AN IMPROVED MULTI-AGENT COOPERATIVE SOLUTION PROCESS

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Summary
Cooperation is one of multi-agent system's characteristics, which has received a growing attention in the past few years. We present a model of multi-agent cooperative solution that describes the situation of reiteration and failing in cooperation's basic steps based on the work of Wooldridge and Jennings, and consider the effect of environment. The mental state of BDI agents is related to the environment state, we describe the multi-agent system which is combined with the environment state under the partial observable environment. The relationship among the visible operator, observe operator and belief operator is considered and the formal semantics are given in terms of a general model of multi-agent systems. Our model is a better embodiment of dynamic property in multi-agent system and easier to realize than their.
Key words:
Multi-agent; cooperative solution process; environment

1. Introduction

The research on the multi-agent system cooperative solving at present has became an important problem [1,2,3,4,5]. Barber [6] thought that problem solving consists of five relative independence compositions: organization formation, planning formation, task decomposition, planning centralization and execution. The complete cooperative problem solving process represented by Wooldridge and Jennings [7] contains four parts: recognition, team formation, plan formation and execution. But the model can not distinguish between subjective desire and objective capability because which makes assumption that it is not influenced by environment. Wooldridge [8] presented an VSK logic which based on MAS, distinguished all of the objective facts in the external environment: the visible facts, the see facts and the know facts. He combined the external environment states and the internal mental states as global states, and gave a semantic model, described the axiom system using modality operator, but didn't subdivide the mental states. Zhang [9] represented two new operators VIS and SEE which can relate the environment and internal mental state, analyzed the environment and internal mental state separately, and discussed the relationships which exist between them. Then, in paper [10], he introduced three new operators included Able, Fit, Can which can distinguish between subjective desire and objective capability. Moreover, he thought that the cooperative solving process consists of five compositions: motivation, preliminary team formation, task decomposition, final team formation, execution. However, he only considered the cooperation requester's subjective desire and the cooperation supplier's objective capability in the process, didn't consider the supplier's subjective desire. This is illogicality in real word.

Normally, autonomous agent would not accept other's request about cooperation at any time except she chooses to do so because autonomous agent has her own subjective desire. For example, in RoboCup, agent i_1 may think that agent i_2 both has the capability and fits to cooperate with her, but agent i_2 can not accept the request because some reasons. Although i_2 can cooperate with i_1 but she will take part in cooperative activities only if she choose to do so. That's to say she has subjective desire.

In paper [10], there will form more than one teams because of not considered enough factors in the stage of preliminary team formation. Rational agent would not request two teams to do a same cooperative solving task. Moreover, the stage of preliminary team formation may fail in real word, and also the final team formation.

Our work bases on the work of Wooldridge [7] and Zhang [9, 10]. We consider the cooperation supplier's subjective desire. There are four basic stages in our cooperative solving process including motivation, preliminary team formation, final planning and team, execution of the final planning, and the four basic stages may be iterative and failing.

2. Semantic model and basic properties

We extend the model of Zhang [9].

We have operators $(BEL \quad i \quad \varphi)$, $(DES \quad i \quad \varphi)$, $(INT \quad i \quad \varphi)$, $(VIS \quad i \quad \varphi)$ and $(SEE \quad i \quad \varphi)$, which respectively mean that agent i has a belief of φ, agent i has a desire of φ, agent i intents φ, agent i visits φ and agent i sees φ in the current mental state. And we have the operators Able, Fit, Can respectively denote that agent i has the capability to do something, fits to do something and both has the capability to do and fit to do something.

2.1. Semantic model

Definition 1 multi-agent's semantic model is as follows:

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$$M =< E, L, U_{ag}, U_{ac}, U_{gr}, \delta, \gamma, Act, J\_Act, P,$$
$$Rb, Rd, Ri, Rv, Rs, \pi >$$

where

E is the environment state, which comes from the agent's observation.

L is the agent's internal state, including belief, desire and intention.

$U_{ag} = \{i_1, i_2, ..., i_n\}$ is the set of agents.

$U_{ac} = \{Ac_1, Ac_2, ..., Ac_n\}$ is the set of agent's alternative action.

U_{gr} is a set which consists of the subsets of U_{ag}.

δ : $E \times U_{ac} \times U_{ac}, ..., \times U_{ac} \rightarrow E$ is the transition function of state, which is determined by all of the agents' action. We assume the new state is certain after transition.

