Optimal Strategies for Agents in an Alternating Offers Negotiation Protocol Considering Time Constraint

Linlan Zhang and Huaming Gui
School of Business, Hubei University, Wuhan, China
E-mail: misalinlan9904@163.com

***Abstract*—This paper analyzes the automated negotiation process between two competitive agents in an alternating offers negotiation model. Generally speaking, the outcome of a negotiation depends on some parameters—the agents' reservation prices, their attitude toward time and the strategies they use, etc. In most realistic situations, it is not possible for agents to have complete information about all these parameters for its opponent. However, it is general for agents to have partial information about these parameters for its opponent. Under such uncertain situation, our aim is to determine how an agent can exploit the available information in selecting an optimal strategy which maximizes its expected utility. Here, in particular, the optimal strategies are determined considering time constraint. Moreover, we set the concession constraints for each agent to assure the negotiation process is continually shortened. This design can assist researchers in AI (Artificial Intelligence) to construct software agents, where these intelligent agents can optimally negotiate on behalf of users in a given state of knowledge and context.**

***Index Terms*—automated negotiation, time constraint, alternating offer, optimal strategy**

I. Introduction

With rapid growth of electronic commerce, autonomous agents can play an increasing variety of roles in an automated negotiation system. Humans seldom negotiate effectively during negotiation process owing to limited information-processing capabilities [1] and biases [2]. Thus, automated negotiation has become an important research subject in the artificial intelligence (AI) field and economics field. Many studies have been done to solve this challenge in agent-based negotiation [3]-[6]. Automated negotiations exist in many different forms (see ref. [7] for a taxonomy). Here, we consider a particular class of automated negotiation; namely, alternating bargaining over a single issue (price) between two agents that both have firm time deadlines.

For solving bilateral negotiation problem, alternating-offer bargaining protocol is the most predominant way in autonomous agent negotiation. The pioneering work about alternating-offer negotiation in economics field is Rubinstein's infinite horizon alternating-offer bargaining game [8]. Since there has a unique solution in this work, it has been applied to automated negotiation widely [9]. However this model assumes perfect information while takes time into consideration. There are also some works with incomplete information, outside options, etc [10]-[12] from the perspective of game theory. Faratin *et al.*'s negotiation framework considers the agent's time deadlines and is not based on the assumption that both agents have perfect information [13]. They assumed both agents have limited knowledge and computational resources and studied the design of reasoning mechanisms in a service-oriented negotiation. Ren and Zhang [14] presented a bilateral single-issue negotiation model considering time constraint and nonlinear utility. Zhang and Chen [15] presented a sealed-bid negotiation model in which both agents simultaneously submit offers instead of alternating offer by introducing a mediator agent. Narayanan and Jennings [16], [17] constructed a bilateral negotiation model through a Markov-chain framework, and gave an optimal strategy in incomplete information settings by bayesian learning. Fatima *et al.* [18] investigated the negotiation outcomes in an incomplete information setting based on time constraints and an agenda-based framework.

However, most existing researches assumed that both agents have perfect information, or incomplete information under time constraints. These works doesn't take into account the concession constraints. In this paper, we design an automated negotiation model with agents having partial information for its opponent, and analyze the optimal strategy of both agents. Especially, to assure the negotiation process is continually shortened, we set the concession constraints for both agents. The remainder of this paper is organized in the following manner. Section II presents our general negotiation model and constructs both agent's concession constraints. In Section III, we analyze how an agent can exploit the available information in selecting an optimal strategy which maximizes its expected utility. Section IV demonstrates the negotiation procedure by employing the proposed negotiation strategy. Finally, in Section V, we draw the conclusion and outline some directions for future plans.

