Journal of Universal Computer Science, vol. 18, no. 10 (2012), 1379-1404
submitted: 1/9/11, accepted: 24/5/12, appeared: 28/5/12 © *J.UCS*

BDI Agent Architecture for Multi-Strategy Selection in Automated Negotiation

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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 strategy selection is very important for agent to take risk to achieve better negotiation outcomes. The lack of such study has hampered the development in applying automated negotiation to real world problems. This research focuses on operationalizing risk taking 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.

Keywords: Automated negotiation, negotiation agent, multi-agent system, belief-desire-intention model, agent architecture, risk taking
Categories: I.2.11, K.4.4

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 [Gregory, 2007] [Lomuscio, 2003].

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 [Femando, 2008].

Jennings et al. [Jennings, 2001] 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 [Faratin, 1998].

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) [Jennings, 2001]. 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 [Femando, 2008].

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 [Femando, 2008].

Research in automated negotiation to date has been focusing on the development of the negotiation protocols and strategies [Tamma, 2002]. 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 [Lin, 2008].

Larrick et al. [Richard, 2009] proposed that specific, challenging goals can make people more willing to take risks in both negotiation and decision making tasks. Risk taking negotiators incline to try different strategies other than one strategy to get a better negotiation outcome. A basic assumption in goal-setting theory [Richard, 2009] is that, as people face a goal, they search through established strategies. If an existing strategy is available that will reach the goal, they will select it. If not, they will try to generate new strategies and experiment with different strategies to make progress [March, 1958] [Wood, 1990]. Research on goal setting has found challenging goals lead decision makers to experiment more and to be less consistent in applying a strategy (e.g., [Bandura, 1989] [Earley, 1989]). The Prospect Theory value function [Kahneman, 1979] [Tversky, 1992] predicts that people will risk lower outcomes to try for higher outcomes. Given this valuation of outcomes, experimentation is more valuable than sure-fire strategies that fall short of a goal, and people will risk some dead ends and false starts to reach a goal. The value function also predicts that people are exceptionally conservative when they have a strategy that will reach their goal and risk seeking when they do not [Richard, 2009]. In automated negotiation, people entrust the software agent to negotiate automatically on line, and normally hope the agent can try different strategies to get a better negotiation outcome. People will make the final decision for accepting the negotiation result returned by the agent or not. Even if the negotiation risks a dead end, it does not matter, we can start another negotiation. As a result, the negotiation agent discussed in this work is basically risk taking agent.

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 [Femando, 2008]. Hence, effective negotiators may move back and forth among different strategies in discernible patterns [Putnam, 1990]. Despite the importance of strategy selection in automated negotiation, existing AI research has ignored many issues related to strategic choices [Femando, 2008] hence has hindered the development of the real-world applications of the system [Lin, 2008].

The theory of Practical Reasoning [Bratman, 1998] has been used to construct the agent's theoretical model [Rao and Georgeff 1995]; it can also be extended to support the multi-strategy selection in automated negotiation. Through observing the human beings' decision making behaviour, the theory of practical reasoning identifies two stages of the decision-making process: the deliberation process and the means-ends reasoning. The deliberation process establishes a goal based on the agent's own knowledge, and the means-ends reasoning process performs the appropriate actions to achieve the goal. In negotiation, the action agent performs is called Speech Act, which is first proposed by [Austin, 1962], and 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. The intentional stance can interpret and analyse the practical reasoning process. Intentional stance means the agent is an intentional system composed of three cognitive components; Belief, Desire, and Intention [Bratman, 1987]. These components make up of the agent's inner data structure, and can be used to define the agent's mental state. The three cognitive components interact with each other, and allow the agent to act autonomously and freely.

The main objective of this research is to construct a generic decision-making model based on the BDI agent architecture, which can support risk taking agent's 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, and the negotiation speech act and negotiation communication. Section 4 proposes a conceptual model for the negotiation agent that can also be regarded as the abstract agent architecture, and Section 5 presents the negotiation agent's software architecture. Section 6 proposes a negotiation reasoning algorithm for the decision-making model, whose theoretical background is discussed in section 7. Section 8 illustrates an exemplified negotiation process through an aircraft purchasing case. The paper is concluded in Section 9 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 [Brazier, 2000]. 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 [Huang, 2010] 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. [Catholijn, 2007] who designed 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 [Catholijn, 2007] 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 chosen strategies; moreover, most models do not support the selection of new strategies as the negotiation unfolds [Femando, 2008]. However, the work of Nguyen and Jennings presented an exception.

