{(1)}$ ... $E_1^{(K_1)}$	...	$E_j^{(1)}$ ... $E_j^{(K_j)}$	...	$E_N^{(1)}$ ... $E_1^{(K_N)}$
A_1 ... A_i ... A_M	W_{111} ... W_{11K_1} W_{i11} ... W_{i1K_1} W_{M11} ... W_{M1K_1}		W_{1j1} ... W_{1jK_j} W_{ij1} ...W_{ijK_j} W_{Mj1} ... W_{MjK_j}		W_{1N1} ... W_{1NK_N} W_{iN1} ... W_{iNK_N} W_{MN1} ... W_{MNK_N}

TABLE I. DEGREE OF PARTICIPATION OF THE AGENTS IN THE NEGOTIATION

Each agent A_i has a private utility function U_i, which is continuous and concave with values between 0 and 1 ($U_i \in [0, 1]$); where on the one hand, the value 0 indicates that for the proposal under evaluation the agent has no utility and, on the other hand, the value 1 indicates that the agent has the maximum utility. Each agent has a reserved and private utility ($ru_i \in [0, 1]$), which is used to determine whether it should accept or reject the offer (offers with lower utility than the reserved utility are rejected).

As the work of Zheng et al. [2] (who defined that any point inside of the agreement zone is a *satisfactory agreement*) the aim of this proposal is to find as a group an offer inside of this agreement zone. Agents sequentially generate offers following an established order agreed before the negotiation starts. During a *round*, all agents have made an offer or have accepted one from the previous agent if and only if the value of the offer is inside of their set of acceptable values. Let $\mathbf{x}_i^t = [x_{ij}^{(k)}(t)]_{j=1..N,k=1..K_j}$ be the vector representing the offer of the agent A_i during the round t, where the value $x_{ij}^{(k)}(t)$ is given by the agent A_i to the aspect k of the element E_j during the round t.

Algorithm 1 shows the negotiation process of the multi-agent system. At the beginning, each agent makes an initial offer by each element (see line 2). After that, lines 9 to 14 show the negotiation rounds, where each agent makes an offer in a pre-established order. The negotiation may ends with or without an agreement.

Algorithm 1 NegotiationProcess

```
1: for all agent A_i, i = 1..M, in the negotiation do
2:    Generate the initial offer x_i^0
3:    Send x_i^0 as message to the rest of the agents
4: end for
5: ended ← FALSE;
6: t = 0;
7: while NOT ended do
8:    t ← t + 1;
9:    for each agent A_i, i = 1..M, do
10:      call Algorithm EvaluateOffers(A_i, t);
11:      if negotiation is closed or negotiation without agreement then
12:         ended ← TRUE;
13:      end if
14:   end for
15: end while
```

Algorithm 2 shows that each agent receives a set of offers $\mathbf{X}_t$ from all the other agents (line 1). For each iteration, the minimum acceptable utility is computed. Depending of which round of negotiation the agents are, this utility is computed with different formulas (line 3 and line 14 if the negotiation is in the first round, or any other round respectively). The minimum utility $s_i(t)$ for agent A_i in the round t is computed as follows:

$$s_i(t) = \begin{cases} 1 - (1 - ru_i)\left(\frac{1}{T}\right)^{\frac{1}{\beta_i}} & t = 1 \\ s_i(t-m) - \Delta U_{ir}(t) & t > 1 \end{cases} \tag{4}$$

where ru_i is the reserved utility of the agent A_i, T is an estimation of the maximum number of epochs, and $\beta_i > 0$ is a private parameter of the reduction strategy of the agent A_i. As the work of Lai, G. and Sycara, K. en [1] the parameter value β regulates the concession of each agent. Therefore, when $\beta_i < 1$, the agent A_i will concede slowly at the beginning but faster when it approaches the limit time T and when $\beta_i = 1$, the agent A_i will concede uniformly during the entire negotiation.

After the initial iteration, the reduction of the minimum utility depends of the minimum perceived utility change $\triangle U_{ij}(t)$ from the last two offers of all the agents. Therefore, each agent must at least have proposed as minimum two offers before. For this last case, if the current minimum utility is less than the reserved one, then the reserved is now the current minimum utility (lines 15 to 17). The negotiation ends satisfactorily if the agent A_i receives from the agent A_{i-1} the same offer that it sent in the previous round. In other words, if the offer was accepted by all the other agents (line 5 to 8). However, if no agent changes its offer from one round to another, then no agreement will be reached because there is not any agreement zone for all the agents (line 9 to 12).

