BDI 에이전트 환경에서 협상을 위한 에이전트 통신 언어

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요 약

인간의 협동적인 활동에서 협상은 협동적인 행위를 방해할 수 있는 충돌을 해결하는데 중요한 역할을 담당한다. 이를 위해 멀티 에이전트 시스템에서의 협상이 공통의 에이전트 통신 언어를 사용하는 메시지의 교환을 통해 진행한다고 가정한다. 본 논문에서는 자율적이고, 자기 목표에 충실하며, 한정된 자원을 가진 BDI 에이전트를 위한 합리적인 협상 메타 언어를 가정한다. 또한 에이전트의 정신적인 상태에 바탕을 두고 통신하는 BDI 에이전트를 위한 협상 프로토콜을 제안한다.

An Agent Communication Language for Negotiation in BDI Agents Environments

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ABSTRACT

Negotiation plays a fundamental role in human cooperative activities, allowing people to resolve conflicts that could interfere with cooperative behaviors. Negotiation in multi-agent systems is achieved through the exchange of messages in a shared agent communication language (ACL). We introduce a rational negotiation meta-language for autonomous, self-interested, and resource-bounded artificial BDI agents. We then propose a negotiation protocol for BDI agents with communicative acts based on their mental states.

키워드 : 멀티 에이전트 시스템(Multi-agent Systems), BDI 에이전트(BDI Agent), 에이전트 통신 언어(Agent Communication Language), 협상 프로토콜(Negotiation Protocol)

1. Introduction

A language for inter-agent communication should allow agents to enlist the support of others to achieve goals, commit to the performance of actions for another agents, monitor their execution, report progress, success and failure, refuse task allocations, and acknowledge receipt of message. As such, it is essential that the functions being offered by the communication language be common across the language of intelligent agents. It so happens that there is such a language of *speech acts*, or more precisely, *illocutionary acts* which actions include requesting, promising, offering, acknowledging, proposing, accepting, etc.

A speech act is defined to be an action that a speaker performs in order to convey part of its mental state to the hearer that the act is directed to. This notion has been adopted in agent communication languages (ACL) such as Knowledge Query Manipulation Language (KQML) [1, 8] and Foundation for Intelligent Physical Agents (FIPA) ACL [2, 3], which prescribe the syntax and semantics of a collection of speech act-like messages, each of which is comprised of a performative, a content, and some additional parameters as the sender and receiver of the message.

KQML has the lack of semantics for communicative acts and so agent designers cannot be certain that the interpretation they are giving to a performative is in fact the same as the one some other designer intended it to have. FIPA ACL has several shortcomings. For example, the distinction among *inform*, *tell*, and *assert* is only relevant for an external observer. For an agent's subjective view they are equivalent. Also, an *inform* may be used answer queries which should, however, be done only by a *reply*.

In this paper, we consider three modalities : *B* for beliefs used to represent an agent's mental attitudes to the state of the environment, *D* for desires used to represent motivations of the agent, and *I* for intentions used to represent goals of the agent. We address rational communicative

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behaviors in autonomous, self-interested, resource-bounded artificial BDI agents that have to what to communicate, to whom, and how. We then introduce a variant of KQML, FIPA ACL specification, and the negotiation meta-language as our negotiation language for BDI agents to resolve goal conflicts. Finally, we present a negotiation protocol for BDI agents with our negotiation language. When an agent receives a message from another agent, it interprets the message and generates a reply message based on its mental state.

2 Agent Communication Languages

2.1 KQML

KQML is intended as a general purpose communication language for the exchange of information and knowledge between software agents and it is conceptually a layered language [7]. It can be viewed as being divided into three layers : the *content layer*, the *message layer*, and the *communication layer*. The content layer is the actual content of the message in the programs own representation language. The message layer forms the core of the language. It determines the kinds of interactions one can have with a KQML-speaking agent. Finally, the communication level encodes a set of features to the message which describe the lower level communication parameters. KQML consists of logical combinations of the following five operators : *bel* (α, ϕ) denoting that φ is in the knowledge base of α and *know* (α, ϕ), *want* (α, ϕ), *intend* (α, ϕ), standing for the fact that α knows φ, wants φ, and is committed to φ, respectively. Finally, there is an operator *process* (α, m) denoting that the message m will be processed by agent α.

