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Keywords

Multi-agent systems, agent negotiation, partner selection, fuzzy logic

Disciplines

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A Fuzzy-Based Approach for Partner Selection in Multi-Agent Systems

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Abstract

Traditional negotiation approaches pay intensive attention to decision making models in order to reach the optimal agreements, while placing insufficient efforts on the problem of partner selection. In this paper, a fuzzy-based approach for partner selection in multi-agent systems is proposed. By employing both the fuzzy logic and the extended dual concern model, agents can adapt their individual behaviors for partner selection in negotiation. The proposed approach has three merits, which are: (1) both the agent's own benefit and its potential partners' benefits are considered for partner selection in negotiation; (2) by employing the extended dual concern model, agents' attitudes to its potential partners are considered for partner selection in negotiation; and (3) by employing the fuzzy logic, the proposed partner selection approach can be applied in open and dynamic environments easily and flexibly, and the selection results are much more accurate and reasonable.

Keywords: Multi-agent systems, agent negotiation, partner selection, fuzzy logic

1 Introduction

Traditional negotiation approaches in multi-agent systems (MASs), such as the game theory [4] [2] and the argumentation-based negotiation [6] [5], emphasize on the decision making models to determine the optimal coalition structure and the division of payoff, with a little devotion to the negotiation partner selection. In recent years, some researchers have recognized the importance of partner selection in agent negotiation and proposed several approaches for selecting suitable partners during agent negotiation. In [2], a significant model is introduced by Faratin et al., which defines a range of strategies and can be employed by computational agents to generate initial offers, evaluate proposals and offer counter proposals. With such a model, in each cycle of the negotiation, a comprehensive analysis is applied

to help agents find the optimal offers. Kraus further classifies negotiations into three categories, which are data allocation, resource allocation and task distribution, according to their application domains [3]. In each of these categories, complicated and heuristic methods are introduced to help agents find the optimal negotiation agreements under different situations. However, as the rapid development of autonomous agents and the Internet techniques, most work environments of MASs become uncertain and dynamic. How to select the most suitable partners from a huge potential partners in such an open and dynamic environment is promoted as an issue in front of researchers.

In order to address the issue mentioned above, this paper presents a fuzzy-based approach for partner selection in multi-agent systems based on the extended dual concern model. The proposed approach is used to identify different types of partners in different negotiation cases by taking consideration of both collaboration degrees between an agent and its potential partners, and the dynamic feature of agent behaviors in different negotiation cases. Agents can adapt their individual behaviors for partner selection in negotiation.

The remainder of this paper is organized as follows. In Section 2, an extended dual concern model is proposed, the partner selection problem is formally described, and potential partners in general negotiation in MASs are further classified and analyzed. In Section 3, the framework of this fuzzy-based approach is introduced. In Section 4, the principle of this fuzzy-based approach is introduced, which includes fuzzification, approximate reasoning, and defuzzification methods. In Section 5, several examples by employing this approach are demonstrated and evaluated. In Section 6, this paper is concluded and further work is outlined.

2 Potential Partners Analysis in General Negotiations

In [7], Zhang et al. proposed a dual concern model which gives an outline about the degrees of concern of an agent

Figure 1. The extended dual concern model

for its own and other's outcomes. However, this model just briefly presents the main trend of these degrees, without offering any calculation method about how to decide the values of these degrees and how to compare these degrees. To address these problems, we further extended this dual concern model to allow agents to make reasonable decisions on their behaviors during partner selection based on these degrees. The extended dual concern model is shown in Figure 1.

The x-axis indicates the percentage of the self-concern of an agent while the y-axis is the percentage of other-concern from the agent. θ presents a *ReliantDegree* (i.e. reflection of the collaborate degree), where $\theta \in [0^\circ, 90^\circ]$. We use *selfness* to represent the percentage of self-concern of an agent, which can be calculated by $\cos(\theta)$, and *selflessness* to represent the percentage of other-concern, which can be evaluated by $\sin(\theta)$. A *ReliantDegree* can illustrate the level of collaboration between the agent and its potential partners.

