An Agent Bidding Strategy Based on Fuzzy Logic in a Continuous Double Auction

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ABSTRACT

This paper presents the design and implementation of a fuzzy logic based bidding strategy, the FL-strategy, for an agent in a Continuous Double Auction (CDA). Experiment results show that the FL-strategy outperforms some of the commonly used bidding strategies in a range of situations.

1. PRELIMINARIES

In a CDA [2], an *ask* a is the amount submitted by a seller agent (s-agent) willing to sell a unit of good. The lowest ask in the market is the *outstanding ask* (oa). Similarly, a *bid* b is the amount submitted by a buyer agent (b-agent) willing to buy a unit of good. The highest bid in the market is the *outstanding bid* (ob). A CDA can be described as a protocol where s-agents submit asks to decrease oa, while b-agents submit bids to increase ob, until ob is not less than oa. Then, the s-agent which submits oa and the b-agent which submits ob can make a transaction. A descriptor of a CDA can be formally defined as:

Definition 1. *The* **descriptor** *of a CDA is*

$$P_{CDA} =< g, \mathcal{B}, \mathcal{S}, V_b, C_s, \Delta_{price}, t_{round}, min_{ob}, max_{oa} >,$$

where g is the good to be auctioned; $\mathcal{B} = \{b_1, \cdots, b_n\}$ is the set of identifiers of b-agents; $\mathcal{S} = \{s_1, \cdots, s_m\}$ is the set of identifiers of s-agents; $V_b = (\vec{V}_1, \cdots, \vec{V}_n)$, $\vec{V}_i$ is a vector of unit valuations, i.e., $\vec{V}_i = (v_{i1}, v_{i2}, \cdots, v_{in_i})$, n_i is the amount of units that b-agent i requires, v_{ij} is the redemption value for the jth unit acquired; $C_s = (\vec{C}_1, \cdots, \vec{C}_m)$, where $\vec{C}_j$ is a vector of unit costs, i.e., $\vec{C}_j = (c_{j1}, \cdots, c_{jm_j})$, m_j is the number of units that s-agent j wants to sell, c_{jk} is the cost of the kth unit; Δ_{price} is the minimum price step required in the auction; t_{round} defines the condition for the termination of a CDA; min_{ob}/max_{oa} is the minimum/maximum bid/ask allowed for a b-agent/s-agent;

Definition 2. *A* **round** *in a CDA is the time period between two successive transactions or the period from the beginning of the CDA to the time when the first transaction takes place. If a round is the rth ($r \in \mathbb{N}^+$) round of the CDA, then r is called the* **round number** *of the round, denoted r.* □

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Definition 3. *Let l ($l \in \mathbb{N}^+$) be the history length and p_i ($1 \leq i \leq r$) denote the price of the ith transaction. For a CDA that has lasted r ($r \geq l$) rounds, A* **history** *H_l in a CDA is the set of transaction prices during the last l rounds, $H_l = \{p_{r-l+1}, \cdots, p_i, \cdots, p_r\}$.* □

Definition 4. *A* **CDA protocol** *with the descriptor P_{CDA} consists of the following steps:*

1. *A new round starts. Let $oa = min_{ob}$ and $ob = max_{oa}$.*
2. *Several situations might arise during this round:*
   (a) *If an s-agent, s_i, submits an ask a,*
      i. *if $a \geq oa$ then a is an invalid ask;*
      ii. *if $ob < a < oa$ then $oa = a$;*
      iii. *if $a \leq ob$ then a transaction is made at ob; go 1.*
   (b) *If a b-agent, b_j, submits a bid of b,*
      i. *if $b \leq ob$ then b is an invalid bid;*
      ii. *if $ob < b < oa$ then $ob = b$;*
      iii. *if $b \geq oa$ then a transaction is made at oa; go 1.*
3. *Step 2 repeats until no new bids/asks are submitted during a time period t_{round}.*□

2. THE FL-STRATEGY

For the sake of space, we only provide the FL-strategy for s-agents, and the strategy for b-agents is similar.

