MULTI-AGENT SYSTEM FORMAL MODEL BASED ON NEGOTIATION AXIOM SYSTEM OF TEMPORAL LOGIC

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Abstract: In this paper we describe the formal semantic frame and introduce the formal language $\mathcal{L}_{TN}$ to express the time and the ability and right of an agent on selecting action and negotiation process in a Multi-Agent System, the change of the right over time, the free action of an agent and the time need by a agent to complete an action. Based on the above, the independent negotiation system has been further complete. In this paper, it is also addressed that the axiom system is rational, validate and negotiation reasoning logic is soundness, completeness and consistent.

1 INTRODUTION

The research of agent technique is a new field of software design and realization , and has caught people's attention for years, especially in distribution and open Internet software developing field. As the mature of technique and more complex application problems being put forward, the requirements of multi-agent system based on peer-to-peer mode communication have become more and more urgent. The research of the key technology of MAS's design and effective implement has been carried out for many years in the field of distribution artificial intelligence.

For MAS, besides the consideration of the representation and formalization of consciousness attitude concerning individual agent, it must consider the alternation of multi agents, the consciousness attitude that is one of the important portions of MAS theory research. As being able to reason about other agents, consciousness attitude is the main request that makes the agents to coexist, compete and collaborate. The cooperation and negotiation can be produced and accomplished under the control of psychosis. Negotiation of MAS include negotiation protocol, negotiation strategy and negotiation disposal. The first part focus on dealing with the intercommunication among agents, and the second part has five basic types: one-part giving in strategy, competitive strategy, cooperation strategy, destroying strategy and delaying strategy.

This paper is based on Li Jing's work, and add temporal logic to complete negotiation between independent agents by using linear temporal logic describe right change to make contribution on letting agents act more freely.

2 NEGOTIATION AXIOM SYSTEM WITH TEMPORAL LOGIC

The Negotiation Axiom System based on Capability and Thought of MAS(Li Jing 03)is viewed as a sequence of "Perceiving→Selecting actions→Negotiating to resolve conflicts→Deciding actions by arbitrage →Executing actions".

In the *TN* system (the abbreviation of the negotiation axiom system with temporal logic), the primary work unit is spitted into many small units, that allow agents behaviors to be asynchronous, that is the starting point of negotiations and the other actions taken by agents can be different, so a agent is able to start a negotiation when there is another agent is still executing an action; Further, when some agents are executing actions, other agents keep observing the environment, and then choose their

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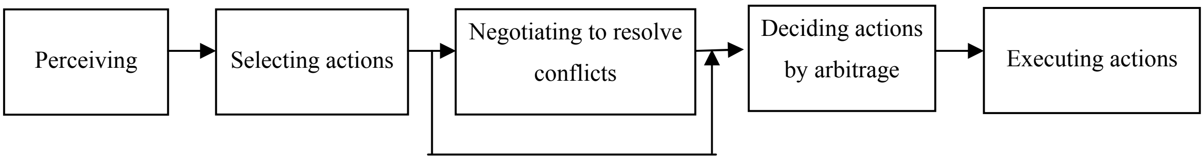

Figure 1: Interpretation of the negotiation axiom system based on capability and thought of MAS

Figure 2: Interpretation of the negotiation axiom system with temporal logic

next movements based on local states, power and rights, that is the environment observations are simultaneous.

In our work, the VSK-AF logic system is still valid in the course of perceiving, but in the course of selecting actions, negotiating to resolve conflicts, deciding actions by arbitrage and executing actions, we use the negotiation with temporal logic. In the *TN* system , negotiation concurrence is allowed, and all those negotiations may start at a different time point, last for a different time period, end at a different time point.

2.1 Semantic Frame

To discus the *TN* system we define the following semantic frame:

T = $\{t_0, t_1, t_2, \ldots, t_n, \ldots\}$: a set of time points;

Actions = $\{\alpha_0, \alpha_1, \ldots\}$: a set of actions, which consists of all actions involved in this system;

NS = $\{ns_0, ns_1, \ldots\}$: a set of negotiation strategies;

AS = $\{as_0, as_1, \ldots\}$: a set of arbitrage strategies;

Message = a set of (i,α,w), Ag_i select the action α to execute the task w;

E = $\{e_0, e_1, \ldots\}$: a set of the external environment states;

S = $\{s_0, s_1, \ldots\}$: a set of the Agents environment states;

W = $\{w_1, w_2, \ldots\}$: a set of tasks;

Environment: one of the two important parts of the model, denoted as Env = $<E, S, W, vis_1, \ldots, vis_n, acce_1, \ldots, acce_n, Arbitrage, \tau_g, e_0, s_0>$;