Nguyen and Jennings [Thuc, 2004] [Thuc, 2005] 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 [Brazier, 2000], 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 [Faria, 2009]. 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 [AOS, 2011] and JADEX [DSISG, 2011].

3 Reasoning Style of the Negotiation Agent Based on Intentional Stance

Since the negotiation behavior of the agent is neither a pure responsive, nor a pure reasoning process like theorem proving, the agent's negotiation reasoning process is in fact a practical reasoning process.

3.1 BDI Properties of the Negotiation Agent

Though the concept of practical reasoning is easy to understand as explained in section 1, it does not provide guidance to operationalize the negotiation agent. In this research, we use intentional stance (Belief, Negotiation Desire, and Negotiation Intention) to interpret and analyze the practical reasoning process of the negotiation agent.

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. The negotiation intention possesses the following characteristics:

First, negotiation intention is durative. In order words, the negotiation agent doesn't give up the determined negotiation intention easily. This embodies the characteristic of commitment, which means if an agent possesses a negotiation intention it will sustain the intention in the changing negotiation environment until it is accomplished, or the condition for realizing the intention does not exist yet. For example, when an agent produces a negotiation intention "accept", it will sustain the intention until a responding negotiation speech act is delivered to the opposing party. Subsequently, the negotiation intention is deleted from its intention set. Another possible scenario is when the opposing party has aborted the negotiation or the network has broken down, which prevents the physical condition from occurring, thus the agent has to abort the negotiation as well. Durative is one of the necessary conditions for the agent to achieve negotiation goal and to maintain reliability and user trust.

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 φ 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.

3.2 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.

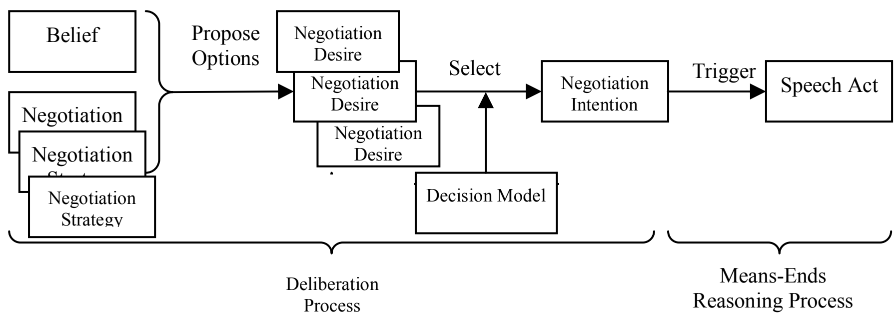

Figure 1: The Negotiation agent's BDI relationship

Figure 1 shows one snippet of the whole negotiation circle, it describes how the negotiation agent carries out practical reasoning. First, the negotiation agent proposes alternative negotiation proposals, which are negotiation desires, based on belief from the environment and existing pre-designed negotiation strategies. Then the agent employs a decision-making model to choose a negotiation desire. The selected negotiation desire becomes the negotiation intention, which can best meet the current needs of the negotiation agent. The agent triggers corresponding negotiation speech act to realize the negotiation intention, and complete this negotiation process.

Through analyzing the decision process of the negotiation agent, we compare the differences between the proposed model and the traditional agents, such as the Procedural Reasoning System (PRS) [Georgeff, 1999].

First of all, the PRS has a “plan base” to perform the means-ends reasoning process. Every behavior plan consists of a series of actions to implement a certain task. We use the negotiation speech acts to substitute for the actions. Every speech act is designed for one negotiation situation. For example, if the agent intends to reject a proposal, it can send a speech act directly to the opposing party. Unlike the PRS, this is a special feature of the negotiation agent, because negotiation is a linguistic behavior, and every negotiation action is implemented through the speech act.

Unlike the proposed model, the goal in the PRS, replaced by desire in the proposed model, is generated by outer mechanisms other than the agent itself. This breaks the autonomous of the agent to some extent. In contrast, the negotiation desire in the proposed model is based on the negotiator’s current belief and strategy. This design provides explicit definition to desire thus makes it easier to implement.

The relationship between desire and intention was not explicitly defined in the former agent model. In the PRS, for example, intention is a data structure made up of some certain action plans. There is no explicit distinction between intention and action. In general, intention needs action to be implemented. In contrast, the negotiation agent can select desires to generate intention, which in turn triggers speech act to form the negotiation action, i.e. negotiation language. This design meets the essential meanings of desire and intention, meanwhile agrees with the human logic thinking process.