Finally, if the offer that the agent A_i receives from the agent A_{i-1} is in its agreement zone, then it accepts it and sends it

Algorithm 2 EvaluateOffers

1: Agent A_i receives the offers from the rest of the agents $\mathbf{X}_{t-1} = [\mathbf{x}_1(t-1), ..., \mathbf{x}_M(t-1)]$;
2: **if** $t == 1$ (first round) **then**
3: For each agent A_i compute equation (4):

$$s_i(1) \leftarrow 1 - (1 - ru_i)(\frac{1}{T})^{\frac{1}{\beta_i}}$$

4: **else**
5: **if** all agents accept the offers $\mathbf{X}_t$ **then**
6: Close negotiation;
7: **return**
8: **end if**
9: **if** none agent changed its offer $\mathbf{x}_i(t-1)$, $i = 1..M$ **then**
10: Close negotiation without agreement;
11: **return**
12: **end if**
13: Compute the utility reduction $\triangle U_{ir}(t)$ using equation (3);
14: Compute equation (4):

$$s_i(t) \leftarrow s_i(t-m) - \triangle U_{ir}(t)$$

15: **if** $s_i(t) < ru_i$ **then**
16: $s_i(t) = ru_i$;
17: **end if**
18: **end if**
19: **if** $\mathbf{x}_{i-1}(t-1)$ is in its agreement zone **then**
20: Accept the offer from the predecessor agent

$$\mathbf{x}_i(t) \leftarrow \mathbf{x}_{i-1}(t-1)$$

21: Send the new offer $\mathbf{x}_i(t)$ to all the agents
22: **return**
23: **else**
24: Reject $\mathbf{x}_{i-1}(t-1)$;
25: Determine the set Z_i of the acceptable offers for the agent A_i at time t
26: Compute $\mathbf{w}_p \leftarrow \frac{1}{m}\sum_{i=1}^{m} \mathbf{x}_i(t-1)$, with $\mathbf{x}_i(t-1) \in Z_i$.
27: Compute the new offer using the projection method: $\mathbf{x}_i(t) \leftarrow Proj(\mathbf{w}_p) = \min_{\mathbf{x}} \mid\mid \mathbf{x} - \mathbf{w}_p \mid\mid^2$.
28: Send offer x_i^t; *//to all agents.*
29: **end if**

(line 19 to 22). If not, the agent creates and sends to others an offer based on the point of a new *indifference curve* of the current agent A_i, which has the minimum distance respect to the media of the latter received proposals and its own (line 23 to 29). The *indifference curve* is computed at each iteration, and it is the curve that contains all the combinations of values of the several and different aspects that do not change the current minimum utility for the agent.

V. Case study

In this work, we apply our proposal to *VirtualMarket* [3]. Suppose that we have three agents: a tenderer agent AL and two provider agents APs. The AL (A_1) publishes a tender, where it requests a set of products specifying the *desired* and *reserved* values for all the negotiable aspects (e.g. price). As a response to this request, provider agents form an alliance of two: A_2 who is a syringe provider, and A_3 who is a cotton provider. A_2 provides 200 syringes where *desired* and *reserved* values are specified in the Table III. A_3 provides both, cotton and syringes, whose *desired* and *reserved* values are specified in the Table IV.

[3] http://dev2.toeska.cl/virtualmarket/

Good	syringe	cotton
Quantity	300	40 kilos
Total price	60.000	

TABLE II. Parameters of the tenderer agent A_1.

Good	syringe
Reserved prive	200
Desired price	400
Quantity	200

TABLE III. Parameters of the provider agent A_2.

Good	syringe	cotton
Reserved prive	200	400
Desired prive	800	1000
Quantity	100	40 kilos

TABLE IV. Parameters of the provider agent A_3.

Table V shows the values of the proposal of the different agents after the *round* 0. The tenderer agent, in its first proposal, distributes uniformly its bidget to each needed product. In this example, we assume that both provider agents also use the budget information to determine to which price they would like to sell their products. Moreover, the provider agents ensure that their first proposals maximize their utility, assigning number 1 to those aspects in which they are interested and 0 to those in which thay are not.

	Syringe price by Agent 2	Syringe price by Agent 3	Cotton price by Agent 3
A_1	20000	20000	20000
A_2	80000/100000	0	0
A_3	0	80000/100000	40000/100000

TABLE V. Values of the first proposal of each agent.

The Algorithm was executed using different utility decreasing levels' values, whose results are shown in the Table VI.

VI. Conclusions

In this work, we have described a *decentralized negotiation* that extends the proposal of Zheng et al. [2] allowing to more than two agents negotiate at the same time multiple aspects of multiple products. Besides, agents may use private and more complex and realistic utility functions. As future work, we expect to validate our proposal studying the convergence of the algorithm.

Acknowledgments

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Decreasing level	Participation proportion			utility A_1	utility A_2	utility A_3
0.01	0.42532	0.29025	0.18582	0.984571	0.425257	0.24908
0.005	0.43066	0.28475	0.16922	0.984571	0.430735	0.240715
0.001	0.43613	0.28912	0.08806	0.984571	0.436135	0.240715
0.0005	0.43687	0.28966	0.04962	0.984571	0.436879	0.230293
0.0001	0.43742	0.28889	0.00710	0.984571	0.437428	0.2293
0.00005	0.43754	0.28862	0.00789	0.984571	0.437548	0.22908

TABLE VI. FINAL PROPOSALS AND UTILITIES FOR DIFFERENT DECREASING VALUES

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