Suppose that there are n potential partners for an agent ID_x in a MAS. If we use a four-tuple p_i^x to present the i th potential partner of agent ID_x , p_i^x can be formally defined by the following equation

$$p_i^x = \langle ID_i, GainRatio_i^x, ContributionRatio_i^x, ReliantDegree_i^x \rangle \quad (1)$$

where ID_i is the unique identification of the i th potential partner, and $GainRatio_i^x$, $ContributionRatio_i^x$ and $ReliantDegree_i^x$ are factors used to evaluate the potential partner ID_i to be selected in the negotiation. These three factors are defined from Definitions 1 to 3, respectively.

Definition 1 *GainRatio_i^x* is the percentage of the benefit that agent ID_x obtains out of the global benefit upon the completion of the task. *GainRatio_i^x* can be calculated as $GainRatio_i^x = \frac{S}{L} \times 100\%$, $GainRatio_i^x \in [0, 100\%]$, where S denotes the benefit that agent ID_x gains by selecting agent ID_i as its partner, and L denotes the global benefit by completing the task.

Definition 2 *ContributionRatio_i^x* is the percentage of the benefit that agent ID_i obtains out of the global benefit upon the completion of the task. *ContributionRatio_i^x* can be calculated as $ContributionRatio_i^x = \frac{I}{L} \times 100\%$, $ContributionRatio_i^x \in [0, 100\%]$, where I denotes the benefit that agent ID_i gains by cooperating with agent ID_x , and L denotes the global benefit by completing the task.

Definition 3 *ReliantDegree_i^x* represents agent ID_x 's attitude to the negotiation, and also indicates the dynamic behavior of the agent, such as selfness, selflessness or other cases. *ReliantDegree_i^x* can be calculated as $ReliantDegree_i^x = \arctan(\frac{Cr_x^i}{Cr_i^x})$, $ReliantDegree \in [0^\circ, 90^\circ]$, where Cr_x^i indicates how much agent ID_x trusts agent ID_i , which can be defined as the trading success ratio from agent ID_x to ID_i or can be assigned by the system based on the performance record of agent ID_i , and Cr_i^x indicates how much agent ID_i trusts agent ID_x , which can be defined in the similar way as Cr_x^i .

Then agent ID_x 's evaluation on its potential partner ID_i is presented by *CollaborateDegree_i^x*, which is defined as follows:

$$CollaborateDegree_i^x = f(p_i^x) \quad (2)$$

where $CollaborateDegree_i^x \in [0, 1]$. It indicates the tendency that agent ID_i will be selected as a partner in subsequent negotiation by agent ID_x . The bigger the *CollaborateDegree_i^x*, the higher changes agent ID_i will be selected.

The purpose of this research is to find such a function $f(p_i^x)$ based on a fuzzy logic approach, which can help agents make reasonable decisions on partner selections.

3 Framework of A Fuzzy-Based Approach

A fuzzy-based partner selection approach is proposed in this section, by which agents can select their suitable partners dynamically in consideration of *GainRatio*, *ContributionRatio* and *ReliantDegree*.

The framework of this proposed approach is graphically illustrated in Figure 2. There are five units in the process, which are: (1) a library of fuzzy functions, (2) a fuzzy rule base, (3) a fuzzification module, (4) an approximate reasoning module, and (5) a defuzzification module.

The input parameters of the framework are *GainRatio*, *ContributionRatio* and *ReliantRatio* which have defined in Section 2. The output of this framework is *CollaborateDegree*, which provides a guideline to agent for partners selection. The methods of fuzzification, approximate reasoning, and defuzzification will be introduced in detail in next section.

Figure 2. The framework of the fuzzy-based approach

4 Principle of Fuzzy-Based Partner Selection

In this section, the principle of a fuzzy-based partner selection is proposed. The methods of fuzzification, approximate reasoning, and defuzzification are introduced in detail through subsection 4.1 to subsection 4.3.