3.3 Speech Act and the Negotiation Communication

The proposed negotiation agent’s communication is based on the speech act theory [Kone, 2000], whose research emphasis is on the behavior expressed by natural language rather than semantics. The principle is that language can be considered as a kind of action, similar to the physical action that can be used to change the state of the world to realize the speaker’s intention. In agent theory, it can usually change the opposing agent’s mental states [Austin, 1962]. Speech Act Planning is to properly select and organize the speech act to achieve the language goal [Cohen, 1979].

Speech act theory is no doubt important to the negotiation agent, because the negotiation is essentially a linguistic behavior, and the language is a method to realize the negotiation behavior. If a negotiation agent wants to deliver its negotiation intention to another agent, or to affect the opposing agent’s belief and decision making, it needs to select and organize the negotiation speech act according to its own negotiation intention. When the opposing agent receives the message, it will analyze and decode the message to understand the speaker’s negotiation intention, and carry out the corresponding measures. The process can be expressed by the abstract model shown in Figure 2.

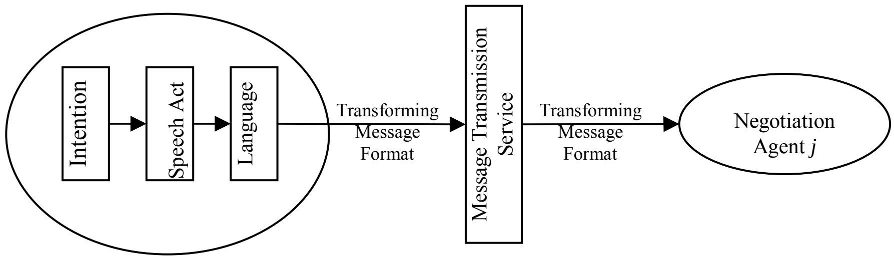

Figure 2: The negotiation agent's abstract communication model

In figure 2, the negotiation agent i generates the negotiation intention from its negotiation desire. Selection of the speech act depends on the type of intention generated. The process, depicted by left oval in Figure 2 is considered the speech act planning process. The speech act is a basic element of the Agent Communication Language (ACL). The negotiation agent integrates the negotiation intention and the speech acts to create the negotiation communication language, and then sends the language to the opposing agent *j* through a physical transmitting mechanism. Agent *j* unscrambles the language sent by agent *i* to reveal the negotiation intention of agent *i*.

We define the negotiation and dialog speech acts to describe what the agents need to say in different circumstances. The negotiation and the dialog speech acts are expansions to the speech acts defined in KQML (Knowledge Query Manipulation Language), which contains tell, propose, argue, accept, reject, ask-if, and error. Table 1 shows details of these speech acts and their definitions, where S indicates the sender agent, R indicates the receiver agent, and F indicates the facilitator (the communication server).

Speech Act	**Definition**
Tell	S let R know some of its knowledge from its belief base
propose	S let R know its proposal during a certain round of negotiation
argue	S let R know the reason for the proposal in a certain round of negotiation
accept	S let R know it accepts R's last proposal
reject	S let R know it rejects R's last proposal
ask-if	S wants to know whether certain knowledge is in R's belief base.
error	S tells R it cannot understand the last message sent by R

Table 1: The automated negotiation's speech acts

Figure 3 shows the logical relationship among the possible speech acts in the process of automated negotiation. The direction of the arrow indicates the message flow, labeled by the negotiation speech acts. The two states "Accepted" and "Rejected" indicate two possible results of negotiation, success and failure. In addition, there are three intermediate states: "Proposed", "Argued", and "Counter argued".