$\mathbf{L_i} = \{ l_i^0, l_i^1 \ldots\}$: the set of local state for $Agent_i$;

Agents: one of the two important parts of the model, denoted as $Ag_i=<L_i, See_i, Feel_i, Th_i, Ability_i, Power_i, SelectAP_i, Donetime_i\ NS_i, Decide_i, CR_i, \tau_i, l_i^0, Poss_i>$;

Negotiation: denoted as N=<Ags, Isu, O, V_O, Ans, Time, Thread, Protocol>;

***TN* System**: denoted as S=<Actions, NS, AS, Env, Agents, N, PoS, SR, **T**>;

Global states for a *TN* system: denoted as $G=\{\varepsilon_0, \varepsilon_1, \ldots\}$;

The class of *TN* system: consists of all *TN* system, denoted as *S;*

Run: A sequence $\varepsilon_0, \varepsilon_1, \ldots$(enumerable) over G represents the run of a *TN* system

The set of reachable states for *TN* system: denoted as G_S;

At the very beginning, L_i is initialized as the initial local state, E is initialized as the external state, and S is initialized as the initial agent state, then each agent start the first observation and use the vis (the partition function of the external environment for $Agent_i$) and the $acce_i$ (the partition function of the Agents environment for $Agent_i$) to product a p_i^0 (the acknowledge of the external environment) and a q_i^0 (the acknowledge of the agents environment), thus the L_i transfer to a new local state L_{i+1} and we get a initial global states for the *TN* system. With the initial global states, each agent makes its own selection according to the power and right they have at this moment, on the contrary, a agent has no power and right doing nothing till the next time point comes, they start a new observation. Those agents with power and right select an action and the corresponding task, if there is no confliction among those selected actions, the agent then execute the selected action, transfer the environment states. When they finish the execution start an observation again. Once the conflictions occur, those agents involved negotiate with each other till the agreements are finally reached, and they act according to the agreement to transfer the state of the system. Till all problems are solved, the process will be repeated.

2.2 Negotiation Logic in *TN* System

This section gives an overview of the formal framework in which the model of negotiation will be expressed in language $\mathcal{L}_{TN}$. The language expresses the model of negotiation, and describes the system information, which consists of two parts: the first part—the language of VSK-AF logic, is used in the course of perceiving , to express the objective phenomenon in multi-Agent systems, the information that can be visited, learn or perceived by a agent in the system, the second part—$\mathcal{L}_{TN}$, is used in the rest phases, to describe how the time, power, and right effect the agent on the action selection and negotiation, especially the change of the right during the whole process.

In *TN* system, we introduce five temporal operators: $\square$(always) , $\diamond$(eventually) , $\circ$(next) , $\blacklozenge$ (ever) , $\cup$(until).

Given a set P of prepositional variables, set Agents of agents, set Actions of actions, set W of task, and for an action $\alpha \in$ Actions has a set of preconditions Pre(α), and a set of effects Eff(α), the language $\mathcal{L}_{TN}$ is defined as below:

A list of predications as following: Exu(Agi,α,w), Capable(Agi,α), R-Entitle (Agj,Agi,α), NR-Entitle (Agj, Agi,α), Entitle(Agj,Agi,α), Right(Agi,α), Done(Agi,α,w), Agree(Γ,φ), Bound (Agi,agm), Commit (Agi, Agj, agm), Benefit(Agi,α), Select(Agi,α,w), Collision(Agts,α,w), Negotiation (Agts,α,w), DuringNegotiation (Agts, α, w), Join-Negotiation(Agi,α,w), OverNegotiation(Agts,Agk,α, w), Permit(Agi,Agj,Entitle(Agj,Agk,α)), Deprive (Agi, Agj,α) and so on.

Φ_0 (the set of atomic propositions of $\mathcal{L}_{TN}$): consists of P and predications mentioned above.

Φ (the set of compound formula of $\mathcal{L}_{TN}$):

1 . True, False$\in\Phi$, $\Phi_0\subseteq\Phi$;

2 . If φ_1, $\varphi_2\in\Phi$, then $\neg\varphi_1\in\Phi$, $\varphi_1 \wedge \varphi_2\in\Phi$, $\circ\varphi_1\in\Phi$, $\blacklozenge\varphi_1\in\Phi$, $\square\varphi_1\in\Phi$, $\diamond\varphi_1\in\Phi$, $\varphi_1\cup\varphi_2\in\Phi$;

3 . If $\varphi\in\Phi$ and $\pi\in\Pi$, where $\Pi=\{(Exu(Ag_i,\alpha_i,w_i),\cdots Exu(Ag_j,\alpha_j,w_j))\}$, then $[\pi]\varphi\in\Phi$, $<\pi>\varphi\in\Phi$;

$[\pi]\varphi$ means it is certain that the execution of actions in π lead to a state in which φ is True; $<\pi>\varphi$ means it is possible that the execution of actions in π lead to a state in which φ is True.