4.1 Fuzzification

• *GainRatio*

For the input parameter *GainRatio*, five linguistic states are selected and expressed by appropriate fuzzy sets which are { *VerySmall*, *Small*, *Medium*, *Large*, *VeryLarge*}. Figure 3 depicts these fuzzy sets as applied to parameter *GainRatio*. The triangle membership function [1] is adopted here to define fuzzy memberships. Fuzzy membership functions for parameter *GainRatio* are defined from Equation 3 to 7, respectively.

$$F_{VerySmall}(x) = \begin{cases} \frac{20-x}{20} & 0 \leq x \leq 20 \\ 0 & x > 20 \end{cases} \quad (3)$$

$$F_{Small}(x) = \begin{cases} 0 & x \leq 10 \\ \frac{x-10}{20} & 10 < x \leq 30 \\ \frac{50-x}{20} & 30 < x \leq 50 \\ 0 & x > 50 \end{cases} \quad (4)$$

$$F_{Medium}(x) = \begin{cases} 0 & x \leq 30 \\ \frac{x-30}{20} & 30 < x \leq 50 \\ \frac{70-x}{20} & 50 < x \leq 70 \\ 0 & x > 70 \end{cases} \quad (5)$$

Figure 3. Fuzzy membership function for *GainRatio*

$$F_{Large}(x) = \begin{cases} 0 & x \leq 50 \\ \frac{x-50}{20} & 50 < x \leq 70 \\ \frac{90-x}{20} & 70 < x \leq 90 \\ 0 & x > 90 \end{cases} \quad (6)$$

$$F_{VeryLarge}(x) = \begin{cases} 0 & x \leq 80 \\ \frac{x-80}{20} & x > 80 \end{cases} \quad (7)$$

where $x \in [0, 100]$

• *ContributionRatio*

For the parameter *ContributionRatio*, both the fuzzy sets and membership functions are same as *GainRatio*'s (Equation 3-7).

• *ReliantDegree*

For the parameter *ReliantDegree*, five linguistic states are selected and expressed by appropriate fuzzy sets, which are { *Complete Self-Driven*, *Self-Driven*, *Equitable*, *External-Driven*, *Complete External-Driven*}. Figure 4 depicts these fuzzy sets as applied to parameter *ReliantDegree*. Fuzzy membership functions for parameter *ReliantDegree* are defined from Equation 8 to 12, respectively.

$$F_{CompleteSelfDriven}(x) = \begin{cases} \frac{22.5-x}{22.5} & 0 \leq x \leq 22.5 \\ 0 & x > 22.5 \end{cases} \quad (8)$$

$$F_{SelfDriven}(x) = \begin{cases} \frac{x}{22.5} & 0 < x \leq 22.5 \\ \frac{45-x}{22.5} & 22.5 < x \leq 45 \\ 0 & x > 45 \end{cases} \quad (9)$$

$$F_{Equitable}(x) = \begin{cases} 0 & x \leq 22.5 \\ \frac{x-22.5}{22.5} & 22.5 < x \leq 45 \\ \frac{67.5-x}{22.5} & 45 < x \leq 67.5 \\ 0 & x > 67.5 \end{cases} \quad (10)$$

Membership Value

Figure 4. Fuzzy membership function for *ReliantDegree*

<i>GainRatio</i>	<i>ContributionRatio</i>	<i>CollaborateDegree</i>
<i>VerySmall</i>	Any	<i>Averse</i>
<i>Small</i>	Any	<i>Reluctant</i>
<i>Medium</i>	Any	<i>Indifferent</i>
<i>Large</i>	Any	<i>Acceptable</i>
<i>VeryLarge</i>	Any	<i>Anticipant</i>

Table 1. Fuzzy rule base (*ReliantDegree*=*Complete Self-Driven*)

$$F_{ExternalDriven}(x) = \begin{cases} 0 & x \leq 45 \\ \frac{x-45}{22.5} & 45 < x \leq 67.5 \\ \frac{90-x}{22.5} & 67.5 < x \leq 90 \end{cases} \quad (11)$$

$$F_{CompleteExternalDriven}(x) = \begin{cases} 0 & x \leq 67.5 \\ \frac{x-67.5}{22.5} & x > 67.5 \end{cases} \quad (12)$$

where $x \in [0^\circ, 90^\circ]$.