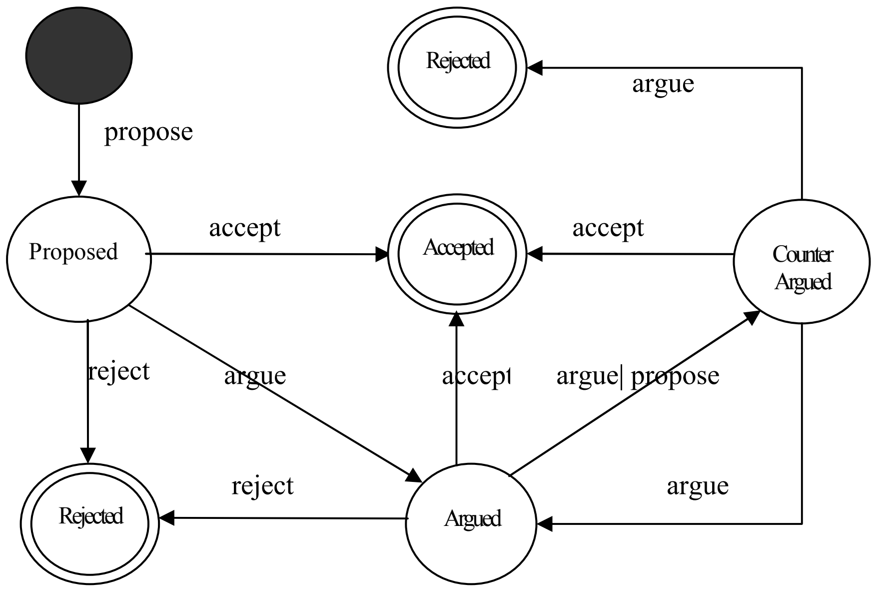

Figure 3: The logical relationships among the negotiation speech acts

4 The Negotiation Agent's Abstract Architecture Model

Recent theoretical work about agent has clarified the role of goals, intentions, and commitment in constraining the reasoning that an agent performs [Azzurra, 2008] [Kiam, 2008] [Jiang, 2006]. In this study we construct the negotiation agent's concept based on the Belief-Desire-Intention (BDI) model of rational agency. The name of the BDI model is from the fact that it recognizes the primacy of beliefs, desires, and intentions in rational action. Once the negotiation agent's concept is formally constructed, its abstract architecture can also be derived. The formal definition is as follows.

Definition 1 (Negotiation Agent): a negotiation agent is in the form

$$Agent =< B, D, I, NS, SA, listen, filter, plan, choose, say, react > \quad (1)$$

Where

$B = \{b_0, b_1, \cdots, b_k\}$ is the set of negotiation agent's beliefs, corresponds to the information the agent has about the negotiation, including the domain knowledge, the environment parameters, the opponents' believes, and so on.

$D = \{d_0, d_1, \cdots, d_m\}$ is the set of negotiation desires, represents the states of the negotiation that the negotiation agent would, in an ideal world, wish to be brought about.

$I=\{i_0,i_1,\cdots,i_n\}$ is the set of negotiation intentions, represents the desires that the negotiation agent is committed to achieve.

$NS=\{ns_1,\cdots,ns_i,\cdots,ns_n\}$ is the set of negotiation strategies performed by the negotiation agent.

$listen:\wp(B)\times GS\times LS\rightarrow\wp(B)$ is the listening function, represents the new beliefs generated based on the current beliefs, the global state(*GS*), and the local state(*LS*).

$filter:\wp(B)\times NS\times\wp(I)\rightarrow\wp(D)$ is the function of filtering negotiation desire, takes sets of beliefs and negotiation strategies to generate a set of desires. It means that the desire is generated from the beliefs and the negotiation strategies.

$choose:\wp(B)\times\wp(D)\times\wp(I)\rightarrow\wp(I)$ is the function that chooses the negotiation intention from the existing desires. The function takes sets of beliefs, desires, and intentions, and returns a set of chosen intentions based on its former beliefs, desires, and intentions. This function describes the negotiation agent's deliberation process.

$plan:\wp(B)\times\wp(G)\times\wp(I)\rightarrow AS$ is the function that plans the negotiation speech act. The agent determines a negotiation speech act to achieve the intention on the basis of an agent's current beliefs, goals, and intentions.

$say:\wp(I)\times AS\rightarrow Message$ is the answer function, that generates the negotiation message based on the current negotiation intentions and all available speech acts.

$react:GS\times LS\rightarrow Message$ is the reaction function mapping the Cartesian product of the sets *GS* and *LS* to the set of *Message*. In order to promote the reactive ability of the negotiation agent, in certain circumstances the negotiation agent can bypass the above deliberation process and response directly to the changing environment through this function.

5 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 [Georgeff, 1999]. 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 4) 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.

