

Formal Model of Joint Achievement Intention ^{*}

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Abstract: The joint achievement intention represents the common task of agents to achieve collectively and is an important concept to specify and analyze the social behaviors in multi-agent system. The paper discusses the meaning and characteristics of joint achievement intention, analyzes the limitation and problems in existing work, defines the joint achievement intention with new and clear semantics based on the logic framework of multi-agent system, specifies and proves its important properties. The novel formal model of joint achievement intention can be used to effectively support the development of multi-agent system.

Key words: multi-agent system, joint achievement intention, belief

1. Introduction

Agent is an encapsulated computational entity that is situated in some environment, and that is capable of flexible, autonomous action in that environment in order to meet design objectives [11]. Multi-agent system is composed of a number of interacting and cooperating agents, each of them having limited capabilities and resources. As the abstract model that agent techniques provide can express the computational entities and problem-solving manner in applications more naturally and effectively, much attention has been imposed on the researches of agent techniques nowadays.

In multi-agent system, as the dependencies among agents' actions, the limitation of each agent's capabilities, and the distribution of system's resources, the joint work among agents is absolutely necessary to meet global constraints and natural problem solving. The joint work among agents represents the social behaviors in multi-agent system. In order to develop the multi-agent system, we must put forward some effective tools to specify and analyze such social behaviors, for instance, what is the social behaviors among agents, how will it affect agent's actions, how is it related with agent's internal state such as belief and intention, etc.

In the area of artificial intelligence, agent is taken as an intentional system with such cognitive components as belief, goal, intention, etc. The representative work is the BDI agent architecture. However, the agent's internal cognitive components only define individual behaviors and, as such, are an insufficiently rich base on which to build a principled representation of social behaviors. There are two main limitations with the individualistic approach. Firstly, joint action is more than just the sum of individual action, even if the action happens to be coordinated. For example, it will be somewhat unrealistic to claim that there is

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any real teamwork involved in ordinary automobile traffic, even though the drivers act simultaneously and are coordinated by traffic signs. Secondly, there is a fundamental difference between individuals and groups [10]. Therefore, some new abstract concept model is needed to describe and investigate the joint social behaviors in multi-agent system.

Joint achievement intention is an important abstract concept in distributed artificial intelligence to examine the social behaviors in multi-agent system. The paper is structured as follows. The paper discusses the meaning and characteristics of joint achievement intention informally (see section 2), introduces the existing research work on joint achievement intention and analyzes their limitation (see section 3), and based on logical framework of multi-agent system (see section 4), defines the formal and rigorous semantics of joint achievement intention, specifies and proves its properties (see section 5). The final section concludes the paper and outlines directions for future work.

2. Characteristics of Joint Achievement Intention

The joint achievement intention of agent means that agents will together achieve some preposition by joint behaviors and represents the common task of agents to achieve. It corresponds to the joint intention concept in [2,3,4,11]. In multi-agent system, the purposes of joint social behaviors among agents are not only to achieve some collective tasks, but also to maintain the system state. For instance, there are two robot agents in some environment, which are assigned the task to move objects from one place to another place cooperatively. In order to meet the system constraints, some restriction that the object must be moved horizontally and stably are imposed on the joint social behaviors of the two agents. Obviously, such a restriction will affect the action choice of the related agent in the process of the coordination. However, the traditional meaning and theory of joint intention concept cannot represent and analyze such system constraints, which widely exist in multi-agent system. Therefore, we have introduced a new and novel concept of joint maintenance intention (the work is introduced in other paper). In order to distinguish the joint intention from joint maintenance intention, we give a new name to joint intention as joint achievement intention.

Intuitively, the joint achievement intention has the following properties.

- Action choice, which exhibits some rational choice for future joint behaviors and will restrict the agents' actions. The joint achievement intention is the factor that promotes agents to take joint social behaviors;
- Relativity, including mutual belief and cooperation during the process of joint social behaviors;
- Satisfiable, which means that the joint achievement intention of agents is achievable;
- Persistent, which means agents will not abandon their joint achievement intention in the process of joint social behaviors, and exhibits some commitment to joint social behaviors;
- Consistent, which means that it is consistent among several joint achievement intentions, and agents' joint achievement intention should be consistent with individual agent's internal state;
- Non-conflict, which means that there is no conflict among several joint achievement

intentions of agent;

- Consistent with belief, which means that agents' joint achievement intention should be consistent with agents' belief. If agents have some joint achievement intention, then they should believe that the joint achievement intention should be achievable.