For the output parameter *CollaborateDegree*, five linguistic states are selected and expressed by corresponding fuzzy sets {*Averse*, *Reluctant*, *Indifferent*, *Acceptable*, and *Anticipant*}. The fuzzy membership functions for parameter *CollaborateDegree* are same as *GainRatio*'s (Equation 3-7).

4.2 Approximate Reasoning

The approximate reasoning is hired to calculate output membership values, which can further be used to compute corresponding output values. The approximate reasoning is based on the use of rules in the rule base.

A rule base is a matrix of combinations of each of the input linguistic parameters. The rule base in this approach is displayed separately through Table 1 to 5, based on the five linguistic states of parameter *ReliantDegree*.

<i>GainRatio</i>	<i>ContributionRatio</i>	<i>CollaborateDegree</i>
<i>VerySmall</i>	<i>VeryLarge</i>	<i>Reluctant</i>
	<i>Others</i>	<i>Averse</i>
<i>Small</i>	<i>VeryLarge</i>	<i>Indifferent</i>
	<i>Others</i>	<i>Reluctant</i>
<i>Medium</i>	<i>VeryLarge</i>	<i>Acceptable</i>
	<i>Large</i>	<i>Acceptable</i>
	<i>Others</i>	<i>Indifferent</i>
<i>Large</i>	<i>VerySmall</i>	<i>Indifferent</i>
	<i>Others</i>	<i>Acceptable</i>
<i>VeryLarge</i>	<i>VerySmall</i>	<i>Acceptable</i>
	<i>Others</i>	<i>Anticipant</i>

Table 2. Fuzzy rule base (*ReliantDegree*=*Self-Driven*)

<i>GainRatio</i>	<i>ContributionRatio</i>	<i>CollaborateDegree</i>
<i>VerySmall</i>	<i>VeryLarge</i>	<i>Indifferent</i>
	<i>Large</i>	<i>Reluctant</i>
	<i>Medium</i>	<i>Averse</i>
	<i>Small</i>	<i>Averse</i>
	<i>VerySmall</i>	<i>Averse</i>
<i>Small</i>	<i>VeryLarge</i>	<i>Acceptable</i>
	<i>Large</i>	<i>Indifferent</i>
	<i>Medium</i>	<i>Reluctant</i>
	<i>Small</i>	<i>Averse</i>
	<i>VerySmall</i>	<i>Averse</i>
<i>Medium</i>	<i>VeryLarge</i>	<i>Anticipant</i>
	<i>Large</i>	<i>Acceptable</i>
	<i>Medium</i>	<i>Indifferent</i>
	<i>Small</i>	<i>Reluctant</i>
	<i>VerySmall</i>	<i>Averse</i>
<i>Large</i>	<i>VerySmall</i>	<i>Anticipant</i>
	<i>Large</i>	<i>Anticipant</i>
	<i>Medium</i>	<i>Acceptable</i>
	<i>Small</i>	<i>Indifferent</i>
	<i>VerySmall</i>	<i>Reluctant</i>
<i>VeryLarge</i>	<i>VerySmall</i>	<i>Anticipant</i>
	<i>Large</i>	<i>Anticipant</i>
	<i>Medium</i>	<i>Anticipant</i>
	<i>Small</i>	<i>Acceptable</i>
	<i>VerySmall</i>	<i>Indifferent</i>

Table 3. Fuzzy rule base (*ReliantDegree*=*Equitable*)