2.3 The Semantic of Negotiation Logic

Definition 2.3.1 The negotiation model is defined as $\mathcal{M}=<G_S, \rho, \lambda>$, where:

- ✧ $G_S\subseteq E\times S\times L_1\times\ldots\times L_n$ is the set of all possible multi-agent world states; the element ε_i of G_S is (n+2)-ary tuple (e,s, l_1, l_2, …, l_n) called as global state;
- ✧ ρ:$G_S\times\Pi\rightarrow G_S$, is a function that defines the accessibility relation from states associated with the action tuple to state. For instance, if there is a state $\varepsilon_i\in G_S$ in which the execution of actions in π produces a new state $\varepsilon_j\in G_S$, then (ε_i,ε_j) is said to be "reachable", denoted (ε_i, ε_j)$\in\rho(\pi)$;
- ✧ $\lambda:\Phi\rightarrow 2^{GS}$, is the interpretation function for formulae; for $\varphi\in\Phi$ and $\varepsilon_i\in G_S$, $\lambda(\varphi)$ refers to the set of states in which φ holds, and $\varepsilon_i\in\lambda(\varphi)$ if and only if φ holds in ε_i.

Definition2.3.2 Semantic rules of negotiating logic:

I_T $<\mathcal{M}, \varepsilon_I>\models$ true

I_P $<\mathcal{M}, \varepsilon_i>\models\varphi$ iff $\varepsilon_i\in\lambda(\varphi)$

I_F $<\mathcal{M}, \varepsilon_i>\models\neg\varphi$ iff $<\mathcal{M}, \varepsilon_i>\not\models\varphi$

I_O $<\mathcal{M}, \varepsilon_i>\models\varphi\wedge\psi$ iff $<\mathcal{M}, \varepsilon_i>\models\varphi$且$<\mathcal{M}, \varepsilon_i>\models\psi$

I_N $<\mathcal{M}, \varepsilon_i>\models\circ\varphi$ iff, $<\mathcal{M}, \varepsilon_{i+1}>\models\varphi$

I_A $<\mathcal{M}, \varepsilon_i>\models\square\varphi$ iff 对$\forall\varepsilon_j\in G_S:\varepsilon_i\prec\varepsilon_j$, $<\mathcal{M}, \varepsilon_j>\models\varphi$

I_E $<\mathcal{M}, \varepsilon_i>\models\diamond\varphi$, iff $\exists\ \varepsilon_j\in G_S:\varepsilon_i\prec\varepsilon_j$, $<\mathcal{M}, \varepsilon_j>\models\varphi$

I_G $<\mathcal{M}, \varepsilon_i>\models\blacklozenge\varphi$, iff $\exists\ \varepsilon_j\in G_S:\ \varepsilon_j\prec\varepsilon_i$, $<\mathcal{M}, \varepsilon_j>\models\varphi$

Iu $<\mathcal{M}, \varepsilon_i>\models\varphi\cup\psi$ iff $\exists\ \varepsilon_j\in G_S:\varepsilon_i\prec\varepsilon_j$, $<\mathcal{M}, \varepsilon_j>\models\psi$,and $\forall\ \varepsilon_k$, ε_i M$\varepsilon_k\prec\varepsilon_j$, $<\mathcal{M}, \varepsilon_k>\models\varphi$

Theorem 2.3.1 $\mathcal{M}$, $\varepsilon_i\models[\pi]\varphi\Leftrightarrow\mathcal{M}$, $\varepsilon_i\models\neg<\pi>\neg\varphi$

Theorem 2.3.2 $\mathcal{M}$, $\varepsilon_i\models<\pi>\varphi\Leftrightarrow\mathcal{M}$, $\varepsilon_i\models\neg[\pi]\neg\varphi$

2.4 Axiomatics of $\mathcal{L}_{TN}$

Transmutation rule of formulas in negotiation logic

T1 . Substitution rule: If φ, ψ are formulae of $\mathcal{L}_{TN}$, and $\vdash_{\mathcal{L}_{TN}}\varphi$, then if p is a variable in φ, substituting p in φ with ψ, the result φ' satisfies $\vdash_{\mathcal{L}_{TN}}\varphi'$;

