Abstract
Research in automated negotiation has traditionally been focusing on the negotiation protocol and strategy design, but little on the implementation related issues such as how to select the best negotiation strategy, especially for problems involving multi-strategy selection. The lack of such study has hampered the development in applying automated negotiation to real world problems. This research focuses on operationalizing agent’s independent decision-making process through the design of a negotiation decision-making model and the software architecture, based on an abstract architecture model that can support both goal-directed reasoning and reactive response. We formally define the automated negotiation agent’s abstract architecture model and propose an algorithm for the architecture and the decision-making model. Grounded on the theory of Belief-Desire-Intention, the model can support the agent’s multi-strategy negotiation. A prototype of the model is built and applied to an aircraft purchase negotiation process to demonstrate the effectiveness of our model.

1. Introduction
The role of e-commerce has not only been to provide a trading place and a communication channel for the buyers and the sellers, but also changed from a simple matchmaker to a price coordinator. The tremendous success of the online auction market suggests that the dynamic trade based on e-negotiation has gradually become the mainstream of e-commerce [1][2].

Automated negotiation is an active area of research in e-negotiation in general and artificial intelligence in particular. Automated negotiation systems composed of computational agents from different individuals or organizations that are capable of reaching agreement through negotiation is becoming more and more important and pervasive. E-commerce oriented negotiation is increasingly assuming a pivotal role in many organizations and a number of prominent automated negotiation models have been proposed over the past decade [3].

Jennings et al. [4] considered that automated negotiation research can include three broad topics: the negotiation protocols, the negotiation strategies, and the agent’s decision-making models. The decision-making model is also called the reasoning model whose function is to determine: which potential agent should be contacted; whether the negotiation should proceed in parallel with all agents or run sequentially; what initial offers should be sent out; what the range of acceptable agreements is; what counter offers should be generated; when the negotiation should be abandoned; and when an agreement is reached [5].

Negotiation Protocol is the set of rules that governs the interactions. It covers the permissible types of participants, the negotiation states (e.g., accepting proposals), the events that cause the negotiation states to change (e.g., proposal accepted), and the valid actions of the participants in the particular states (e.g., which messages can be sent by whom, to whom, and at what stage) [4]. While the protocol restricts the possible actions to perform, it often does not specify any particular action. Rather, it marks the branching points at which every agent has to make decisions according to its strategy [3].

Negotiation strategies refer to the patterns or plans to accomplish the goals of the parties. The negotiation strategy accounts for the decisions of each agent. It can reflect a variety of behaviors and lead to strikingly different outcomes. The following three fundamental groups of strategies are commonly used by human negotiators: contending, concession making, and problem solving. Most negotiation situations call forth a combination, often in sequence, of strategies from different groups. Rarely is a strategy of one group used to the exclusion of the strategies of the other groups [3].

Research in automated negotiation to date has been focusing on the development of the negotiation protocols and strategies [6]. Most researchers have developed models that include specific protocols (notably, the alternating offers protocol) and libraries of negotiation strategies (notably, the concession and...
problem solving strategies). They have investigated the behaviors of these strategies to determine the most effective strategies in various negotiation situations. Although there are many research achievements concerning protocols and strategies in the field of automated negotiation, there are many implementation related issues yet to be resolved [7].

The selection of an appropriate initial strategy is a critical step in preparing for negotiation. Effective negotiators often make a conscious analysis of the negotiation situation and the opposing parties, and actively prepare initial strategies that match their judgment. They also update their judgment as negotiation unfolds—information received during the negotiation frequently causes them to adjust their perception of the negotiation situation and the other parties [3]. Hence, effective negotiators may move back and forth among different strategies in discernible patterns [8]. Despite the importance of strategy selection in automated negotiation, existing AI research has ignored many issues related to strategic choices [3] hence has hindered the development of the real-world applications of the system [7].

The main objective of this research is to construct a generic decision-making model based on the BDI agent architecture which can support multi-strategy selection during the automated negotiation. The remainder of this paper is organized as follows. Section 2 reviews related works on the negotiation agent architecture and explains the basic concepts for constructing a negotiation agent’s decision-making model based on the BDI theory. Section 3 includes the explanation of the agent’s practical negotiation reasoning process, the introduction of BDI negotiation agent properties, the description of the agent’s negotiation decision process. Section 4 presents the negotiation agent’s software architecture. Section 5 proposes a negotiation reasoning algorithm for the decision-making model, and Section 6 illustrates an exemplified negotiation process through an aircraft purchasing case. The paper is concluded in Section 7 with summary of findings and suggestion for future research directions.