2.1 Basic Concepts

Definition 5. *A* **situation** *s^* during a negotiation procedure is a 6−tuple, $s^* =< r, \mathcal{B}, \mathcal{S}, oa, ob, H_l >$, where r is the current round number; $\mathcal{B}$ and $\mathcal{S}$ are the set of b-agents and the set of s-agents, respectively; oa and ob are the outstanding ask and the outstanding bid, respectively; and H_l is the history of the last l rounds.* □

Definition 6. *Given a situation s^*, the* **valid asks set** *is the set of valid asks that an s-agent could submit, that is*

$$D_s = \{d \mid d = min_{ob} + m\Delta_{price}, \min(ob, c_{ij}) \leq d < oa, m \in \mathbb{N}^+\},$$

where d is the price at which an s-agent submits an ask; and c_{ij} is the cost of the jth unit of good for seller i. □

The prices of previous transactions are recorded as history and referred to by agents in the subsequent rounds. Due to the self-correcting process of a CDA, the transaction prices are likely to converge to a competitive equilibrium price with the CDA in progress.

Definition 7. *Let r be the current round number ($r \geq 3$). The* **reference price** *P_0 in the situation s^* is given by:*

$$P_0 = \frac{\sum_{r-l \leq i \leq r-1} p_i - \max_{r-l \leq i \leq r-1} p_i - \min_{r-l \leq i \leq r-1} p_i}{l-2},$$

where p_i is the transaction price in H_l, and l ($r > 2$) is the history length. □

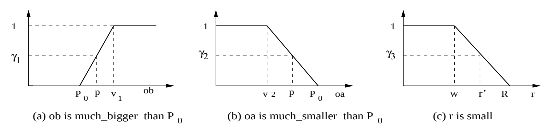

Figure 1: Fuzzy sets in heuristic rules.

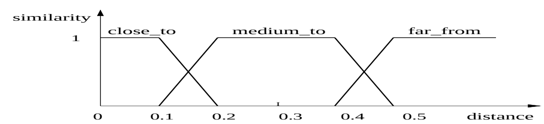

Figure 2: Fuzzy sets used in fuzzy reasoning.

2.2 Fuzzy Reasoning Mechanism

By the extension principle [3], real numbers in the Sugeno controllers [6] could be extended to triangular fuzzy numbers. A triangular fuzzy number can be defined with the triple: $\tilde{a} = (m, \theta, \chi)$, where m is called center, θ and χ are called left and right spreads [5]. Suppose the fuzzy rules are as belows:

$\mathcal{R}_1$:	if x is A_1 and y is B_1 then z is $\tilde{c}_1$
$\mathcal{R}_2$:	if x is A_2 and y is B_2 then z is $\tilde{c}_2$
fact:	x is x_0 and y is y_0
consequence:	z is $\tilde{z}_0$

The following formula hold in the situation where $\tilde{c}_1 = (m_1, \theta_1, \chi_1)$ and $\tilde{c}_2 = (m_2, \theta_2, \chi_2)$:

$$\tilde{z_0} = \frac{\alpha_1}{\alpha_1+\alpha_2}\tilde{c}_1 + \frac{\alpha_2}{\alpha_1+\alpha_2}\tilde{c}_2 = \left(\frac{\alpha_1 m_1 + \alpha_2 m_2}{\alpha_1+\alpha_2}, \frac{\alpha_1\theta_1 + \alpha_2\theta_2}{\alpha_1+\alpha_2}, \frac{\alpha_1\chi_1 + \alpha_2\chi_2}{\alpha_1+\alpha_2}\right). \quad (1)$$

2.3 Fuzzy Reasoning in the FL-strategy

The FL-strategy is based on some heuristic rules and the fuzzy reasoning mechanism described in Section 2.2. The relation of P_0, oa, and ob during a round in a CDA falls into one of the cases: 1) $P_0 \le ob < oa$, 2) $ob < oa \le P_0$, and 3) $ob \le P_0 \le oa$. In the first two cases, we use some heuristic rules; the bidding issue in the third case, which is more complicated, is handled through a fuzzy reasoning mechanism on a rule base.

In the case $P_0 \le ob < oa$, the heuristic rule is

(SR_1) IF ob is *much_bigger* than P_0
THEN accept ob
ELSE ask is $(oa - \beta_1\Delta_{price}, \theta, \chi)$.