3. Evaluation of Existing Work

There are many researchers in the area of computer science and philosophy investigating joint intention. The representative research is Cohen and Levesque's work [2], which introduces joint intention concept to handle cooperative intentions. Joint intentions are intended to clarify the relationships among beliefs, desires and intentions for multiple agents.

Joint intentions' theory of Cohen and Levesque is developed in three levels. Firstly, they define *weak goals*, which specify the conditions under which an agent holds a goal, and the actions it must take if the goal is satisfied or impossible.

$$\begin{aligned} \mathbf{WG}(x, y, p) = & (\neg \text{Bel}(x, p) \wedge \text{Goal}(x, \diamond p)) \vee (\text{Bel}(x, p) \wedge \text{Goal}(x, \diamond \text{MB}(x, y, p))) \\ & \vee (\text{Bel}(x, \square \neg p) \wedge \text{Goal}(x, \diamond \text{MB}(x, y, \square \neg p))) \end{aligned}$$

The above definition means that $\mathbf{WG}(x, y, p)$ is satisfied if and only if one of the following conditions hold: (1) agent x believes that p is not true and desires p to be true at some future time; (2) agent x believes that p is already true and desires that y also mutually believes that p is true; (3) agent x believes that p will never be satisfied and wants y to mutually believe that p will never be satisfied.

Secondly, they define *joint persistent goals* for multiple agents.

$$\begin{aligned} \mathbf{JPG}(x, y, p, q) = & \text{MB}(x, y, \neg p) \wedge \text{MG}(x, y, p) \wedge \\ & \text{Until}(\text{MB}(x, y, p) \vee \text{MB}(x, y, \square \neg p) \vee \text{MB}(x, y, \neg q), \text{MB}(x, y, (\text{MG}(x, y, p) \wedge \text{MG}(y, x, p)))) \end{aligned}$$

In order to hold a joint persistent goal, agents must therefore: (1) Mutually believe that the p is not satisfied; (2) Hold p as a mutual goal; (3) Hold p as a weak mutual goal until either they mutually believe that p is satisfied, or they mutually believe that p will never be satisfied, or they mutually believe that some other condition q will never be satisfied.

Finally, they define *joint intentions* in terms of weak goals and joint persistent goals.

$$\mathbf{JI}(x, y, a, q) = \text{JPG}(x, y, \text{DONE}(x, y, \text{Until}(\text{DONE}(x, y, a), \text{MB}(x, y, \text{DOING}(x, y, a))))?; a, q)$$

The theory of Cohen and Levesque gives entire meaning of joint intention. However, there are a number of limitations and shortcomings in it. Firstly, action choice is the basic and essential characteristics of joint intention. Their work defines the semantics of joint intention concept based on the linear temporal logic and possible world model. Therefore, the semantics definition of joint intention cannot well capture the action choice characteristics. Secondly, the semantics definition of joint intention includes the modification strategy of joint intention, which not only cannot well describe the essential meaning of joint intention, but also make the theory much more complicated. Thirdly, the semantics definition is based on possible world model, which has logical omniscience problem.

Other researches include Nunes, Raimo, Jennings's work [3,4,10]. Some of them extend Cohen and Levesque's theory, others investigate the joint intention from the point of philosophy. Here we will not introduce and give comments on them.

4. Logical Framework

The semantics definition of joint intention is based on logical framework of multi-agent system, which includes three parts: syntax, model and semantics. The formal language L is the extension of branch temporal logic $CTL^*[7]$, which is composed of two parts: state formulas L_t and path formulas L_s , defined in the follows. Let Φ is the atomic proposition symbol set, $Const_{ag}$ agent symbol set. To simplify description, the paper has the following symbol convention: p, q, \dots as proposition symbol, and φ, ψ, \dots as formula, and x, y, \dots as agent symbol.