KQML is offered to the agent community as an extensible language with an open-ended set of performatives, whose meaning is independent of the propositional content language such as Prolog, first-order logic, and SQL. KQML, however, has yet to provide a precise semantics for these languages, as is customary with programming languages. Without one, agent designers cannot be certain that the interpretation they are giving to a performative is in fact the same as the one some other designer intended it to have. Moreover, the lack of semantics for communication acts leads to a number of confusions in the set of reserved performatives supplied.

2.2 FIPA ACL

FIPA ACL specification is based on *speech act theory* : messages are actions, or *communicative acts*, as they are intended to perform some action by virtue of being sent [4]. Every communicative act is described with both a narrative form and a formal semantics based on modal logic. The format of messages is similar to that of KQML, while their semantics are given by means of *feasibility preconditions* (FP) on the mental state of the sending agent that should hold prior to the dispatch of the message and *rational effects* (RE) that the sender can expect as a result of the dispatch. For example, *inform* act that agent i informs agent j that "it is true that it is raining today" can be represented as follows :

```
(inform
        : sender i
        : receiver j
        : content "weather(today, raining)"
        : language Prolog
)
```

Above *inform* act has the following underlying formal model :

$$\langle i,\ inform(j,\ \varphi)\rangle$$
$$\text{FP}: \quad B_i\varphi \wedge \neg B_i(Bif_j\varphi \vee Uif_j\varphi)$$
$$\text{RE}: \quad B_j\varphi$$

The semantics of *inform* act is that a sending agent i holds that proposition φ is true and i does not already believe that a receiver j has any knowledge of the truth of φ, and, as the RE of the *inform* act, j believes that φ is true.

2.3 Negotiation meta-language

Wooldridge and Jennings [5, 6, 12] have explored two important computational problems in the use of logic-based languages for multi-agent negotiationthe *success problem*, i.e., given a particular negotiation history, has agreement been reached? and the *guaranteed success problem*, i.e., does a particular negotiation protocol guarantee that agreement will be reached?. They have considered three more complex languages for negotiation*classical propositional logic*, a *language for electronic commerce*, and a *negotiation meta-language*.

In classical propositional logic, agents are negotiating over a domain that may be characterized in terms of a finite set of attributes, each of which may be either true or false. An outcome is thus an assignment of true or false to every attribute. In a language for electronic commerce, agents are trying to reach agreement on the values of a finite set of negotiation issues, where each issue has a natural number value. They have also considered a negotiation meta-language which consists of illocutions : for example, *request*(i, j, φ) means a request from i to j for a proposal based on φ, where φ is a formula in classical propositional logic.

3 An Agent Communication Language for Negotiation

3.1 An ACL for BDI Agents

Our language is for negotiation between multiple agents over scarce resources. In this case, negotiation is achieved through the exchange of messages in a shared communication language. We assume that BDI agents meet the following requirements :

- Agents may interact asynchronously with more than one other agent at the same time ;
- Agents are known to one another by their names, rather than their IP addresses ; and
- The arguments of a message may affect the mental state of both the sender and the receiver

We also consider that the *B*, *D*, and *I* are taken as meta-predicates. In order to represent these predicates, we take advantage of several characterizations in logic programming such as declarativity, unification, deduction rules, and meta-programming.

The actual exchange of messages is driven by the participating agents' own needs, goals, or mental attitudes. We represent the set of beliefs as ***B***, the set of desires as ***D***, and the set of intentions as ***I***. Each agent has a unique identifier and we denote the set of identifiers of the agents involved in negotiation as *Agents*. Assumed BDI agents are negotiating about the allocation of deficient resources, agents require the allocation of deficient resources to achieve their goals. We denote a set of goals as *Goals* and a set of the resources as *Resources*. In this case, we can define a communication language *CL*, communicative acts, for BDI agents as follows :

Definition 1 Given $a1, a2 \in$ *Agents*, $g \in$ *Goals*, $r \in$ *Resources*, and $m \in$ ***B***, ***D***, or ***I***, we define a *CL* :