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II. NEGOTIATION MODEL

A. Alternating Offer Negotiation Protocol

Here, we use an alternating offers negotiation protocol for our study. Let *B* denote the buyer and *S* denote the seller. Let $[IP_B, RP_B]$ and $[RP_S, IP_S]$ denote the price intervals of the buyer and seller agent, respectively. RP_a denotes agent a 's reservation price and IP_a denotes agent a 's initial price, where $a \in \{B,S\}$. A value for price acceptable to both agents (i.e., the zone of agreement) is the interval $[RP_S, RP_B]$. The difference between RP_B and RP_S is known as the price-surplus. Moreover, we introduce the concept of sincerity price in our proposed negotiation protocol, in order to exclude some speculators who are without sincerity to negotiate. Here, the sincere price is defined as the price constraint that the initial price of the opponent should be satisfied the negotiator considers. Let SP_a denote the sincere price that agent a set for the opponent agent. If IP_B is lower than SP_S, the buyer will be excluded since it be considered non-sincerity. Similarly, if the seller's initial price IP_S is higher than SP_B, the seller will be excluded. Generally, the assumption $SP_B \geq RP_B \geq IP_B, IP_S \geq RP_S \geq SP_S$ is reasonable.

In addition, generally, each agent has a time deadline since a negotiation should consider time constraint. The negotiation will fail if an agreement cannot be reached before either agent's time deadline. During the negotiation process, each agent send respective alternating offers to the opponent agent until one agent accepts the offer or quits the negotiation since it reaches its time deadline.

Let $T_a, a \in \{B,S\}$ denote agent *a*'s time deadline. Let $p^t_{B\rightarrow S}$ denote the price offered by agent *B* to agent *S* and $p^t_{S\rightarrow B}$ denote the price offered by agent *S* to agent *B* at negotiation round $t, t \in \{0,1,\cdots,\min\{T_B,T_S\}\}$. The negotiation process starts when the first offer is made by an agent. When an agent, for example S, receives the buyer agent's offer $p^t_{B\rightarrow S}$ at round t, it will compare the value of its utility function U_S. If the value of $U_S(p^t_{B\rightarrow S})$ is greater than $U_S(p^t_{S\rightarrow B})$, then the agent will accept the offer $p^t_{B\rightarrow S}$. Otherwise it will offer a count-offer to the buyer agent. Such a procedure will be repeated until an agreement is reached or one agent reaches its time deadline. Thus, the action $A_a(t)$, that agent *a* takes at negotiation round t is usually defined as follows:

$$A_a(t)=\begin{cases} Quit & if\ t>T_a \\ Accept & if\ U_a(opponent's\ offer)\geq U_a(counter-offer) \\ Counter-offer & otherwise. \end{cases}$$

Concession constraints and utility functions

In this section, the concession constraints and utility functions of both agents will be introduced.

1) *Concession constraints*

In our proposed negotiation protocol, we set the minimal concession constraints for both agents to assure the negotiation process is continually shortened. Let λ_a denote the minimum concession that agent *a* has to make if the negotiation enter the next round, i.e., p^t_a must satisfy the following inequalities:

$$p^t_B \geq p^{t-1}_B + \lambda_B,\ p^t_S \leq p^{t-1}_S - \lambda_S$$

Before the negotiation starts, agent *a* must submit the offer about SP_a, IP_a, T_a to the preset automated negotiation system. The method how calculate the concession constraint for each agent is as follows:

a) Firstly, The system begins calculate the concession factor of each agent at each round t according to the initial information of both agents

$$\rho_B = \frac{SP_B - IP_B}{SP_B - IP_B + IP_S - SP_S},\ \rho_S = 1-\rho_B = \frac{IP_S - SP_S}{SP_B - IP_B + IP_S - SP_S}$$

It can be seen that the larger the difference between SP_a and IP_a, the larger the concession factor that the agent withstands. Moreover, here, we use the sincere price SP_a to calculate the concession factor, instead of the reservation price RP_a. The aim is to avoid revealing the reservation price which is most critical information of both agents.

b) Calculate the average concession distance Δ at each round

$$\Delta = (IP_S - IP_B)/\max\{T_B, T_S\}$$

Note that we use $\max\{T_B,T_S\}$ to calculate the average concession distance, instead of $\min\{T_B,T_S\}$. The aim is to avoid the information about the time deadlines of both agents is exposed.

c) Calculate the concession constraint λ_a of each agent: $\lambda_B = \rho_B \cdot \Delta, \lambda_S = \rho_S \cdot \Delta$.