Definition 4.1 (Syntax of Language L) The formal language L is the smallest closed set defined by the following rules

- (1) if $p \in \Phi$, then $p \in L_t$
- (2) if $\psi, \varphi \in L_t$ and $x, y \in Const_{ag}$, then $\neg\varphi, \psi \wedge \varphi, \mathbf{Bel}(x, \varphi), \mathbf{MB}(x, y, \varphi), \mathbf{AI}(x, y, \varphi), \mathbf{MAI}(x, y, \varphi), \mathbf{MAB}(x, y, \varphi), \mathbf{WAC}(x, y, \varphi), \mathbf{MAC}(x, y, \varphi), \mathbf{JAI}(x, y, \varphi) \in L_t$
- (3) $L_t \subseteq L_s$
- (4) if $\psi, \varphi \in L_s, x \in Const_{ag}$, then $\neg\varphi, \psi \wedge \varphi, \psi \mathbf{Until} \varphi, \psi \mathbf{Until}_{\forall} \varphi \in L_s$
- (5) if $\varphi \in L_s$, then $A\varphi \in L_t$

Definition 4.2 (Formal Model of L) The formal model of L is defined as $M = \langle T, <, U_{ag}, \pi, [], B, C \rangle$, where T is moment set, each member of which representing a world state. $<$ is a partial order on T , which describes the temporal order among moments. The past of each moment is deterministic and linear. It's future may be branching. Figure1 give a schematic description of formal model that is tree-like structure. U_{ag} is an agent set. $\pi: \Phi \rightarrow \wp(T)$ defines the moment set at which p is satisfied. $[]$ defines the assignment to agent symbol. $B: U_{ag} \rightarrow \wp(T \times T)$, $(t, t') \in B(x)$ means that at moment t agent believes that moment t' is possible and is used to define agent's belief.

A path at moment t describing some way that the world may evolve is a branch that evolves from t and is composed of future moment of t .

Definition 4.3 (Path) A path of moment t is a set $S \subseteq T$ which satisfies: (1) $t \in S$; (2) $\forall t_1, t_2 \in S: (t_1 < t_2) \vee (t_2 < t_1) \vee (t_1 = t_2)$; (3) $\forall t_1, t_2 \in S; t_3 \in T: (t_1 < t_3 < t_2) \Rightarrow (t_3 \in S)$; (4) $\forall t_1 \in S; t_2 \in T: (t_1 < t_2) \Rightarrow (\exists t_3 \in S: (t_1 < t_3) \wedge \neg(t_3 < t_2))$; (5) $\forall t_1 \in S: (t = t_1) \vee (t < t_1)$

(1) denotes that the path of moment t contains t ; (2) describes the linearity property of the path; (3) describes the density property; (4) describes the relative maximum; (5) denotes the initiate of the path. Let S_t the set of all paths at moment t , $S_{\mathcal{F}}$ the set of all paths.

In multi-agent system, each agent takes actions concurrently and asynchronously. At any moment, agent can take action to influence and control the way that the world evolves. However, such an influence is limited, because the way that the world may evolve is also influenced and controlled by the environment events and the actions that other agents take. All of the actions taken by agents in multi-agent system and the environment events together determine the evolution way of the world.

For example, Figure1 describes a formal model of a multi-agent system composed of two agents. The node in the figure denotes moment represented by a set of propositions. The edge denotes the combination of actions taken by all agents. The symbol “||” denotes that the actions of several agents are taken concurrently. In order to simplify description, we assume that the

action symbol on the left part of “||” represents the action of agent₁ and the right part represents the action of agent₂. At moment t_0 agent₁ can take action a to make the world evolve to the moment t_1 or t_2 , or take action b to make the world evolve to the moment t_3 or t_4 . But when agent₁ take action a , whether the world evolves toward moment t_1 or moment t_2 is also depended on the action taken by agent₂. When agent₂ takes action c , then the world evolves to moment t_1 . If agent₂ takes action d , then the world evolves to moment t_2 .