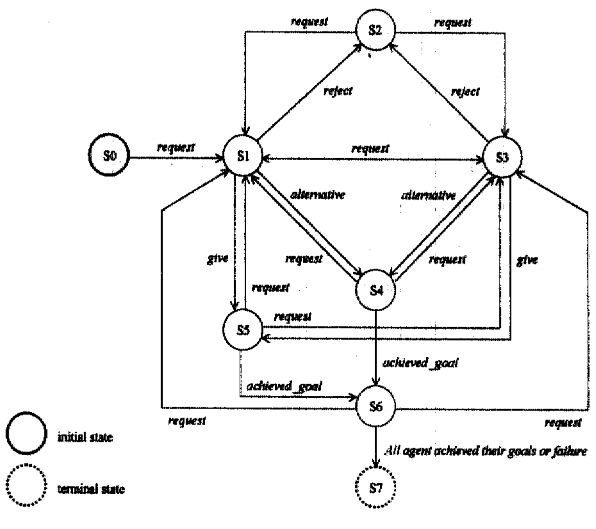
$$request(a1, a2, g, r) \in CL$$
$$ask\_if(a1, a2, m) \in CL$$
$$inform(a1, a2, m) \in CL$$
$$give(a1, a2, r) \in CL$$
$$reject(a1, a2, g, r) \in CL$$
$$alternative(a1, a2, g, subgoals) \in CL$$
$$achieved\_goal(a1, a2) \in CL$$

In definition 1, *request*($a1$, $a2$, g, r) means that agent $a1$ requests deficient resources r from agent $a2$ to achieve its goal g where g is the reason why $a1$ needs r. *ask_if*($a1$, $a2$, m) indicates that $a1$ asks $a2$ if m is true while *inform*($a1$, $a2$, m) that $a1$ informs $a2$ that m is true.

3.2 A Negotiation Protocol for BDI Agents

Intelligent agents are software programs that use agent communication protocols to exchange information and to achieve their conflicting goals and resources allocation. The interaction protocols for intelligent agents are agent communication rules and based on speech-act language theory. They can be used as negotiation protocols which specify the messages that each agent is allowed to make.

In order to simplify protocol analysis, we assume that two BDI agents are involved in our negotiation protocol. The sequence of our negotiation protocol for BDI agents can be shown in (Figure 1) as a finite state diagram. In (Figure 1), S0~S7 represent different negotiation states during a negotiation process. S0 is the initial state and S7 is the terminal state in which an agreement or disagreement is reached. The process of negotiation starts when an agent generates a *request* message. This process continues until all the agents involved agree on a request or they cannot reach an agreement.



(Figure 1) A negotiation protocol for BDI agents

In our negotiation protocol, a sequence of simple negotiation message can be shown as follows :

① State that starts a negotiation (S0). An agent knows that it wants to have any resources to achieve its goal. It sends a *request* message to another agent that has the resources. Negotiation processes start from this state.

② State that receives a request (S1). An agent has received the *request* message, it interprets the *request* message, and generates a respond message. The message that can be generated in this state is a *reject*, a *request*, an *alternative*, or a *give*.

...

⑦ State that terminates the negotiation (S7). Two agents involved in the negotiation reach an agreement. The negotiation is terminated.

4. Experiments and Comparisons

4.1 Experiments

Our simple BDI agents' negotiation mechanism is tested on InterProlog supporting Java 2 SDK version 1.3.1 and XSB Prolog version 2.4. InterProlog is a programming environment for XSB Prolog. It consists of a Java application front-end that communicates with a Prolog system running as a subprocess, using standard console redirection and TCP/IP sockets. It is implemented as a set of standard Java classes and Prolog predicates.

We consider three home improvement BDI agents with different objectives and resources. Agent $a1$ has the intention of hanging a picture, *i*(*do*($a1$, *hang_picture*)), and believes that it has in its possession a picture, a screw, a hammer, a hanger nail, and a screwdriver. It also believes that its name is $a1$ and agent $a3$ has a hanger. Agent $a2$ has the intention of hanging a mirror, *i*(*do*($a2$, *hang_mirror*)), and believes that it has a mirror and a nail. It also believes that its name is $a2$ and agent $a1$ has a screw, a hammer, and a screwdriver. Finally, agent $a3$ has the intention of hanging a clock, *i*(*do*($a3$, *hang_clock*)), and believes that it has a clock and a hanger. It also believes that its name is $a3$ and agent $a1$ has a hanger nail.

We construct BDI agents and allow them to negotiate with each other from the top-level window. NegotiationWindow class is responsible for creating this window, constructing the BDI agents, and starting a negotiation with the agents. <Table 1> illustrates the roles of the methods in NegotiationWindow class.