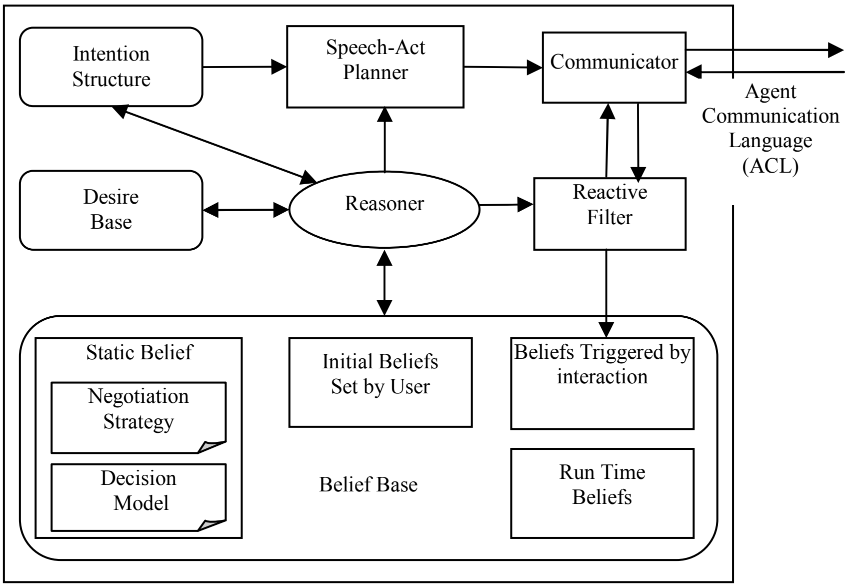

Figure4: The Negotiation Agent Architecture (NAA)

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 (computer, 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 that 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 instabillity 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 characteristc of reactive artificial intelligence to some extent.

6 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. Figure 5 is the formal description of the proposed negotiation reasoning algorithm.

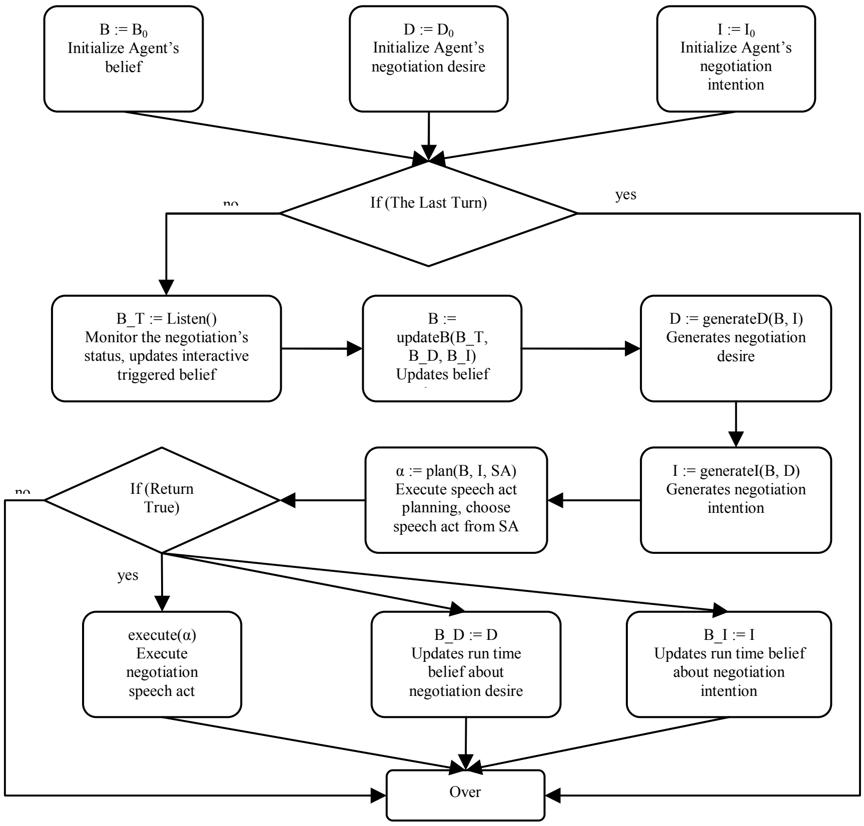

Figure 5: The negotiation-reasoning algorithm

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: Judge whether it is the last turn of the whole negotiation process. If the answer is “yes”, it will proceed to the “over” node and quit the reasoning process. If the answer is “no”, go to step 3.

Step 3: 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 4: Update belief base *B* using the current interactively triggered belief *B_T* and the run-time belief *B_D*, *B_I*

Step 5: 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 6: 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 7: 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 8: 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 9: 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 2.