2. Related Work on Negotiation Agent Architecture

Research in negotiation agent architecture studies both the technology and the method needed to improve the way information is gathered, managed, distributed, and utilized by decision-makers in key business functions and operations.

Generic Agent Model (GAM) is a universal model for agent architecture, proposed by Brazier et al. Its aim is to provide a unified formal definition of a model for weak agent hood. It can be reused as a template or pattern for a large variety of agent types and application domain types [11]. GAM has been later refined to obtain a formal design description of the BDI agent. More precisely, the beliefs on the environment (the world and the other agents) are preserved by the maintenance of the world information and the agent information components while the desires and intentions are represented through a refinement of the Own Process Control component.

Huang and Liang [9] designed an Intelligent Negotiation Agent Architecture which includes Negotiator, Manager, Searcher, and Agent Interface. The Negotiator optimizes the product utility based on customers’ requirements and constraints. The Manager delivers the status messages of active services between the Negotiator and the clients, an agent and its agency, and between the peer agents. The Searcher searches the products located in other distributed databases and performs the role of managing, querying, or collating product information from many distributed sources. The Agent Interface communicates between the customer and the other agents. The architecture can be considered as a multi-agent system that includes several functional agents. All the agents work together to perform autonomous negotiation. This represents a type of method to design the negotiation system based on agent theory.

Another way to start the implementation of the negotiation agent architecture is to construct an agent body responsible for managing the agent’s activities and interacting with the peers and other agencies. The body should contain several functional components each responsible for one of its main activities. A representative work is by Jonker et al. [10] who designed a generic agent architecture for multi-attribute negotiation, and formally defined it using DESIRE, a refinement of GAM. The architecture includes components such as Own Process Control, World Interaction Management, Agent Interaction Management, Maintenance of World Information, Maintenance of Agent Information, Cooperation Management, and Agent Specific Task. The negotiation model has been defined as a compositional structure within the component cooperation management of GAM.

However, universal agent architecture model cannot support special application demand required by the various agent applications. For example, Jonker’s work
cannot support dynamic strategy selection during the agent’s negotiation decision process.

Most previous research has neglected the important pre-negotiation step of selecting appropriate strategies for the specific negotiation situations; also most studies have treated strategies as rigid or static elements of negotiation, i.e., elements that do not change during the negotiation. There have been few attempts to develop models that incorporate effective approaches to dynamically choose strategies; moreover, most models do not support the selection of new strategies as the negotiation unfolds [3]. However, the work of Nguyen and Jennings presented an exception.

Nguyen and Jennings [12] [13] proposed a model that handles one-to-many negotiation in a service-oriented context. A particular negotiation situation where an agent (representing the buyer) wishes to purchase a service engages in multiple concurrent bilateral negotiations with a set of agents (representing the sellers) that are capable of providing such service. The main components of the buyer agent includes a coordinator, a number of negotiation threads (one per seller), and a commitment manager. The coordinator decides the negotiation strategy for each thread using a probability distribution based on the types of sellers, the percentage of success matrix, and the payoff matrix. The sellers can be of two types: conceder (concede in the search for deals) or non-conceder (adopt tough stance). The percentage of success matrix measures the chances of having an agreement as the outcome of the negotiation when the buyer applies a particular strategy to negotiate with a specific type of seller. The payoff matrix measures the average utility value of the agreement reached in similar situations. For each thread, the coordinator calculates the expected utility of applying different strategies to negotiate with a particular seller and selects the strategy that maximizes the expected utility.

Nevertheless, there are two shortcomings in Nguyen’s work. First of all, the negotiation agent’s architecture, which includes a coordinator, the negotiation threads, and a commitment manager, is designed based on the buyer’s view point. There is no guideline provided regarding the construction of the architecture for sellers. As a result, the architecture lacks generalizability. Secondly, the architecture lacks the corresponding functional components required in the generic agent model defined in Brazier [11], such as the World Interaction Management, the Agent Interaction Management, the Maintenance of World Information, and the Maintenance of Agent Information. The model also does not support the communication between the negotiation agents and the environment.