<Table 1> The methods in NegotiationWindow class

Method names	***Roles***
negotiationWindow	Constructor to create the instance
constructWindowContents	Creates a 600×500 pane
constructMenu	Creates menubar and menu, handles action events
createSimpleBDIAgent 1	Creates agent 1's window with Prolog engine
createSimpleBDIAgent 2	Creates agent 2's window with Prolog engine
createSimpleBDIAgent 3	Creates agent 3's window with Prolog engine
addItemtoMenu	Adds items to menu
main	Displays system information and take an array as a default Prolog engine

When we click *Create simple BDI Agent* 1 item in the top-level window, Agent1Window class displays *Simple BDI agent*1 window with two panes : the top shows all outputs, *stdout* and *stderr*, from Prolog and the bottom is an editable text field which is sent to Prolog's input, *stdin*, after hitting the Enter key. Agent1Window class then consults a routine of initializing agent $a1$ using *sendAndFlush* method in PrologEngine class. Agent2Window and Agent3Window classes perform similar tasks to Agent1Window class. PrologEngine class represents and gives access to a running Prolog process in background. Multiple instances correspond to multiple Prolog processes, outside the Java virtual machine. *sendToFlush* method in this class sends a string to Prolog's input.

Let's look at the initialization routine of $a1$ in the form of XSB Prolog. This routine consults negotiation mechanism routines for BDI agents and the knowledge base of $a1$. It also prepares $a1$ for communication with $a2$ and $a3$. There are many mechanisms of communication such as stream-oriented and message-oriented, but we use buffered, message-based communication mechanism using sockets : communication processes exchange messages that have well-defined boundaries, and use *socket_send*/3 and *socket*/3 to talk to each other where *p*/*n* represents predicate *p* has an arity of *n*.

On the other hand, the initialization routine of $a2$ consults negotiation mechanism routines for BDI agents and the knowledge base of $a2$. After it prepares $a2$ for communication with $a1$, $a2$ sends a message to $a1$, receives a confirmation message, and waits for a message from $a1$ to negotiate with $a1$. This means that we assume that $a1$ gives an initial request, but if *a*2 does, we may have the same result.

When we click *Start simple BDI agents negotiation* item in the top-level window, negotiation among *a*1, *a*2, and a3 starts. <Table 2> shows how these three agents can reach a mutual agreement state through a shared communication language. In <Table 2>, communication messages, *ask_if*(*a*1, *a*2, *b*(*have*(*a*2, *nail*))) and *ask_if*(*a*1, *a*3, *b*(*have*(*a*3, *nail*))), means that *a*1 asks *a*2 and *a*3 if they have a nail. *a*2 which receives an *ask_if* message from *a*1 checks its knowledge base, informs *a*1 that it has a nail, *inform*(*a*2, *a*1, *b*(*have*(*a*2, *nail*))). Now, *a*1 comes to know that *a*2 has a nail, requests a nail from *a*2, *request*(*a*1, *a*2, *hang_picture*, *nail*). This message means that *a*1 requests a nail from *a*2 to achieve its goal, hanging a picture.

〈Table 2〉 Communication messages in negotiation processes

Direction	Messages
*a*1 → *a*2, *a*1 → *a*3	*ask_if*(*a*1, *a*2, *b*(*have*(*a*2, *nail*))), *ask_if*(*a*1, *a*3, *b*(*have*(*a*3, *nail*)))
*a*2 → *a*1	*inform*(*a*2, *a*1, *b*(*have*(*a*2, *nail*)))
*a*1 → *a*2	*request*(*a*1, *a*2, *hang_picture*, *nail*)
*a*2 → *a*1	*request*(*a*2, *a*1, *hang_mirror*, *hammer*)
*a*1 → *a*2	*alternative*(*a*1, *a*2, *hang_mirror*, [*screwdriver*, *screw*, *mirror*])
*a*2 → *a*1	*request*(*a*2, *a*1, *hang_mirror*, *screwdriver*)
*a*1 → *a*2	*give*(*a*1, *a*2, *screwdriver*)
*a*2 → *a*1	*request*(*a*2, *a*1, *hang_mirror*, *screw*)
*a*1 → *a*2	*give*(*a*1, *a*2, *screw*)
*a*2 → *a*1, *a*2 → *a*3	*achieved_goal*(*a*2, *a*1), *achieved_goal*(*a*2, *a*3)
*a*3 → *a*1	*request*(*a*3, *a*1, *hang_clock*, *hanger_nail*)
*a*1 → *a*3	*give*(*a*1, *a*3, *hanger_nail*)
*a*3 → *a*1, *a*3 → *a*2	*achieved_goal*(*a*3, *a*1), *achieved_goal*(*a*3, *a*2)
*a*1 → *a*2	*request*(*a*1, *a*2, *hang_picture*, *nail*)
*a*2 → *a*1	*give*(*a*2, *a*1, *nail*)
*a*1 → *a*2, *a*1 → *a*3	*achieved_goal*(*a*1, *a*2), *achieved_goal*(*a*1, *a*3)