In the case $ob < oa \le P_0$, the heuristic rule is

(SR_2) IF oa is *much_smaller* than P_0 and r is small
THEN no new ask
ELSE ask is $(oa - \Delta_{price}, \Delta_{price}, \Delta_{price})$.

Rule (SR_1) states that when ob is *much_bigger* than P_0, it is already very profitable if an s-agent accepts the current outstanding bid. Otherwise, the s-agent will decrease oa to a fuzzy number $(oa - \beta_1\Delta_{price}, \theta, \chi)$. Fuzzy rule ($SR_2$) is applied in the case when oa is much smaller than P_0. Fig. 1 describes all the fuzzy sets used in the above heuristic rules.

The third case ($ob \le P_0 \le oa$) represents a more complicated scenario. The fuzzy reasoning on a rule base is required. First, the rule base for s-agents is presented in Table 1. The fuzzy numbers in the rule base are all triangular fuzzy numbers. θ, χ and $\lambda_1, \cdots, \lambda_4$ are suitable parameters predefined by the users, and *or* corresponds to operator Max. Fuzzy linguistic terms, far_from, *medium_to*, and *close_to*, are defined in Fig. 2.

Then, based on the rule base, we perform inference through the fuzzy reasoning mechanism. The overall output of our fuzzy reasoning is a fuzzy number, *i.e.*, a set of asks with membership degrees.

Subsequently, the decision sets, DS_s of s-agents can be decided. Suppose $z_s = (m_s, \theta_s, \chi_s)$ is the output fuzzy number of the fuzzy reasoning or the heuristic rules for an s-agent,

Table 1: Fuzzy rule base for s-agents

IF	(ob is *far_from* or *medium_to* P_0) and (oa is *far_from* P_0)
THEN	ask is $(oa - \lambda_1\Delta_{price}, \theta, \chi)$.
IF	(ob is *far_from* or *medium_to* P_0) and (oa is *medium_to* P_0)
THEN	ask is $(oa - \lambda_2\Delta_{price}, \theta, \chi)$.
IF	(ob is *far_from* or *medium_to* P_0) and (oa is *close_to* P_0)
THEN	ask is $(oa - \lambda_3\Delta_{price}, \theta, \chi)$.
IF	ob is *close_to* P_0
THEN	ask is $(P_0 + \lambda_4\Delta_{price}, \theta, \chi)$.

and the parameter π_s, is the threshold to decide to which degree the ask could be accepted. The asks that the s-agent could submit are in the set

$$DS_s = \{d | d \in D_s \cap \{d | z_s(d) \ge \pi_s\}\}. \quad (2)$$

Finally, the agent can decide whether to accept a bid or submit an ask, or submit nothing. For an s-agent, if the decision set, DS_s is empty, it will not submit an ask. Otherwise, the ask to submit is decided by the following:

$$ask = \begin{cases} ob & \text{if } ob \in DS_s, \\ \arg\max_{d \in DS_s} \{z_s(d)\} & \text{otherwise.} \end{cases} \quad (3)$$

3. EVALUATION

Four experiments are performed to evaluate the performance of the FL-strategy.

The first experiment reveals that an agent with a short or intermediate history length can react to changes quickly. The second experiment shows that the FL-strategy outperforms some of the commonly used bidding strategies (ZI [1], FM, Preist [4] and Gjerstad-Dickhaut [2]) in a CDA market in a range of situations. The third experiment presents the transaction price distribution of agents using different strategies. Compared with agents using other strategies, an FL-agent can sell/buy goods at higher/lower prices. Finally, we investigate to what extent the behaviour of FL-agents, as well as the efficiency of the CDA market are affected by the increase of FL-agents. The profit of an individual FL b-agent decreases until the proportion of FL b-agents is more than a proportion of about 40%. Smilarly, the profit of an individual FL s-agent decreases until the proportion of FL s-agents is more than a proportion of about 37.5% when supply is equal to and less than demand. But this feature does not hold for the situation when supply is greater than demand. Moreover, with the increase of number of FL-agents, the efficiency of the market is not significantly affected.

The FL-strategy is useful for designing profit-seeking agents. Moreover, the idea behind the FL-strategy can be easily adapted to other double auction institution.

4. REFERENCES

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