Researchers are aware that in order to enhance the realism of rational bargaining behavior in Multi Agent System (MAS), it is pertinent to develop a more human-like model. Adding personality to the intelligent agents makes them more human-like, in the mean time increases their flexibility [14]. The well-known Belief-Desire-Intention (BDI) theory has presented itself as the perfect candidate to help constructing a more human-like agent model. Belief, desire, and intention all come from the real mental states of the human beings, and can truly reflect the human’s thinking behavior in the decision-making process.

In this study, we extend the BDI model to construct an automated negotiation system that supports multi-strategy selection. Another advantage of adopting BDI is owing to the maturity of the theory and the availability of the software development kits and platforms to implement the BDI agent architecture, such as JACK and JADEX.

3. Reasoning Style of the Negotiation Agent Based on Intentional Stance

3.1 Practical Reasoning of the Negotiation Agent

Through observing the human beings’ negotiation behavior, we can identify two stages of the decision-making process: the deliberation process and the means-ends reasoning. In order words, stage one establishes a negotiation goal based on the agent’s own knowledge and the current state of the negotiation, and stage two performs the appropriate negotiation actions to achieve the goal. The negotiation action, also called negotiation Speech Act, is an expression that can be accepted by both parties. If everything goes smoothly, implementing the speech act can help the agent to achieve the negotiation goal.

Since the negotiation behavior of the agent is neither a pure responsive, nor a pure reasoning process like theorem proving, the integration of the two stages is also known as Practical Reasoning [15].

3.2 BDI Properties of the Negotiation Agent

Though the concept of practical reasoning is easy to understand, it does not provide guidance to operationalize the negotiation agent. In this research, we use intentional stance to interpret and analyze the practical reasoning process of the negotiation agent. Intentional stance means the negotiation agent is an intentional system composed of three cognitive
components; Belief, Negotiation Desire, and Negotiation Intention. These components make up of the negotiation agent’s inner data structure, and can be used to define the agent’s negotiation state. Every component has its specific function to support the agent’s negotiation process autonomously. The three cognitive components interact with each other, and allow the agent to negotiate autonomously and freely.

Belief is the negotiation agent’s understanding and cognition of the negotiation environment. It is the foundation for the agent’s negotiation decision-making. It can also be understood as the negotiation agent’s knowledge. These knowledge updates dynamically during the agent’s negotiation decision-making process.

Negotiation desire is an agent’s preliminary judgment and decision on the current negotiation circumstances and is constructed on the basis of the agent’s Belief. It represents the possible negotiation goals that the agent tries to achieve and the agent makes its choices between those possible goals based on certain constraints. The negotiation desire has the following properties:

First of all, the negotiation desires maybe conflicting with each other. In other words, the negotiation agent may consider conflicting negotiation desires concurrently against the current negotiation circumstances. For example, a negotiation agent may consider two contradicting strategies at the same time: Strategy 1 is to accept the opposing party’s proposal while strategy 2 is to reject the proposal and quit the negotiation. These two clearly conflicting desires reflect the negotiator’s dilemma at the negotiation decision point.

Secondly, negotiation desire lacks continuity. That means the negotiation agent may terminate or give up its existing negotiation desire at any time. Using the above example, if the agent decides to reject the opposing party’s proposal, it must give up the previously accepted desires.

Thirdly, negotiation desire cannot directly lead to negotiation action. As mentioned above, the negotiation agent may consider conflicting negotiation desires concurrently and may terminate or give up the existing negotiation desire at any time. If the negotiation desire can directly lead to negotiation action, the negotiation activity will be confused. As a result, we need other conditions to trigger the agent to implement the speech act for the corresponding negotiation desire. That is negotiation intention.

Negotiation intention is a properly selected desire from the existing set of negotiation desires in the current negotiation situation. Selectivity is an essential aspect of negotiation intention. In fact, the selected negotiation desire becomes the negotiation intention. We also call this process commitment, which means the negotiation agent will continuously sustain its negotiation intention until it is fulfilled. Negotiation intention can affect and constrain the execution of the agent’s negotiation behavior and decision-making, and lead to the agent’s negotiation speech act.