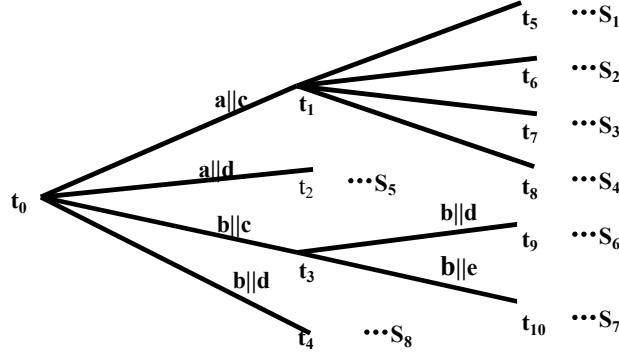


Figure1. formal model of multi-agent system

$C: U_{ag} \times T \rightarrow \wp(S_{\Sigma})$ is to define joint intention of agent, where $C(x, t)$ is the path set that agent chooses at moment t and $C(x, t) \subseteq S_t$. To simplify research, there is a model constraint: $\forall t \in T, x \in U_{ag}: C(x, t) \neq \emptyset$.

The satisfactory semantics of the formula in L_t is defined by model M and moment t . $M \models_t \varphi$ denotes that formula φ is satisfied at the moment t in model M . The satisfactory semantics of the formula in L_s is defined by model M , path S and moment t . $M \models_{s,t} \psi$ denotes that formula ψ is satisfied at moment t on path S of moment M .

Definition 4.4 (Semantics of L)

- (1) $M \models_t p$ iff $t \in \pi(p)$
- (2) $M \models_t \psi \wedge \varphi$ iff $M \models_t \psi$ and $M \models_t \varphi$
- (3) $M \models_t \neg \varphi$ iff $M \not\models_t \varphi$
- (4) $M \models_t \mathbf{A}\varphi$ iff $\forall S: S \in S_t \Rightarrow M \models_{s,t} \varphi$
- (5) $M \models_t \mathbf{Bel}(x, \varphi)$ iff $\forall t': (t, t') \in B(x) \Rightarrow M \models_{t'} \varphi$
- (6) $M \models_t \mathbf{MB}(x, y, \varphi)$ iff $M \models_t \mathbf{Bel}(x, \varphi)$ and $M \models_t \mathbf{Bel}(y, \varphi)$
- (7) $M \models_{s,t} \psi \wedge \varphi$ iff $M \models_{s,t} \psi$ and $M \models_{s,t} \varphi$
- (8) $M \models_{s,t} \neg \varphi$ iff $M \not\models_{s,t} \varphi$
- (9) $M \models_{s,t} \psi \mathbf{Until} \varphi$ iff $\exists t' \in S: (t \leq t')$ and $(M \models_{s,t'} \varphi)$ and $(\forall t'': t \leq t'' < t' \Rightarrow M \models_{s,t''} \psi)$
- (10) $M \models_{s,t} \psi \mathbf{Until}_{\forall} \varphi$ iff $\forall t' \in S: (\forall t'': t \leq t'' \leq t' \Rightarrow M \models_{s,t''} \neg \varphi) \Rightarrow M \models_{s,t'} \psi$
- (11) $M \models_{s,t} \varphi$ iff $M \models_t \varphi$, where $\varphi \in L_t$.

Other operators can be derived based on the above semantics definition. **Until** is a “until” operator, **Until_∃** is a weak “until” operator. $\mathbf{F}\varphi = \text{true } \mathbf{Until} \varphi$ is existential temporal operator. \mathbf{G} is the dual of \mathbf{F} and is universal temporal operator. \mathbf{A} is universal path operator, $\mathbf{A}\varphi$ is satisfied at moment t if and only if φ is satisfied on all paths of moment t . \mathbf{E} is the dual of \mathbf{A} , that is $\mathbf{E}\varphi = \neg \mathbf{A}(\neg \varphi)$, therefore \mathbf{E} is existential path operator. $\mathbf{Bel}(x, \varphi)$ denotes that agent_x has belief φ . Here, we assume that $B(x)$ is reflexive and transitive. Therefore **Bel** corresponds to the modal operator in S4 normal modal system.