T2 . Separation rule: From $\vdash_{\mathcal{L}_{TN}}\varphi\rightarrow\psi$ and $\vdash_{\mathcal{L}_{TN}}\varphi$, $\vdash_{\mathcal{L}_{TN}}\psi$ holds;

T3 . Certainty rule: From $\vdash_{\mathcal{L}_{TN}}\varphi$, $\vdash_{\mathcal{L}_{TN}}[\pi]\varphi$ holds;

T4 . Temporal rule: From $\vdash_{\mathcal{L}_{TN}}\varphi$, $\vdash_{\mathcal{L}_{TN}}\triangle_i\varphi_j$

holds , where $\triangle_i$={□, ◆, ○, ◇},

From $\vdash_{\mathcal{L}_{TN}}$ φ_i and $\vdash_{\mathcal{L}_{TN}}$ φ_j, $\vdash_{\mathcal{L}_{TN}}$ $\varphi_i \cup \varphi_j$ holds;

The strategy of selecting action

S1 . If Capable(Ag_i,α) and Right(Ag_i,α) and Benefit(Ag_i,Exu(Ag_i,α,w))then

Select(Ag_i,α,w)

S2 . If Right(Ag_i,α) and Capable(Ag_j,α) and ¬Right(Ag_j,α) and Benefit(Ag_i,Exu(Ag_j,α,w))

then Entitle(Ag_i,Ag_j,α)

S3 . If ¬Benefit(Ag_i,Exu(Ag_i,α,w)) then ¬Exu(Ag_i,α,w)

3 SOUNDNESS AND COMPLETENESS OF NEGOTIATION LOGIC

Theorem 3.1 (Soundness of $\mathcal{L}_{TN}$) $\Gamma \vdash_{\mathcal{L}_{TN}} \varphi \Rightarrow \Gamma \models \varphi$

Theorem 3.2 (Consistency of $\mathcal{L}_{TN}$)There does not exist formula φ that makes $\Gamma \vdash_{\mathcal{L}_{TN}} \varphi$ and $\Gamma \vdash_{\mathcal{L}_{TN}} \neg\varphi$ hold at the same time.

Theorem 3.3 (Completeness of $\mathcal{L}_{TN}$) $\Gamma \models \varphi \Rightarrow \Gamma \vdash_{\mathcal{L}_{TN}} \varphi$.

Theorem 3.4 (Logic completeness of $\mathcal{L}_{TN}$)$\forall \varphi \in \mathcal{L}_{TN}$, there is one and only one holds between $\vdash_{\mathcal{L}_{TN}} \varphi$ and $\vdash_{\mathcal{L}_{TN}} \neg\varphi$.

Theorem 3.5 The *TN* system is uncontradictory.

4 NEGOTIATION AND ARBITRAGE MECHANISM OF CONFICTS RESOLVING

Definition 4.1 arbitrage strategies

Strategy 1 :

If conflict(select(Ag_i,α,w), select(Ag_j,α,w)) then Exu(Ag_i,α,w);

Strategy 2 :

If conflict(select(Ag_i,α,w),select(Ag_j,α,w)) and $\exists w_1(w_1 \neq w)$ and capable(Ag_j,α_1) and right(Ag_j,α_1) then Exu(Ag_i,α,w) and Exu(Ag_j,α_1,w_1);

Strategy 3 :

If conflict(select(Ag_i,α,w), select(Ag_j,α,w)) and $\exists w_1(w_1 \neq w)$ and capable(Ag_j,α_1) and ¬right(Ag_j,α_1)and ∃m right(Ag_m,α_1) then Entitle(Ag_m,Ag_j,α_1) and Exu(Ag_i,α,w) and Exu(Ag_j, α_1,w_1);

Strategy 4 :

If conflict(select(Ag_i,α,w),select(Ag_j,α,w)) and $\exists w_1(w_1 \neq w)$ and ¬capable(Ag_j,α_1) and ¬right(Ag_j,α_1) and ∃m capable(Ag_j,α_2) and right(Ag_j,α_2) and capable(Ag_m,α_1) and right(Ag_m,α_1) then Exu(Ag_i,α,w) and Exu(Ag_j,α_2,w_2) and Exu(Ag_m,α_1,w_1).

5 CONCLSION

In this paper we design a negotiation model of Multi-Agent system based on the temporal logic in formal theory. In this model we describe the application of the time and the ability and right of an agent on selecting action and negotiation process in a Multi-Agent system, the change of the right over time, and the free action of an agent.

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