Second, negotiation intention is attainable. The negotiation agent must guarantee in advance that the negotiation intention is possible before it can be established. The selection of a negotiation intention indicates that the agent must have corresponding negotiation speech act to accomplish the intention.

Third, negotiation intentions are consistent with each other. An agent cannot have negotiation intentions both \( \varphi \) and \( \neg \varphi \) at the same time. Different from the negotiation desire, the negotiation agent cannot intend to both “accept” the opposing party’s proposal and “reject” the proposal at the same time.
3.3 Decision Process of the Negotiation Agent

From the analysis above, we can see that belief, negotiation desire, and negotiation intention are three crucial components for making negotiation decision, and the speech act is used to implement the decision. In order to clearly explain the relationship among the four parts, we illustrate the relationship in Figure 1, which shows one snippet of the whole negotiation circle, and describes how the negotiation agent carries out practical reasoning.

4. The Negotiation Agent’s Software Architecture

The Negotiation Agent Architecture (NAA) is designed for describing internal structure of the negotiation agent. The theoretical foundation of the architecture comes from the negotiation agent’s abstract architecture model defined above.

Autonomous negotiation is the basic capability of a negotiation agent. As a result, we demand the negotiation agent to be able to run without any intervention and guidance from the outer environment, and can make negotiation decisions according to its inner state and the input from the outer environment. The decision process is based on the negotiation agent’s belief and the means-ends reasoning mechanism. Thus, the software developer can simply inform the agent what need to be negotiated but not how.

Recent work in agent theory has classified the agent architecture into reactive system, real-time reasoning system, and hybrid system [16]. The hybrid agent has features in common with both the reactive agent and the real-time reasoning agent. The NAA is a type of hybrid agent architecture (see Figure 2) that consists of features from both the BDI deliberative agent, using practical reasoning, and the reactive agent, controlled by reactive behavior.

Belief Base is a container for the agent’s current beliefs, which realizes the set of beliefs in the negotiation agent’s abstract architecture model. Typically, beliefs include facts about static properties of the negotiation application domain, and facts acquired when the agent executes its reasoning function. The knowledge contained in the belief base is represented in first-order predicate calculus. The belief base contains four kinds of beliefs. They are the static beliefs, the initial beliefs set by the users, the beliefs triggered by interaction, and the run time beliefs.

Static beliefs: contains the negotiation strategy and the decision model, which have been established when a negotiation agent is initiated. The negotiation strategy and the decision model is the knowledge about how to accomplish the initial negotiation goals or to react to certain bids from other agents. They are presented by declarative procedure specifications. Each specification consists of a body, which describes the algorithm of the strategy and the decision model, and a condition that specifies under what situations the strategy and the model can be applicable. The condition and the body
together express the declarative fact about the results and the utility of performing certain negotiation strategies and decision model under certain conditions.

Initial beliefs set by the users: typically are conclusions and basic description about the current negotiation, usually set by the users when a negotiation agent is instantiated.

Beliefs triggered by interaction: is received from the environment or other negotiation agent during the negotiation process.

Run time beliefs: the records beliefs acquired when the agent executes its reasoning function. The run time beliefs may change over time.

We prescribe the belief knowledge to be expressed as a triplet \((object, attributes, value)\). For example, the price of a computer is \$1,000, and it can be expressed as \((\text{computer}, \text{price}, 1,000)\).

Desire Base stores the negotiation desire; it implements the set of desires in the abstract architecture model.

Intention structure implements the set of intentions in the abstract architecture model. It is a data structure organizing all the desires the agent has chosen for execution, either immediately or at a later time. These adopted desires are called intentions. The set of intentions comprising the intention structure form a partial ordering. The intentions appear earlier in the ordering must be either realized or dropped (and thus disappeared from the intention structure) before the intentions appearing later in the ordering can be executed.

Reasoner runs the entire system. It performs the listen, choose, filter, and plan functions in the abstract architecture model. From a conceptual standpoint, it operates in a relatively simple way. At any particular point in time, when there are beliefs held in the belief base, a subset of the strategies in the system will be invoked, desires are produced in the system, and selected desires will be placed on the intention structure. Finally, one or more speech acts will be chosen for execution.