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.

The reasoning about belief, desire, and intention is the core of the *reasoner*’s negotiation principle. We propose a BDI interpreter to process the negotiation reasoning between the three mental states.

Moreover, in the proposed system the negotiation agent uses negotiation strategy in a different way. In general, the usual negotiation systems, such as Kasbah [Chavez, 1996], 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.

7 The Reasoning Principles

The proposed negotiation reasoning algorithm is based on the BDI reasoning principles. The principles comply with the BDI-U logic proposed in our former work [Cao, 2008], whose main function is to provide a theoretical basis for implementing the negotiation agent and the multi-agent system. All the principles have been validated in the former work.

The generation and update of belief, desire, and intention is the core functions of the negotiation reasoning algorithm, therefore the reasoning principles is to explain the inner relationship and the cooperation process between the negotiation agent's belief, desire, and intention.

Before introducing the principles, we first declare the following expressions and hypotheses.

$Bel(i,\alpha,u)$, $Des(i,\alpha,u)$ and $Int(i,\alpha,u)$ means negotiation agent i believes/desires/intents proposition α is true with the utility u for making such a decision.

System Hypothesis: the belief of the negotiation agent can be held for a time longer than the desire and intention. The desire and intention don't need to maintain their run time state in our system after the negotiation. In other words, one round of negotiation is a complete cycle of belief-desire-intention reasoning. If current negotiation is completed, the corresponding desire and intention will be released. They will not affect the next round of negotiation decision. This hypothesis is also useful for the following intention generation process.

7.1 The Negotiation Desire Generation Principle

Negotiation desire plays an important role in an agent's negotiation reasoning process. It connects the agent's belief and intention through the following reasoning rules.

Rule NR1 (rule for desire generation):

$$Bel(i,\neg\varphi) \wedge Bel(i,\Diamond\varphi,u) \wedge (u \geq \Theta) \Rightarrow Des(i,\varphi,u) \quad (2)$$

Rule NR1 shows that negotiation desire comes from belief reasoning. More precisely, the desire comes from the proposition φ, which is not true now but will be true in the future. Where, $u \geq \Theta$ indicates that not all of the propositions will become negotiation desire, only when the propositions' utilities exceed the threshold constraint Θ . $\Diamond\varphi$ indicates that proposition φ is possibly true. The symbol "=>" means "if …then…".

The principle of desire generation comes from the following system axiom, which has been validated in [Cao, 2008].

Axiom NA1 $Des(i,\alpha,u) \rightarrow Bel(i,\alpha,u)$ (3)

It means if the negotiation agent has negotiation desire α , then it believes α is true or it has belief α . In other words, the negotiation agent does not have desires which it doesn't believe. On the other hand, the axiom shows that the desires come from beliefs. Therefore, in the software architecture of the negotiation agent, if there are data or data structure representing proposition α in the desire base, then the data or data structure is also in the belief base, but not vice versa (i.e. $Bel(i,\alpha,u) \rightarrow Des(i,\alpha,u)$ is not true.) Here, the symbol "→" derived from the standard connective in classical first-order logic, has been defined in a previous study [Cao, 2008]

7.2 Negotiation Intention Generation Principle

As mentioned above, some negotiation desires are selected by the decision model and the negotiation intention is generated subsequently,

Rule NR2 (the rule for intention generation):

$$Des(i,\varphi,u_1) \wedge Des(i,\psi,u_2) \wedge (u_1 > u_2) \Rightarrow Int(i,\varphi,u_1) \quad (4)$$

Rule NR2 indicates that, if an agent has two incompatible negotiation desires, it will choose the one with larger utility as its negotiation intention in the current round of negotiation. When there are several incompatible negotiation desires, we can apply the rule repeatedly to generate the final negotiation intention.

NR2 is supervised by the following axiom, which has also been proven in [Cao, 2008].

Axiom NA2 $Int(i,\alpha,u) \rightarrow Des(i,\alpha,u)$ (5)

It means if an agent has negotiation intention α, it must have the desire to realize α. In other words, negotiation intention comes from negotiation desire. Therefore, in the negotiation agent's software architecture, if there are data or data structure representing proposition α in the intention structure, the data or data structure is also in the desire base, but $Des(i,\alpha,u) \rightarrow Int(i,\alpha,u)$ is not true. We also deduce the following:

Deduction $Int(i,\alpha,u) \rightarrow Des(i,\alpha,u) \rightarrow Bel(i,\alpha,u)$ (6)

It is obvious that we can get this deduction from axioms NA1 and NA2. The deduction means, if an agent has a negotiation intention α at a certain negotiation state, it must have α as a negotiation desire in advance, and believes α is true.