Theorem 4.1 *Bel* has the following properties:

- (1) $\models \mathbf{Bel}(x, \varphi) \rightarrow \varphi$
- (2) $\models \mathbf{Bel}(x, \varphi) \rightarrow \mathbf{Bel}(x, \mathbf{Bel}(x, \varphi))$
- (3) $\models \mathbf{Bel}(x, \varphi) \wedge \mathbf{Bel}(x, \varphi \rightarrow \psi) \rightarrow \mathbf{Bel}(x, \psi)$
- (4) if $\models \varphi$, then $\models \mathbf{Bel}(x, \varphi)$

5. Joint Achievement Intention Theory

We will extend the intention theory in [1] to establish the theory framework of joint achievement intention in multi-agent system, investigate the relationship between joint achievement intention with the belief and intention of individual agent.

5.1. Intention

The achievement intention of individual agent means that agent intends to achieve some proposition, which is the abstract representation of agent's task and goal. The formal model of multi-agent system is a tree-like structure, each branch at any moment denoting the possible choice that agent may select. The achievement intention φ of agent means that agent selects the world evolving paths, on each of which agent believes that φ will be satisfied eventually.

Definition 5.1.1 (Achievement Intention) $M \models_t \mathbf{AI}(x, \varphi)$ iff

$$M \models_t \mathbf{Bel}(x, \neg\varphi) \text{ and } (\forall S: S \in C(x, t) \Rightarrow M \models_{s,t} \mathbf{FBel}(x, \varphi))$$

The above semantics defines the basic characteristic of achievement intention, i.e., action choice. Different from existing methods, we define achievement intention as the choice of the world evolving paths, not the accessible relationship between possible worlds. In the formal model, the world evolving path is related to agent's action. Such a definition not only clearly describes the choice characteristic of achievement intention and how agent's intention will restrict agent's future behaviors.

5.2. Joint Achievement Intention

Action choice and relativity are the basic and essential characteristics of joint intention. In the following we will define the semantics of joint intention based on the two characteristics, analyze and validate its important properties. One of the preconditions of joint intention is that the both sides of agents have the common choice, viz. with the same achievement intention.

Definition 5.2.1 (Common Achievement Choice) $\mathbf{MAI}(x, y, \varphi) = \mathbf{AI}(x, \varphi) \wedge \mathbf{AI}(y, \varphi)$

Two agents having the common choice do not mean that they have the joint intention. The relativity condition must be satisfied before forming joint intention, which includes two parts: mutual belief intention and cooperation.

Definition 5.2.2 (Mutual Achievement Belief) $\mathbf{MAB}(x, y, \varphi) = \mathbf{MB}(x, y, \mathbf{AI}(x, \varphi) \wedge \mathbf{AI}(y, \varphi))$

$\mathbf{MAB}(x, y, \varphi)$ means agent_x and agent_y mutual know that the two sides have the achievement intention φ . In order to define the semantics of mutual achievement cooperation, we firstly introduce the "weak achievement cooperation" concept.

Definition 5.2.3 (Weak Achievement Cooperation) $\mathbf{WAC}(x, y, \varphi) =$

$$(Bel(x, \varphi) \wedge \neg Bel(x, Bel(y, \varphi)) \rightarrow AI(x, MB(x, y, \varphi))) \wedge \\ (Bel(x, AG\neg\varphi) \wedge \neg Bel(x, Bel(y, AG\neg\varphi)) \rightarrow AI(x, MB(x, y, AG\neg\varphi)))$$

$AG\neg\varphi$ means that φ will never be satisfied on all paths. $WAC(x, y, \varphi)$ denotes that agent_x has weak achievement cooperation with agent_y with regard to φ . $WAC(x, y, \varphi)$ is satisfied, if and only if, when agent_x knows that φ is satisfied and does not know that agent_y knows φ is satisfied, then agent_x intend to let two sides know φ is satisfied, and when agent_x knows that φ will never be satisfied and does not know that agent_y knows φ will never be satisfied, then agent_x intend to let two sides know φ will never be satisfied. In term of the weak achievement cooperation, the semantics of mutual achievement cooperation is defined as follows.