Speech-Act Planner is a language generator, which performs the say function in the abstract architecture model. The function is to select the appropriate speech acts to express the negotiation intention generated during the deliberation process. The agent must select what it should say based on the relevance of the speech-act’s expected outcome or the rational effect of its intentions. Speech-Act Planner can select appropriate speech acts and form the Agent Communication Language (ACL) messages according to the prospective rational effect of a certain intention. In other words, with the aid of the speech-act planner, the communicator creates something to say.

Communicator is in charge of the agent’s interaction with the environment, including other agents. It implements the say function in the abstract architecture model. The communicator’s function is using the selected speech acts to form the grammar conformed agent communication language and send the message to other negotiation agents. In the meanwhile, it is also in charge of receiving the negotiation message and parsing the ACL from other agents. Finally, it sends the ACL messages back to the environment. The Speech-Act Planner and the Communicator together construct the interaction mechanism between the negotiation agent and the outer environment.

Reactive Filter performs the react function in the abstract architecture model. The purpose of the filter is to provide the agent with fast, reactive capabilities for coping with events that are unnecessary or difficult for the reasoning mechanism to process. A typical event would be a wrong ACL message received by the communicator. Wrong messages can only bring instability to the system if they are processed by the reasoner. Whenas the Reactive Filter can make rapid reactive treatment to the exceptional messages. The reactive filter provides the agent with a series of situation-reaction rules to handle wrong messages, and other unpredictable situations. When a given rule is activated, an appropriate action is sent to the agent’s communicator, which in turn quickly sends a responsive ACL message directly to the environment. Therefore, this mechanism guarantees a certain degree of reactivity. The Reactive Filter supports the negotiation agent the characteristic of reactive artificial intelligence to some extent.

5. THE NEGOTIATION REASONING ALGORITHM

The proposed negotiation agent architecture contains a reasoning algorithm that controls and coordinates the reasoning between the negotiation belief, desire, and intention. The reasoning algorithm is described as follows

Step 1: Initialize the belief base \(B\), the negotiation desire base \(D\), and the negotiation intention structure \(I\)

Step 2: The negotiation agent monitors changes in the status of the negotiation (such as receiving bargaining information sent by other agents), and adds the informed events in the interactively triggered belief base \(B_T\).

Step 3: Update belief base \(B\) using the current interactively triggered belief \(B_T\) and the run-time belief
Step 4: Apply varieties of the negotiation strategies to generate negotiation options, all options will be submitted to the desire base \( D \) to generate a new negotiation desire. That is, every option is a negotiation desire.

Step 5: Combine with a utility model to calculate the utility of all current options in the desire base; according to rule NR2, select the option which has the largest utility to be the current intention of this round of negotiation. Submit it to the intention structure \( I \), where \( I \) is a queue.

Step 6: Determine whether the conditions for implementing the current intention exist. If they do not (such as a network interruption), then withdraw the intention from the circulation and clear the intention queue; if they do, then implement the first intention in the queue.

Step 7: Carry out Speech Act planning; select the appropriate speech act verb to express the content of the negotiation intention, and complete the interaction with the other agent.

Step 8: According to the reasoning rules NR3 and NR4, the data of the negotiation desire and intention generated in the current round of negotiation are stored into the agent’s belief base. This step updates the \( B_D \) (runtime belief about the desire) and \( B_I \) (runtime belief about the intention). Go back to Step 1.

We can see from the above description that the desire base plays a unique role in the agent’s negotiation reasoning process. In fact, it is a temporary mechanism for data storage, similar to the run-time memory, because the system doesn’t retain the desire data’s persistent state. Its main task is to choose the appropriate negotiation intentions. Therefore, it is a logic link between the negotiation agent’s rational reasoning and the decision-making processes.

Moreover, in the proposed system the negotiation agent uses negotiation strategy in a different way. In general, the usual negotiation systems, such as Kasbah [21], pre-define negotiation strategies which can be implemented by agents. We believe this would constrain the agent from obtaining the maximum reward. In the proposed system, we give agents autonomous ability to choose the most appropriate negotiation strategy to implement according to the current negotiation situation. It allows the agent to take full advantage of the high speed computing capability of today’s computer, and identifies the strategy that renders the maximum utility through an exhaustive search.