γ : $U_{ag} \times E \rightarrow 2^{U_{ac}}$ is a set of action that agent can adopt in the environment. Agent can not take any action at any time because of the restriction of environment.

Act : $U_{ag} \rightarrow 2^{U_{ac}}$ is the set of agents' action, $2^{U_{ac}}$ indicates the power set of U_{ac}.

J_Act : $U_{gr} \rightarrow 2^{U_{ac}}$ is the action set which the group of agent can take.

P is the planning set of the final team.

Rb : $U_{ag} \times E \times L \rightarrow 2^L$ denotes all the mental state that an agent's belief can reach in a certain global state $E \times L$, which satisfies three properties: transitive property, Euclidean property and linear property.

Rd : $U_{ag} \times E \times L \rightarrow 2^L$ denotes all the mental state that an agent's all desirability can reach in a certain global state $E \times L$, which satisfies three properties: transitive property, Euclidean property and linear property.

Ri : $U_{ag} \times L \rightarrow 2^L$ denotes all the mental state that an agent's all intention can reach in a certain global state $E \times L$, which satisfies three properties: transitive property, Euclidean property and linear property.

Rv : $U_{ag} \times E \times L \rightarrow 2^E$ denotes all the external environment state that an agent's all visitation can reach in a certain global state $E \times L$, which satisfies three properties: transitive property, Euclidean property and linear property.

Rs : $U_{ag} \times E \times L \rightarrow 2^L$ denotes all the mental state that an agent's all observation can reach in a certain global state $E \times L$, which satisfies three properties: transitive property, Euclidean property and linear property. Agent makes a transition from external visible realities to internal believes by means of this mapping.

π : $Pred \times E \times L \rightarrow \{0,1\}$ is an interpretation function that assigns to each state and each propositional variable a truth value.

Definition 2 the semantics of basic modal operator

$< M, e, l > \models (BEL \quad i \quad \varphi)$ iff $\forall l' \in Rb(i,e,l), < M, e, l' > \models \varphi$

$< M, e, l > \models (DES \quad i \quad \varphi)$ iff $\forall l' \in Rd(i,e,l), < M, e, l' > \models \varphi$

$< M, e, l > \models (INT \quad i \quad \varphi)$ iff $\forall l' \in Ri(i,e,l), < M, e, l' > \models \varphi$

$< M, e, l > \models (VIS \quad i \quad \varphi)$ iff $\forall e' \in Rv(i,e,l)$, $< M, e', l > \models (SEE \quad i \quad \varphi) \vee (SEE \quad i \quad \neg\varphi)$

$< M, e, l > \models (SEE \quad i \quad \varphi)$ iff $\forall e' \in Rv(i,e,l), \forall l' \in Rs(i,e',l), < M, e', l' > \models \varphi$

2.2. The model's basic properties

Axiom 1 $(INT \quad i \quad \varphi) \Rightarrow (BEL \quad i \quad \varphi)$

The belief and intention is consistent, which can expresses as follows according to the reachable relationship: $\forall l' \in Ri(i,e,l)$, has $l' \in Rb(i,e,l)$

Axiom 2 $(INT \quad i \quad \varphi) \Rightarrow (DES \quad i \quad \varphi)$

The intention and desirability is consistent, which can express as $\forall l' \in Ri(i,e,l)$, has $l' \in Rd(i,e,l)$ according to the reachable relationship.

Axiom 3 $(DES \quad i \quad \varphi) \Rightarrow (BEL \quad i \quad (DES \quad i \quad \varphi))$

The desirability is reflexive, which can express as $\forall l' \in Rb(i,e,l), \forall l'' \in Rd(i,e,l)$, has $l' \in Rb(i,e,l'')$ according to the reachable relationship.

Axiom 4 $(INT \quad i \quad \varphi) \Rightarrow (BEL \quad i \quad (INT \quad i \quad \varphi))$

The intention is reflexive, which can express as $\forall l' \in Rb(i,e,l), \forall l'' \in Ri(i,e,l)$, has $l'' \in Ri(i,e,l')$ according to the reachable relationship.