Since we set the minimum concession constraint for both agents, the negotiation process will be strongly monotonic and ensures convergence to a negotiation process.

2) *Utility function*

The utility of each agent depends on the final agreement about the price and the negotiation round. We use the following von Neumann–Morgenstern utility function [19] to define the agents' utilities:

$$U^t_B = (RP_B - p)(\delta_B)^t,\ U^t_S = (p - RP_S)(\delta_S)^t$$

where δ_a is the discounting factor. Agent a 's utility from conflict is defined as $U_a(C)=0$.

III. NEGOTIATION STRATEGY

The negotiation strategy defines the sequence of actions the agent takes during the process of negotiation. In our presented alter-offering model, the negotiation strategy determines the value of a counter-offer which, in turn, depends on some negotiation information. The information that an agent has about the negotiation parameters is called the negotiation environment. In order to determine an optimal strategy, an agent needs to find values of a counter-offer, on the basis of its negotiation environment, that maximize its expected utility.

A. Negotiation Environment

Each agent *a* has a reservation price RP_a, a deadline T_a, a sincere price SP_a, a utility function U_a and a negotiation strategy S_a. These are an agent's own parameters, but the information it has about the opponent is not complete. The negotiation environment E_a for agent *a* can be modeled as a 10-tuple:

$$I_a = \left\langle RP_a, T_a, SP_a, U_a, S_a,\ L_a^p, L_a^t, \alpha_a^t, \beta_a^t, \lambda_a \right\rangle$$

where

- L_a^p denotes agent *a*'s beliefs about the opponent agent's offers at each time.
- L_a^t denotes agent *a*'s beliefs about the opponent agent's time deadline.
- α_a^t denotes the probability that agent *a*'s time deadline is the time $t-1$ (or $t = T_a + 1$);
- β_a^t denotes the probability that agent *a*'s offer is less than the opponent agent's offer at time t, $t \le T_a$;

The outcome of negotiation depends on all these parameters. The agents simultaneously propose their respective offers at each round $t,\ t \in \{0, 1, \cdots, \min\{T_B, T_S\}\}$.

B. Assumptions and Notes

L_a^p and L_a^t are two probability distributions that denote agent *a*'s beliefs about the opponent agent's offers at each round and time deadline. Without loss of generality, it can be assumed that the system selects the buyer agent as first-offer agent. Therefore, the buyer agent submits first an offer to the seller agent at each round after it received the seller agent's offer of last round. We make the following assumptions from the perspective of the buyer (the same assumptions can be taken from the perspective of the seller agent):

1) L_B^p denotes the buyer agent's beliefs about the seller agent's offers at each round. At round *t*, we assume that agent B believes that p_S^t is uniformly distributed over different intervals. For example, at the beginning of the negotiation $t = 0$, it can be assumed that agent B believes p_S^0 is uniformly distributed between p_B^0 and SP_B. At any time $t(t \ge 1)$, agent B knows agent S's offer p_S^t must be less than its previous offer p_S^{t-1} because of the concession constraint, though it does not know the concession constraint λ_S of the seller agent. And at this time, $p_B^{t-1} < p_S^{t-1}$ is common knowledge for both agents. Therefore, we could assume that agent B believes that $p_B^{t-1} < p_S^t$ is reasonable. Thus we could assume that agent B believes that p_S^t is uniformly distributed between p_B^{t-1} and p_S^{t-1}.

2) L_B^t denotes the buyer agent's beliefs about the seller agent's time deadline. The buyer agent doesn't have any other exogenous belief about the opponent's deadline. However, it is reasonable that the buyer agent consider the seller agent's time deadline located on an interval. Therefore, we assume that the buyer agent consider T_S is uniformly distributed on the interval $\left[t_1^S, t_2^S\right]$.