7.3 Negotiation Belief Update Principle

During the reasoning process, the agent records the changing process of its mental states into the belief base. Therefore, we use the following two reasoning rules for updating belief in the design of the negotiation agent's software architecture.

Rule NR3 (the rule for belief update aiming at desire):

$$Des(i,\alpha,u) \Rightarrow Bel(i, Des(i,\alpha,u)) \quad (7)$$

Rule NR4 (the rule for belief update aiming at intention):

$$Int(i,\alpha,u) \Rightarrow Bel(i, Int(i,\alpha,u)) \quad (8)$$

The above two rules indicate that the run time data of desire and intention must be saved in the agent's belief base. When a negotiation is completed, the negotiation agent cleans up the desire and intention base by transferring them from the agent's working memory to the corresponding data structure of the agent's belief base.

The purposes for saving the past data of desire and intention are: first, they are useful for constructing the agent's explanation mechanism that helps the users to understand the negotiation process, and to believe in the agent; second, they are critical for building negotiation cases, which can be used in a case-based negotiation reasoning system.

The following axiom supervises the belief update process.

Axiom NA3 $Des(i,\alpha,u) \rightarrow Bel(i, Des(i,\alpha,u))$ (9)

Axiom NA4 $Int(i,\alpha,u) \rightarrow Bel(i, Int(i,\alpha,u))$ (10)

Axiom NA3/NA4 means if the negotiation agent has the negotiation desire/intention α , then the agent believes (knows) it has the desire/intention.

7.4 The Utility and Strategy Selection Principle

In our system, the negotiation strategy *ns* can be defined as a function $ns : I \rightarrow O$, where the agent receives input proposals (the set of *I*) from the opposing negotiation party, implements the current negation strategy, and produce output proposals (the set of *O*) against the opponent. The $NS = \{ns_1, \cdots, ns_i, \cdots, ns_n\}$ is the set of negotiation strategies, which has been defined in definition 1, section 4.

The concept of utility, generally speaking, is used for measuring the possible cost or profit between the two negotiation states. When the negotiation state transforms from one to the other, the negotiation agent must make corresponding decisions and perform speech acts, which will consume resources. On the other hand it may also generate profit. The utility is used to describe such situation, and makes the agent's outcome measurable during the transforming process of the negotiation states.

Formally, the utility can be defined as $U : NS \times M \rightarrow R$, which means the utility belongs to the real number set *R,* and depends on the negotiation strategy *NS* and the decision model *M* the agent applies.

Although there is a close relationship between the utility and the negotiation strategy, the utility is not used directly to select negotiation strategies. Instead, the agent tries all possible negotiation strategies to generate corresponding negotiation desires. From the reasoning rule NR2 proposed in subsection 7.2, we can see that the utility is used for choosing the most valuable negotiation desire to be the current negotiation intention, hence achieve the goal of multi-strategy selection.

8 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 [Interneg, 2011]. 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.

8.1 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. The weight indicates the importance of the issues to the negotiator. The Seller's and Buyer's preference are shown in Table 2.

Seller's		**Buyer's**	
Negotiation Attributes	Weights (w)	Negotiation Attributes	Weights (w)
Price	0.7	Price	0.5
Warranty	0.3	Warranty	0.5

Table 2: Negotiation agent's preferences

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

$$u_i = \sum_{j=1}^{n} w_j y_i(x_j) \tag{11}$$

Where $i \in (1,\ldots,m)$ represents the negotiation proposal, $j \in (1,\ldots,n)$ represents the issues under negotiation, w_j is the weight of issue j, $x_j \in [x_j^{\min}, x_j^{\max}]$ is a value for issue j to be acceptable by agent i. $x_j^{\max}$ and $x_j^{\min}$ 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 [Faratin, 1998]. 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

$$y_i(x_j) = \frac{x_j - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \tag{12}$$

If attribute j of proposal i is cost related, then

$$y_i(x_j) = \frac{x_j^{\max} - x_j}{x_j^{\max} - x_j^{\min}} \tag{13}$$

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

8.2 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 [Femando, 2008]. 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 [Pruitt, 1981].