4.2 Comparisions

We defined the most basic inter-agent communication acts : *inform*, *ask-if*, *request*. In the case of *request* act, the KQML has *achieve* performative similar to *request* act. We consider a *request* act that *a*1 requests *a*2 to give the resources *r*. There is an important difference between KQML *achieve*, FIPA ACL *request*, and our *request*(*a*1, *a*2, *g*, *r*) act. KQML agent *a*2 does not know the reason why it sets the new value and FIPA agent *a*2 does not know the reason why *a*1 requests the resources *r*, while our BDI agent *a*2 knows the reason why *a*1 requests the resources *r*, i.e., because of the goal *g*. This fact helps an agent to reason about others' mental attitudes so that the agent may plan its goal more effectively.

The mental attitude *m* in definition 1 can be represented as follows : *B*(*p*), *D*(*p*), or *I*(*p*) where *p* is an atomic sentence. The use of *inform* for supplying new information to an agent is related to the data manipulation commands of SQL and Prolog. Assumed that an SQL database has belief, desire, and intention tables, called *b_table*, *d_table*, and *i_table*, respectively, an SQL INSERT of a new row <*p*> into the belief table or a Prolog *assert*(*p*) corresponds to sending an *inform*(*a*1, *a*2, *B*(*p*)) message. Sending *inform*(*a*1, *a*2, *B*(¬*p*)) with the negated sentence ¬*p* as content corresponds to an SQL DELETE of the respective row or a Prolog *retract*. <Table 3> shows these relationships between our communication acts, SQL, and Prolog.

〈Table 3〉 The relationships between our communication acts, SQL, and Prolog

Our ACL	SQL	Prolog
inform(*a*1, *a*2, *B*(*p*))	INSERT INTO *b_table* VALUES *p*	*assert*(*p*).
inform(*a*1, *a*2, *B*(*p*))	DELETE FROM *b_table* WHERE *x* = *p*	*retract*(*p*).
ask-if(*a*1, *a*2, *B*(*p*))	SELECT *x* FROM *b_table* WHERE *x* = *p*	?-*p*.
ask-if(*a*1, *a*2, *B*(*p*))	n.a.	?-*not p*.

In this paper, when each agent interacts one another and notices inconsistency of its beliefs, we try to confine beliefs as much as possible, making each agent modify its beliefs. In Rao and Georgeff axiomatization [9-11], if an agent has an intention to do a particular action, the agent does the action. We also try to confine intentions to commit when the agent believes that it can do the action.

5. Conclusion and Future Research

In this paper, we have represented agents' beliefs, desires, and intentions for MAS in logic programming environments and introduced a negotiation mechanism for BDI agents. We have considered a MAS in which beliefs, desires, and intentions are taken as meta predicates and then introduced an ACL for BDI agents such as *request*, *ask_if*, and *inform*, described the relationships among our ACL, KQML, FIPA ACL, SQL, and Prolog. We finally introduced a negotiation protocol for BDI agents as a finite state diagram and defined a message generation function for BDI agents.

A number of issues raised in this paper require further investigation. We have considered the ACL containing some communication actions or performatives. Existing communication languages consider additional communication actions such as *critique, withdraw, threaten, reward, persuade,* and so on. We need to investigate whether some of these additional actions could be defined via negotiation protocols and have an assumption that different agents share the same communication language. However, this assumption is not essential. Indeed, translator agents could be defined, acting as mediators between agents with different communication languages. This may be possible by virtue of the metalogic features of the language.

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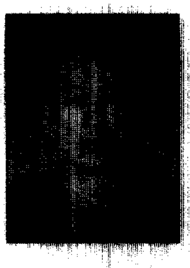

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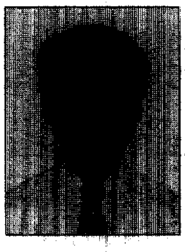

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