The proposed negotiation reasoning algorithm is based on the BDI reasoning principles. The principles complied with the BDI-U logic has been proposed and validated in our former work [17], whose main function is to provide a theoretical basis for implementing the negotiation agent and the multi-agent system.

6. A CASE STUDY

The simplest negotiation model is a bilateral negotiation with a single attribute. However in most cases, the negotiators have to process several attributes of the product at the same time. The following case is a bilateral negotiation with multi-attributes based on an example of the INSPIRE system (InterNeg Support Program for Intercultural REsearch) developed by InterNeg Research Center, Concordia University [18]. We have modified the example to illustrate the implementation process of our system. The core content of the case is described as follows:

A simple negotiation has been set up with the objective of securing a contract between two companies, Rosa Inc. and Casa Ltd. Rosa wants to sell an aircraft which Casa is considering purchasing. Two agents, Seller and Buyer, negotiate for Rosa and Casa, respectively. Both Seller and Buyer have carefully read the information about their respective organizations to understand the problem and their issues. There are only two issues in this simplified negotiation: the price of the aircraft and the terms of the warranty. It has been established that the normal price of this aircraft is in the range of $300 000 to $320 000. Thus, the price options are between $300 000 and $320 000. In this industry there are typically four types of warranty available. The options are: no warranty, a 6 month, a one year, and a 2 year warranty. Both negotiators analyze the two issues and their associated options in terms of their relevance to their respective organizations, and then move on to the pre-negotiation phase.

6.1 Preparation

In the real business negotiations, the issues are always determined in advance, including quantity, price, delivery time, etc. The negotiating parties have different preferences regarding the issues.

A utility function is used to measure the value of each proposal and is given below

\[
  u_i = \sum_{j=1}^{n} w_j y_j(x_j)
\]

Where \( i \in (1,...,m) \) represents the negotiation proposal, \( j \in (1,...,n) \) represents the issues under negotiation, \( w_j \) is the weight of issue \( j \), \( x_j \in [x_j^{\text{min}}, x_j^{\text{max}}] \) is a value for issue \( j \) to be acceptable by
agent $i$. $x_{j_{\text{max}}}^i$ and $x_{j_{\text{min}}}^i$ are the maximum and minimum values of issue $x_j$.

$y_i(x_j)$ is the pre-processing function for the negotiation attributes, called the “scoring function” in Faratin [19]. It gives the score agent $i$ assigns to issue $j$ in the range of its acceptable values. For convenience, we kept the value of the score in the interval $[0, 1]$.

If attribute $j$ of proposal $i$ is benefit related, then

$$y_i(x_j) = \frac{x_j - x_{j_{\text{min}}}^i}{x_{j_{\text{max}}}^i - x_{j_{\text{min}}}^i}$$

If attribute $j$ of proposal $i$ is cost related, then

$$y_i(x_j) = \frac{x_{j_{\text{max}}}^i - x_j}{x_{j_{\text{max}}}^i - x_{j_{\text{min}}}^i}$$

The value of $u_i$ indicates the utility of the offer or counteroffer. In this study, it is assumed that the agents are rational agents who seek to maximize self-interest. Then, in most circumstances, it would choose the offer or counteroffer with the largest utility.

6.2 The Negotiation Strategy

In the negotiation preparation stage, we need to prepare optional strategies in advance. Lopes et al. have summarized three fundamental groups of strategies commonly used by human negotiators [3]. They are contending (also called competing or dominating), concession making (also called yielding, accommodating, or obliging), and problem solving (also called collaborating or integrating), where the concession making strategy is widely used in commercial negotiation. Negotiators always reduce their aspirations partially or totally to accommodate the opposing negotiators; they work toward compromising agreements; such agreements are achieved when the parties concede to a middle ground [20].

Since negotiation strategy is not our research focus, we applied the classic negotiation strategy based on Faratin et al.’s work [19]. The proposed negotiation agent’s architecture and the BDI reasoning process model are general enough to handle different negotiation strategies and decision models.

Faratin et al. [19] presented a model for a bilateral service-oriented negotiation that defines a range of strategies (functions that map a matrix of real numbers ranging from zero to one into another similar matrix) and three groups of concession tactics: time dependent (functions of time), resource dependent (functions of limited resources), and behavior dependent or imitative (functions of the opponent’s behavior).