<i>ContributionRatio</i>	<i>GainRatio</i>	<i>CollaborateDegree</i>
<i>VerySmall</i>	<i>VeryLarge</i>	<i>Reluctant</i>
	<i>Others</i>	<i>Averse</i>
<i>Small</i>	<i>VeryLarge</i>	<i>Indifferent</i>
	<i>Others</i>	<i>Reluctant</i>
<i>Medium</i>	<i>VeryLarge</i>	<i>Acceptable</i>
	<i>Large</i>	<i>Acceptable</i>
	<i>Others</i>	<i>Indifferent</i>
<i>Large</i>	<i>VerySmall</i>	<i>Indifferent</i>
	<i>Others</i>	<i>Acceptable</i>
<i>VeryLarge</i>	<i>VerySmall</i>	<i>Acceptable</i>
	<i>Others</i>	<i>Anticipant</i>

Table 4. Fuzzy rule base (*ReliantDegree*=*External-Driven*)

<i>ContributionRatio</i>	<i>GainRatio</i>	<i>CollaborateDegree</i>
<i>VerySmall</i>	<i>Any</i>	<i>Averse</i>
<i>Small</i>	<i>Any</i>	<i>Reluctant</i>
<i>Medium</i>	<i>Any</i>	<i>Indifferent</i>
<i>Large</i>	<i>Any</i>	<i>Acceptable</i>
<i>VeryLarge</i>	<i>Any</i>	<i>Anticipant</i>

Table 5. Fuzzy rule base (*ReliantDegree*=*Complete External-Driven*)

Each entry of the rule base is a rule, which is defined by *AND*ing three linguistic input parameters to produce an individual output, in the form of:

$$\begin{aligned} \text{IF}((F(\text{GainRatio}) = \alpha) \text{AND} (F(\text{ContributionRatio}) = \beta) \\ \text{AND} (F(\text{ReliantDegree}) = \gamma)) \\ \text{THEN} F(\text{CollaborateDegree}) = \delta \end{aligned} \quad (13)$$

where, $\alpha, \beta \in \{\text{VerySmall}, \text{Small}, \text{Medium}, \text{Large}, \text{VeryLarge}\}$, $\gamma \in \{\text{Complete Self-Driven}, \text{Self-Driven}, \text{Equitable}, \text{External-Driven}, \text{Complete External-Driven}\}$, $\delta \in \{\text{Averse}, \text{Reluctant}, \text{Indifferent}, \text{Acceptable}, \text{Anticipant}\}$. $F(\text{CollaborateDegree})$ denotes a fuzzy set into which the parameter *CollaborateDegree* is mapped. The output membership value $\mu_\delta(\nu)$ is calculated as follows:

$$\mu_\delta(\nu) = \text{MIN}(\mu_\alpha(\text{GainRatio}), \mu_\beta(\text{ContributionRatio}), \mu_\gamma(\text{ReliantDegree})) \quad (14)$$

Agent	<i>GainRatio</i>	<i>ContributionRatio</i>	<i>ReliantDegree</i>
Example 1			
g_a	80%	20%	0°
g_b	50%	50%	0°
g_c	20%	80%	0°
Example 2			
g_a	80%	20%	0°
g_b	80%	20%	45°
g_c	80%	20%	90°

Table 6. Input parameters for two examples

4.3 Defuzzification

There are many defuzzification approaches. The centroid defuzzification method [1] is one approach to defuzzify the output membership values.

$$CD = \frac{\sum_{i=1}^k (\nu_i \times \mu(\nu_i))}{\sum_{i=1}^k \mu(\nu_i)} \quad (15)$$

where $\mu(\nu_i)$ is the i th output membership value, ν_i is its corresponding output value, and k is the number of fuzzy rules which are activated.

CD is the final output value of *CollaborateDegree* in a particular case. CD can be used to evaluate the relationship between the agent and its potential partners, and can also be used as an important factor for selecting or adopting a most suitable partner for an agent in a particular case.