3) α_S^t denotes the probability that the buyer agent *consider* $T_S = t-1$. It can be calculated as follows:

$$\alpha_S^t = p(T_S = t-1) = \begin{cases} 0, & t \le t_1^S \\ \dfrac{1}{t_2^S - t + 1}, & t > t_1^S \end{cases}$$

4) β_S^t denotes the probability that the buyer agent consider the seller agent's offer p_S^t is less than p_B^t. It can be calculated as follows:

$$\begin{aligned} \beta_S^t &= p\left(p_B^t \ge p_S^t\right) \\ &= \int_{-\infty}^{p_B^t} f\left(p_S^t\right) d\ p_S^t \\ &= \begin{cases} 1, & p_B^t \ge p_S^{t-1} \\ \dfrac{p_B^t - p_B^{t-1}}{p_S^{t-1} - p_B^{t-1}}, & p_S^{t-1} > p_B^t > p_B^{t-1} \\ 0, & p_B^t \le p_B^{t-1} \end{cases} \end{aligned}$$

where $f\left(p_S^t\right) = \begin{cases} \dfrac{1}{p_S^{t-1} - p_B^{t-1}}, & p_S^{t-1} < p_S^t < p_B^{t-1} \\ 0, & other \end{cases}$

C. Optimal Strategies

For convenience, the following discussion is from the perspective of the buyer agent (the same analysis can be taken from the perspective of the seller).

1) Expected utility

At any time t, the utility value of agent B has the following two possible situations:

a) If $t = T_S + 1$, the negotiation will result in a conflict. In this case, the utility of agent B is zero.

b) If $t \le T_S$, in this time, when there is $p_B^t \ge p_S^t$, the negotiation ends with an agreement and agent B may obtain plus utility; Otherwise the utility is zero.

Moreover, agent B believes that p_S^t is uniformly distributed between p_B^{t-1} and p_S^{t-1}. Since the system set the concession constraint for both agents, p_S^t must stastify $p_S^t \le p_S^{t-1} - \lambda_S$. If $p_B^{t-1} \ge p_S^{t-1} - \lambda_S$, then the negotiation ends with an agreement. If $p_B^{t-1} < p_S^{t-1} - \lambda_S$, then the probability of $p_B^t \ge p_S^t$ equals β_S^t. We could assume two kinds of situations have the equal probability to appear.

Thus at any time t ($t < T_B$), the expected utility of agent B when it offers p_B^t is

$$EU_B^t = \left(1-\alpha_S^t\right)\cdot\left(0.5U_B^t + 0.5\beta_S^t U_B^t\right)$$

where $U_B^t = \left(RP_B - p_B^t\right)\left(\delta_B\right)^t$ denotes agent B 's utility in case the negotiation ends with an agreement.

2) Main propositions

It can be obtained the following propositions based on expected utility maxima.

Proposition 1: At any time t ($0<t<T_B$), agent B 's optimal offer p_B^{t*} satisfy the following expression:

$$p_B^{t*} = \begin{cases} \max\left\{p_S^{t-1}, p_B^{t-1}+\lambda_B\right\}, \; if \;\; p_B^t \geq p_S^{t-1} \\ \max\left\{\dfrac{RP_B - P_S^{t-1} + 2P_B^{t-1}}{2}, p_B^{t-1}+\lambda_B\right\}, if \;\; p_S^{t-1} > p_B^t > p_B^{t-1} \end{cases}$$

Proof: We could calculate easily the equation of EU_B^t:

$$\begin{aligned} EU_B^t &= \left(1-\alpha_S^t\right)\cdot\left(0.5U_B^t + 0.5\beta_S^t U_B^t\right) \\ &= \frac{\left(1-\alpha_S^t\right)\left(\delta_B\right)^t}{2}\left(RP_B - p_B^t\right)\left(1+\beta_S^t\right) \end{aligned}$$