Axiom 5 $(SEE \quad i \quad \varphi) \Rightarrow (BEL \quad i \quad \varphi)$

Axiom 6 $(VIS \quad i \quad \varphi) \Rightarrow (BEL \quad i \quad (VIS \quad i \quad \varphi))$

Axiom 7 $(SEE \quad i \quad \varphi) \Rightarrow (BEL \quad i \quad (SEE \quad i \quad \varphi))$

Definition 2 $(J\_Des \quad g \quad \varphi) =_{def} \forall i, i \in g (Des \quad i \quad \varphi)$

Definition 3

$(Able \quad i \quad \varphi) =_{def} \exists \alpha, \alpha \in Act(i) \wedge (Achieves \quad i \quad \varphi)$

If agent i has the capability in actualizing the goal φ, it shows that there exists an action or action sequence α in the action warehouse of agent i, which makes φ come into existence after executing α .

Definition 4

$$(Agt\quad g\quad \varphi) =_{def} (\neg(M\_Bel\quad g\quad \varphi) \to (J\_Intend\quad g\quad \varphi))$$

The group g take part in realizing the goal of φ , iff there does not exist the mutual believes about φ in the group of g, then there will come into being the group intention about φ . When there is only one element in the group, the definition degenerated as follows:

$$(Agt\quad i\quad \varphi) =_{def} (\neg(Bel\quad i\quad \varphi) \to (Intend\quad i\quad \varphi))$$

Definition 5

$$(Fit\quad i\quad \varphi) =_{def} \forall\phi(((Agt\quad i\quad \varphi) \wedge (Goal\quad i\quad \varphi)) \to (Bel\quad i\quad \varphi)) \to (Goal\quad i\quad \varphi)$$

When agent i takes part in realizing the goal of φ , all of the possible result φ is what agent i desires.

Definition 6

$$(Can\quad i\quad \varphi) =_{def} (Able\quad i\quad \varphi) \wedge (Fit\quad i\quad \varphi)$$

If agent i can achieve the goal of φ , it shows that agent i both has the capability in achieving the goal φ and fits for it. Zhang perfected the definition of agent's ability according to this definition.

Definition 7

$$(J\_Able\quad g\quad \varphi) =_{def} \exists\alpha, \alpha \in J\_Act(g) \wedge (Achieves\quad g\quad \varphi)$$

If the group of g has the capability in realizing the goal of φ , it shows that there exists an action or action sequence α in the action warehouse of group g, which makes φ come into existence after executing α .

Definition 8 $(J\_Fit\quad g\quad \varphi) =_{def} \forall i \in g(Fit\quad i\quad \varphi)$

Definition 9

$$(J\_Can\quad g\quad \varphi) =_{def} (M\_Bel\quad g\,(J\_Able\quad g\quad \varphi) \wedge (J\_Fit\quad g\quad \varphi))$$

Definition 10

$$(request\quad i\quad g\quad \varphi) =_{def} (Goal\quad i\quad \varphi) \wedge \neg(Can\quad i\quad \varphi) \wedge (Bel\quad i\quad (J\_Can\quad g\quad \varphi))$$

The request takes place when agent i has a goal of φ which it can not achieve on its own and believes that g can achieve. When there is only one element in the group, the definition degenerated as follows:

$$(require\quad i_1\quad i_2\quad \varphi) =_{def} (Goal\quad i_1\quad \varphi) \wedge \neg(Can\quad i_1\quad \varphi) \wedge (Bel\quad i_1\quad (Can\quad i_2\quad \varphi))$$

Definition 11

$$(receive\quad g\quad i\quad \varphi) =_{def} (M\_Bel\quad g\quad \neg\varphi \wedge (J\_Can\quad g\quad \varphi) \wedge (J\_Des\quad g\quad \varphi)) \wedge (See\quad g\quad (request\quad i\quad g\quad \varphi))$$

We say that group g receives an agent's cooperation request iff when it sees the agent sends out the cooperation request to them and believes it can and desire to achieve the goal. When there is only one element in the group, the definition degenerated as follows:

$$(receive\quad i_2\quad i_1\quad \varphi) =_{def} (Bel\quad i_2\quad \neg\varphi \wedge (Can\quad i_2\quad \varphi) \wedge (Des\quad i_2\quad \varphi)) \wedge (See\quad i_2\quad (request\quad i_1\quad i_2\quad \varphi))$$

3. The multi-agent cooperative solution process

We divide the cooperative solution process into four basic stages including motivation, preliminary team formation, final planning and team and execution based on the work of Wooldridge[7] and Zhang[10], and the four basic stages may be iterative and failing(see figure (1)).