Time dependent tactics model the fact that the agent is likely to concede more rapidly as the deadline approaches, if an agent has a deadline by which an agreement must be in place.

Resource dependent tactics model the pressure in reaching an agreement that the limited resources (e.g. remaining bandwidth to be allocated) and the environment (e.g. number of clients, number of servers, or economic parameters) imposed upon the agent’s behavior. The functions in this tactic are similar to that of the time dependent tactic except that the domain is the quantity of resources available other than time.

Behavior dependent or imitative tactic: In situations where the agent is not under pressure to reach an agreement, it may choose to use imitative tactic to protect itself from being exploited by other agents. In this case, the counter-offer depends on the behavior of the negotiation opponent. The tactics in this family differ in accordance with the aspect of their opponent’s behavior they imitate, and to the degree the opponent’s behavior is imitated.

In our system, we use the time dependent tactic (S1) and the behavior dependent tactic (S2) to test the negotiation decision process based on the BDI model.

6.3 The Negotiation Process

Since each negotiator can access the system and make a proposal independently, we will follow Seller's side of the negotiation.

Let us assume that Buyer’s first bid is $300,000 and 24 months of warranty and can be represented by the value pair (30, 24). Seller receives this information, adds it to the interactively triggered belief base, and then gives its initial bid of $320,000 and 6 months of warranty (32, 6). Both proposals were generated by the strategies that offer the greatest utilities based on the initial states.

During the second round of bidding, when Buyer receives Seller’s proposal, it proposes a counteroffer to Seller. Seller then calculates the utilities of all negotiation strategies available in its belief base (i.e. S1 and S2) and adds the results to its desire base.

At this time, Seller’s desire base contains two sets of negotiation desires: (31.7, 12) and (31.5, 12). Based on rule NR2, the option with the highest utility, option 1, is selected as the new negotiation intention, and is added to the queue for processing. According to the reasoning rules R3 and R4, the above negotiation desire and intention data are subsequently stored in the run-time belief base as historical data, which can be used as system log for providing explanation to the user. The course runs repeatedly until the two agents reach an agreement.
At the end of the negotiation process, as expressed in Table 4, the utility of Buyer’s proposal (31, 12) for Seller is 0.5, which is higher than the utilities of the two proposals ((30.5, 12) and (31.2, 18)) made by Seller. Therefore, as a rational agent, Seller logically ACCEPT Buyer's proposal to terminate the negotiation.

During the process of the negotiation, we can see that Seller does not randomly choose a strategy, but select the one that generates the best result. That demonstrates the negotiation agent’s ability of autonomous decision-making based on multi-strategy selection. Moreover, it also prevents other agents from grasping its bidding strategy, thereby enhancing the concealment of decision-making.

The internal states of the negotiation agent change constantly during the process of negotiation,

7. Conclusions and future research directions

In this study, we present an explicit and formal specification of the negotiation agent architecture model for building the negotiation agents in an e-commerce environment. The novelty of the model is its synthesized work in both agent architecture and automated negotiation theory. From the viewpoint of agent architecture, the proposed architecture has a solid foundation grounded on the BDI theory, and allows it to support both practical reasoning and reactive response. The proposed architecture can be easily implemented using existing software agent technology. From the automated negotiation theory viewpoint, the negotiation decision-making model proposed can support dynamic selection of the negotiation strategies during the negotiation process. We believe the proposed model can fill the gap between the theory development and the actual implementation of the negotiation support model. More importantly, the proposed software architecture model helps to build the foundation for developing an automated negotiation system. However, there are a number of issues need to be further investigated. For example, we have not considered the effects of different negotiation strategies and negotiation protocols on the negotiation agent architecture and the decision-making model. In order to achieve this goal, a computational test bed is needed. So far, we have developed an experimental platform based on a BDI theory complied agent software development kit, JADEX. We plan to focus on constructing the experimental platform and perform different experiments to answer the following two questions in our future research. First is whether the negotiation architecture and decision-making model can be smoothly integrated with different negotiation protocols and strategies. Second is whether the multi-strategy selection agent can do better than the agent with single negotiation strategy in same negotiation scene.

Acknowledgements

This work is supported by grants 70902042 of the National Natural Science Foundation of China.

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