For simplicity, let U_t denote EU_B^t, constant A denote $\frac{\left(1-\alpha_S^t\right)\left(\delta_B\right)^t}{2}$ and x denote p_B^t, we have

$$U_t = A\cdot\left(RP_B - x\right)\left(1+\beta_S^t\right)$$

a) when $x \geq p_S^{t-1}$ *, the function* U_t *achieves the maximum value at* $x = p_S^{t-1}$*;*

b) when $p_S^{t-1} > x \geq p_B^{t-1}$ *, we could calculate the function* U_t *as follows:*

$$U_t = A\cdot\left(RP_B - x\right)\frac{P_S^{t-1} - 2P_B^{t-1} + x}{P_S^{t-1} - P_B^{t-1}}$$

Taking the derivative of function U_t with respect to x, we have

$$U_t' = \frac{A}{P_S^{t-1} - P_B^{t-1}}\left(RP_B - P_S^{t-1} + 2P_B^{t-1} - 2x\right)$$

Suppose that x_t satisfies the equation $U_t' = 0$, i.e.,

$$x_t = \frac{RP_B - P_S^{t-1} + 2P_B^{t-1}}{2}$$

Taking the derivative of function U_t' with respect to x, we have $U_t'' = -2 < 0$.

Therefore, the function U_t achieves the maximum value at $x = x_t$. In addition, the buyer agent's offer has to satisfy the minimum concession constraint, i.e., $x \geq p_B^{t-1} + \lambda_B$.

In conclusion, at any time t ($0<t<T_B$), agent B 's optimal offer p_B^{t*} satisfy the following expression:

$$p_B^{t*} = \begin{cases} \max\left\{p_S^{t-1}, p_B^{t-1}+\lambda_B\right\}, \; if \;\; p_B^t \geq p_S^{t-1} \\ \max\left\{\dfrac{RP_B - P_S^{t-1} + 2P_B^{t-1}}{2}, p_B^{t-1}+\lambda_B\right\}, if \;\; p_S^{t-1} > p_B^t > p_B^{t-1} \end{cases}$$

The following proposition for agent S can be obtained using similar analysis and assumptions.

Proposition 2: At any time t ($0<t<T_S$), agent S's optimal offers p_S^{t*} satisfying the following expression:

$$p_S^{t*} = \begin{cases} \min\left\{p_B^{t-1}, p_S^{t-1}-\lambda_S\right\}, \; if \;\; p_S^t \leq p_B^{t-1} \\ \min\left\{\dfrac{P_B^{t-1} - RP_S + 2P_S^{t-1}}{2}, p_S^{t-1}-\lambda_S\right\}, if \;\; p_B^{t-1} < p_S^t < p_S^{t-1} \end{cases}$$

3) Optimal strategies for both agents

Before the negotiation starts, agent *a* must submit the offer about SP_a, IP_a, T_a to the preset automated negotiation system. Both agents will receive respective concession constraints after the system calculated the concession constraint for each agent according to the introduced method in section Ⅱ. Note that we assumed that the system selects the buyer agent as first-offer agent. Based on the above analysis, the action agent *a* takes during the negotiation course of goes in the following steps:

a) At the initial stage of the negotiation, i.e., $t=0$*, agent* a *submits the initial offer* $p_a^0 = IP_a$ *to the opponent agent.*

b) At any time t ($0<t<T_a$ *), agent* a *offers* p_a^t *in accordance with Proposition 1(agent* B*) or Proposition 2(agent* S*).*

c) At time $t = T_a$ *, agent* a *offers its reservation price* RP_a*.*

D. Negotiation Algorithm

Based on the above description, the extended negotiation algorithm is summarized as follows:

Step 1: Each agent assign negotiation parameters to the automated system before a negotiation starts, i.e., the initial offer IP_a , the sincere offer SP_a and the time deadline T_a . The system calculates the concession constraint for both agents after it received the information of both agents, and informs them the concession constraint. Then the system selects randomly an agent *a* as the first offer, the negotiation starts.