1.1 Motivation

If agent i hopes for a cooperative solution then some condition need to be satisfied.
Agent i has a goal of φ :

1. i can not achieve φ on its own, because: :
   (1) i does not has the capability to achieve φ
   (2) i does not fit to achieve φ
2. i believes that there exists a group g which can and desire to achieve φ , namely :
   (1) the group g has capability to achieve φ
   (2) the group g fits to achieve φ
   (3) the group g desires to achieve φ

With foregoing definition, we formalize the motivation

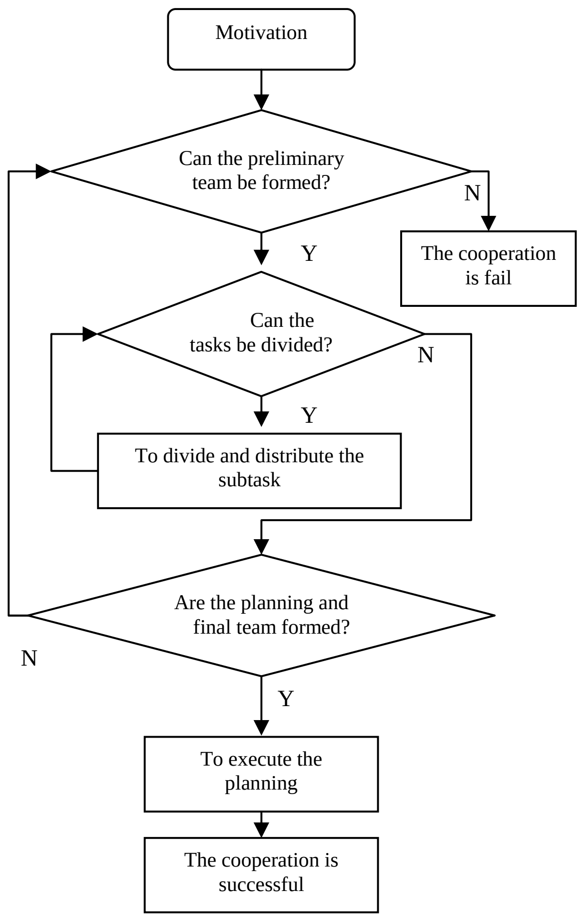

Figure 1.flow chart of the cooperative solution process

of the cooperative solution as follows:

$(Motive' \quad i \quad \varphi) =_{def} (Goal \quad i \quad \varphi) \wedge$

$(Bel \quad i \quad \neg(Can \quad i \quad \varphi) \wedge \exists g$

$((J\_Can \quad g \quad \varphi) \wedge (J\_Des \quad g \quad \varphi))$

Compares with the motive operator which is represented by Zhang [9], Motive' operator considers not only the objective ability but also the subjective desire of the cooperation supplier, which conforms to the real world more.

3.2. Preliminary team formation

The cooperative solution process is possible to success but also possible to fail in the real world.

3.2.1. Preliminary team formation success

Definition 12

$(Successful\_\Pr e\_Team \quad \varphi \quad g \quad i) =_{def}$

$\exists g((request \quad i \quad g \quad \varphi) \wedge (receive \quad g \quad i \quad \varphi))$

Agent i sends out the cooperative request for achieving φ to a group g, and every member in g mutually believes g both can and desire to achieve φ, then they receive the cooperative request. The group g has not make the actual commitment to agent i at present, the commitment is only formal, and the group will make real commitment when the final team formed. We think only the preliminary team is formed now. The situation of two or more teams cannot appear here because a rational agent would not send out request to another group after receiving a cooperation of some one. In fact it is a decision-making or choice when an agent sends out cooperation request. We will discuss in the next article how an agent makes the decision-making or the choice.

3.2.2. Preliminary team formation fail

Definition 13

$(failing\_\Pr e\_Team \quad \varphi \quad g \quad i) =_{def}$

$\forall g(request \quad i \quad g \quad \varphi) \wedge \neg(receive \quad g \quad i \quad \varphi)$

Agent i suffers rejection after sending out the cooperative request to all of the groups she thought can achieve the goal of φ,then the cooperative solution is fail, and the cooperative solution process is unable to continue. The cooperation flow turns to the second stage.