5 Examples

In this session, two examples are demonstrated. In each example, agent g_x is going to select the most suitable partner from three potential partners (agent g_a , g_b and g_c). These examples illustrate the process of the proposed approach and the accuracy of its results. All input parameters for the three examples are shown in Table 5, and all output for the three examples are shown in Table 7.

In Example 1, all of three potential partners share a common *ReliantDegree*, which is 0° (see Table). The agent g_x is a *Complete Self-Driven* agent so that agent g_a should be selected as the most suitable partner because it can contribute the highest *GainRatio* (80%) to agent g_x among three potential partners. Moreover, according to the selection results generated by the proposed approach, agent g_a is the most suitable partner with the highest value (70%, see Table 7) after defuzzification, which is same as the estimation.

In Example 2, all of three potential partners share common *GainRatio* and *ContributionRatio*, but with different values of *ReliantDegree* (see Table 5). The agent g_x has different attitudes to its potential partners. For g_a , g_x performs

Agent	ReliantDegree	GainRatio	ContributionRatio	CollaborateDegree	Defuzzification
Example 1					
g_a	Complete Self-Driven=1	Large=0.5	Small=0.5	Acceptable=0.5	70%
g_b		Medium=1	Medium=1	Indifferent=1	50%
g_c		Small=0.5	Large=0.5	Reluctant=0.5	30%
Example 2					
g_a	Complete Self-Driven=1	Large=0.5	Small=0.5	Acceptable=0.5	70%
g_b	Equitable=1	Large=0.5	Small=0.5	Indifferent=0.5	50%
g_c	Complete External-Driven=1	Small=0.5	Large=0.5	Reluctant=0.5	30%

Table 7. Output results for three examples

as a *Complete Self-Driven* agent so that only the *GainRatio* (80%) will be used to select the most suitable partner. For g_b , g_x performs as a *Equitable* agent so that both *GainRatio* (80%) and *ContributionRatio* (20%) will be used to evaluate whether g_b could be chosen as a suitable partner. Thus, the final benefit by considering both *GainRatio* and *ContributionRatio* for g_b should be between 20% and 80%. For g_c , g_x performs as a *Complete External-Driven* agent so that only the benefit of *ContributionRatio* (20%) will be used for the selection of g_c as a partner. By comparing the three cases, g_a should be selected as the most suitable partner because g_x could gain the largest benefit (80%) when collaborating with g_a . Moreover, according selection results generated by the proposed approach, g_a is also selected as the most suitable partner because the *CollaborateDegree* for g_a is the largest among three potential partners, i.e 70% after defuzzification (see Table 7).

Therefore, from the two examples above, it can be seen that by considering the factors of *GainRatio*, *ContributionRatio* and *ReliantDegree* between the agent and its potential partners, partner selection mechanism can be generated dynamically in different cases. Agents are also allowed to adapt their individual behaviors in negotiation. The selection result is accurate and reasonable by comparing with the expectation results.

6 Conclusion and Future Works

In this paper, we have identified four potential cases of relationships between an agent and its potential partners. A framework of a fuzzy-based approach has been proposed which consists of a fuzzification module, a fuzzy rule base, an approximate reasoning module, a defuzzification module, and a library of fuzzy membership functions. All of the fuzzy membership functions for corresponding fuzzy sets have been carefully defined and rules of fuzzy logic operations during the procedure of approximate reasoning have also been defined.

Comparing with previous works, this research is novel in three aspects. First, we have identified four different potential cases. Second, throughout this research, we have learned that the fuzzy logic is a very good tool for selecting the most suitable partner for an agent. This approach not only offers a *CollaborateDegree* for any potential partners, but produces weights (membership values) for each situation in all possible cases. This information can help agent designers to design reasonable strategies for partners selection. Third, this approach can also be used to estimate the relationship between agent groups.

Further work intends to develop comprehensive fuzzy logic strategies for agents' relationship evaluation under the circumstance when (1) considering factors of punishment, compensation and successful ratio; and (2) considering negotiation with multiple attributes.

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