Step 2: At any stage *t*, agent *a* submit the offer P_a^t to the opponent agent according to the above proposed optimal strategy, and wait for the agent's response. If the opponent accepts the offer, then the negotiation is completed with an agreement. Otherwise, the opponent will send back the counter-offer. If the current negotiation round is the agent's deadline, then the procedure goes to Step 3. Otherwise, the procedure goes to Step 4.

Step 3: If the counter-offer can bring any profit to the agent, then the agent will accept the opponent's counter-offer, and the negotiation succeeds with an agreement. Otherwise, the agent will reject the opponent's offer, and the negotiation fails.

Step 4: The negotiation enters next round. If the opponent's counter-offer can bring more profit to the agent than the agent's offer for the next round, then the agent will accept the opponent's offer, and the negotiation succeeds with an agreement. Otherwise, agent *a* (*B* or *S*) will send the offers to the opponent according to the above propositions (proposition 1 or proposition 2), and the negotiation enters next round. The procedure goes to Step 2.

IV. Experiment

In this section, we demonstrate the negotiation procedure by employing the proposed negotiation strategy between two agents.

We simulate the negotiation between a buyer and a seller on purchasing a piece of clothing online. We respectively set

$$\langle IP_B, RP_B, SP_B, T_B \rangle = (110,190,200,8)$$

$$\langle IP_S, RP_S, SP_S, T_S \rangle = (170,125,110,10)$$

By the method introduced in sectionⅡ, we calculazte the concession constraints of both agents as follows: $\langle \lambda_B, \lambda_S \rangle = (4,2)$. Without loss of generality, we assume the system select the buyer agent as the first offer. According to proposition 1 and proposition 2, we could calculate the offers of both agents at each round. Table I provides the offer process of the application of the proposed negotiation strategy. Table I shows the offer process of application of the proposed negotiation strategy.

TABLE I. The Offer Process of Both Agents

Negotiation round *t*	The offer of the buyer agent p_B^t	The offer of the buyer agent p_S^t
0	110	170
1	120	162.5
2	133.75	160
3	148.75	158
4	164.75	accept

It can be seen that, the seller agent would accept the buyer agent's offer owning to $U_S(164.75)$ is more than its current expected utility at round *t*=4. That is, the agreement is reached with the agreed offer 164.75 at the 4th round.

In this section, we demonstrate the negotiation procedure between two agents with alternating offer by employing the proposed negotiation strategy. It can be seen that the negotiation length is rather short. It shows that the proposed negotiation model can efficiently shorten the negotiation process and successfully help agents to reach the agreement.

V. Conclusions

In this paper, a novel alternating offer negotiation model was proposed. We determined what the optimal negotiation strategies are for both agents that find themselves with incomplete information. Specifically, we set the concession constraints for both agents in order to short the negotiation process. In the future we intend to extend our analysis to determine if this mutual strategic behavior leads to a equilibrium and then analyze if the proposed model can be implied to the in the real world by constructing a simulated Platform.

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Dr. Linlan Zhang was born in China in 1982. She received her Ph. D. from the College of automation, at Huazhong University of Science and Technology in 2010. She received her Master Degree from the Wuhan University in 2006. Currently, she is an associate professor in the School of Business, at Hubei University. Dr. Zhang is an active researcher and published 16 research papers in reputable journals and conferences. Her research interests include agent-based automatic negotiation, the theory of negotiation and optimization.

Prof. Huaming Gui was born in China in 1969. He received his Ph. D. from the School of management, at Huazhong University of Science and Technology in 2007. He received his Master Degree from the Wuhan University in 2002. Currently, He is a professor of management in the School of Business, at Hubei University. Prof. Gui is an active researcher and published 26 research papers in reputable journals and conferences. His research interests include supply chain and logistics management.