3.3. Final planning and team formation

Definition 14 the decomposability of tasks

$(Div \quad i \quad \varphi \quad g) =_{def} \exists \alpha_1,...,\alpha_n (Achieves \quad \alpha_1;...;\alpha_n \quad \varphi)$

$\vee(Achieves \quad \alpha_1 | ... | \alpha_n \quad \varphi)(n \geq 2)$

This definition shows that a task is decomposable for a group g iff there are two or more relative independent action or sequential actions denoted by α exist and the group can achieve the goal of φ by means of performing α.

Making use of the above definition, we can denote the formal definition of task's decomposition and distribution as follows :

$(Team\_Div \quad i \quad \varphi \quad g) =_{def}$

$((Can \quad i \quad \varphi) \wedge (Des \quad i \quad \varphi)) \vee N,$

where

$N = \exists g_1, ..., g_n \in g, \alpha_1, ..., \alpha_n \in J\_Act(g)$

$(Bel \quad i \quad (Div \quad i \quad \varphi \quad g) \rightarrow M)$

$M = ((Achieves \quad \alpha_1; ...; \alpha_n \quad \varphi) \vee$

$(Achieves \quad \alpha_1 | ... | \alpha_n \quad \varphi)) \wedge (Q_1 \wedge ... \wedge Q_n)$

$Q_1 = ((j\_Can \quad g_1 \quad (Does \quad \alpha_1)) \wedge$

$(J\_Des \quad g_1 \quad (Does \quad \alpha_1))) \vee$

$(\exists i_1 \in g_1 (Team\_Div \quad i_1 \quad (Does \quad \alpha_1) \quad g_1)))$

......

$Q_n = ((j\_Can \quad g_n \quad (Does \quad \alpha_n)) \wedge$

$(J\_Des \quad g_n \quad (Does \quad \alpha_n))) \vee$

$(\exists i_n \in g_n (Team\_Div \quad i_n \quad (Does \quad \alpha_n) \quad g_n)))$

The process of task's decomposition and distribution is recursive and can terminate which is proved by Zhang in [10]. Big task can be decomposed into small task in each recursive step. Agent i will distribute one of the small tasks to a subgroup g_i as long as the group can and desire to perform the small task. If a certain subgroup g_i finds no interest in all of the decomposed small tasks, then it chooses to drop out. If every assignment unit can be performed by an agent or a subgroup when the process of task's decomposition and distribution is terminated, then the final planning and team successfully formed. Formally：

$(successful\_Plan \quad \varphi \quad g \quad i) =_{def} \forall p_i \in P$

$\exists g_j \in g (j\_Can \quad g_j \quad p_i) \wedge (J\_Des \quad g_j \quad p_i)$

otherwise， the negotiation is fail and the final team formation is failure. The cooperation flow turns to the second stage.

$(failing\_Plan \quad \varphi \quad g \quad i) =_{def} \exists \alpha_i \in j\_Act(g)$

$\forall g_j \in g (\neg (j\_Can \quad g_j \quad \alpha_i) \vee \neg (j\_Des \quad g_j \quad \alpha_i))$

According to the definition of Zhang, every minimal task distribution unit will be performed by an agent. This is irrational. We think that the minimal task distribution unit in real word can be performed by an agent or a group. For example, a people cooperates with another in carrying an object, they can carry the object to destination by many ways. We only concern whether there have people to perform the task of carrying the object, don't consider how the action be achieved.

Because Agent has the rational characteristic, she will take part in cooperative activities only if she chooses to do so. The process of task's decomposition and distribution is virtually the process of negotiation, and the negotiation may fail. The agent requested for cooperative solution should look for other's cooperation when the negotiation fail, and the process of cooperative solution should turn to the second stage.

3.4. Execution

$(Team \quad \varphi \quad g \quad i) =_{def}$

$(j\_Commit \quad g \quad \varphi \quad (Goal \quad i \quad \varphi)$

$\wedge (j\_Can \quad g \quad p))$

Generally the rational agent will not drop out the cooperative activities after she made a commitment to a goal, and besides, she is able to successfully achieve the goal she committed. This definition ensures that every member in the group g can make contribution to achieving the goal of φ， and finally urges Agent i and the group g to cooperate successfully, which makes them achieve the goal of φ.

4. Conclusions

This article presented a improved Multi-agent Cooperative Solving Process based on the work of Wooldridge and Zhang, considered the subjective desire of the cooperation supplier and the situation of iteration and failing in the process, which embodied the dynamic properties of multi-agent system, enable the theory more approach to practice. The next step of the work is to study the criterion of agent's subjective desire.

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