Since negotiation strategy is not our research focus, we applied the classic negotiation strategy based on Faratin et al.’s work [Faratin, 1998]. 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. [Faratin, 1998] 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.

8.3 The Negotiation Process

Since each negotiator can access the system and make a proposal independently, we will follow Seller's side of the negotiation. Table 3 shows Seller's initial belief set where both the desire base and the intention structure are empty.

Static Belief	Initial Belief Set by the Users (Object, Attribute, Value)	Interactively Triggered Belief	Run Time Belief
Decision-Making Model M Negotiation Strategy S1 Negotiation Strategy S2	T1: aircraft:=price&wrranty E1: (aircraft, max_price, 320,000$) E2: (aircraft, min_price, 300,000$) E3: (aircraft, warranty, 0 months) E4: (aircraft, warranty, 6 months) E5: (aircraft, warranty, 12 months) E6: (aircraft, warranty, 18 months) E7: (aircraft, warranty, 24 months) E8: (price, weight, 0.7) E9: (warranty, weight, 0.3)	Null	Null

Table 3: Seller Negotiation agent's initial belief set

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. The results are shown in Table 4.

Options	Negotiation Strategy	Negotiation Options (x_1, x_2)	Data Preprocessing Results $(y_1(x_1), y_2(x_2))$	Utility u_i
1	S1	(31.7, 12)	(0.85, 0.50)	0.745
2	S2	(31.5, 12)	(0.75, 0.50)	0.675

Table 4: Seller's 1st decision result

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. The whole simulation process is shown in Table 5.

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.

Buyer's proposal	**Seller's Strategy**	**(x_1, x_2)**	**($y_1(x_1)$, $y_2(x_2)$)**	***u* (for Seller)**	**Seller's proposal**
(30, 24)		(32, 6)			(32, 6)
(30.5, 18)	*S1	(31.7, 12)	(0.85, 0.50)	0.745	(31.7, 12)
u=0.25	S2	(31.5, 12)	(0.75, 0.50)	0.675	
(30.7, 18)	S1	(31.3, 12)	(0.65, 0.50)	0.595	(31.5, 12)
u=0.32	*S2	(31.5, 12)	(0.75, 0.50)	0.675	
(31, 18)	S1	(31, 18)	(0.50, 0.25)	0.425	(31.2, 12)
u=0.425	*S2	(31.2, 12)	(0.60, 0.50)	0.570	
(31, 12)	S1	(30.5, 12)	(0.25, 0.50)	0.325	ACCEPT
u=0.5	S2	(31.2, 18)	(0.60, 0.25)	0.495	

Table 5: results of the negotiation process from the seller's point

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, Tables 6 and 7 and Figure 6, respectively lists the final state of Seller's belief base, desire base, and intention structure.

Static Belief	Initial Belief Set by Users	Interactive Triggered Belief	Run Time Beliefs (not including self-known data of negotiation desires because of the space limitation)
M	T1, E1	((price, 30), (warranty,24))	((price, 32), (warranty,6))
S1	E2, E3	((price, 30.5), (warranty,18))	((price, 31.7), (warranty,12))
S2	E4, E5	((price, 30.7), (warranty, 18))	((price, 31.5),(warranty, 12))
......	E6, E7	((price, 31), (warranty, 18)	((price, 31.2), (warranty, 12)
	E8, E9	((price, 31), (warranty, 12))	((price, 31), (warranty, 12))

Table 6: The Final state of Seller's belief set

Round	Strategy S_1	Strategy S_2
1	((price, 32), (warranty, 6))	((price, 32), (warranty, 6))
2	((price, 31.7), (warranty, 12))	((price, 31.5), (warranty, 12))
3	((price, 31.3), (warranty, 12))	((price, 31.5), (warranty, 12))
4	((price, 31), (warranty, 18))	((price, 31.2), (warranty, 12))
5	((price, 30.5), (warranty, 12))	((price, 31.2), (warranty, 18))

Table 7: The final state of Seller's desire set

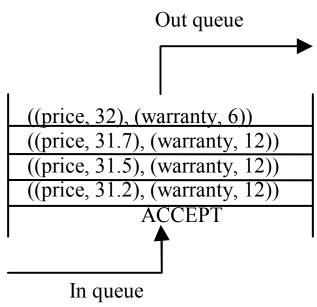

Figure 6: The Seller's negotiating intention queue

9 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 and the speech act 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 abstract architecture model and the software architecture model help 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 risk taking agent with multi-strategy selection ability 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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