Definition 5.2.4 (Mutual Achievement Cooperation) $M \models_t MAC(x, y, \varphi)$ iff

$$(\forall S: S \in C(x, t) \Rightarrow M \models_{s, t} (MB(x, y, WAC(x, y, \varphi) \wedge WAC(y, x, \varphi)) \text{ Until } \neg AI(x, \varphi)) \\ \text{and } (\forall S: S \in C(y, t) \Rightarrow M \models_{s, t} (MB(x, y, WAC(x, y, \varphi) \wedge WAC(y, x, \varphi)) \text{ Until } \neg AI(y, \varphi)))$$

$MAC(x, y, \varphi)$ denotes that agent_x and agent_y have the mutual achievement cooperation φ . $MAC(x, y, \varphi)$ is satisfied if and only if the both sides mutual know that they will cooperate with each other until they drop their achievement intention.

Definition 5.2.5 (Joint Achievement Intention)

$$JAI(x, y, \varphi) = MAI(x, y, \varphi) \wedge MAB(x, y, \varphi) \wedge MAC(x, y, \varphi)$$

$JAI(x, y, \varphi)$ denotes that agent_x and agent_y have the joint achievement intention φ . $JAI(x, y, \varphi)$ is satisfied, if and only if, that they have the common choice, and they know their common choice, and they know they will cooperation with each other during the process of achieving joint intention. The above semantics definition clearly and exactly describes the essential characteristic of joint achievement intention, viz. action choice and relativity. Based on the semantics, a number of important properties of joint achievement intention can be specified and proved.

Theorem 5.2.1 $\models JAI(x, y, \varphi) \rightarrow MB(x, y, \neg\varphi)$

The theorem describes the condition under which agents will accept or drop their joint achievement intention. agent_x and agent_y have joint achievement intention φ only if agent_x and agent_y mutual believe that φ is not satisfied. Rational agents will not jointly achieve proposition that is already satisfied. The theorem can be proved by the semantics definition of JAI , MB and AI .

Theorem 5.2.2 (Consistent) $\models \neg(JAI(x, y, \varphi) \wedge JAI(x, y, \neg\varphi))$

The theorem denotes that the joint achievement intentions of agents should be consistent. At any moment, agents cannot have the joint achievement intention φ and at the same time have the joint achievement intention $\neg\varphi$. The theorem can be proved by theorem 5.2.1 and theorem 4.1.

Theorem 5.2.3 (Consistent with individual's achievement intention)

$$\models \neg(JAI(x, y, \varphi) \wedge (AI(x, \neg\varphi) \vee AI(y, \neg\varphi)))$$

The above theorem shows that agent's joint achievement intention is consistent with individual agent's internal achievement intention. At any moment, agent will not have the joint achievement intention φ and at the same time have the achievement intention $\neg\varphi$. According to the theorem 4.2.1, together with the semantics of JAI , MB and AI , the theorem can be proved.

Theorem 5.2.4 (Satisfiable) $\models JAI(x, y, \varphi) \rightarrow MB(x, y, EF\varphi)$

$EF\varphi$ denotes that there exists a path on which φ will be eventually satisfied. Agents' joint

achievement intention should be satisfiable, or achievable. If agent_x and agent_y have the joint achievement intention ϕ , then they should mutual believe that ϕ is satisfiable. The theorem can be proved according to semantics of *JAI*, *MAB*, *AI*, and the model constraint: $\forall t \in T, x \in U_{ag}: C(x, t) \neq \emptyset$ in section 4.

Theorem 5.2.5 (Consistency with belief)

$$\models \neg (JAI(x, y, \phi) \wedge (Bel(x, \neg EF\phi) \vee Bel(y, \neg EF\phi)))$$

The theorem shows that agents' joint achievement intention should be consistent with agents' belief. Agent will not have the joint achievement intention ϕ and at the same time believes that ϕ is not achievable. The theorem can be proved by theorem 5.2.4 and theorem 4.1.

Theorem 5.2.6 (Non-Conflict) $\models JAI(x, y, \phi) \wedge JAI(x, y, \psi) \rightarrow MB(x, y, E(F\phi \wedge F\psi))$

The theorem shows that the joint achievement intentions of agent should be non-conflict. If agent_x and agent_y have joint achievement intention ϕ and ψ , then they mutually believe that there exists a path on which ϕ and ψ will be eventually satisfied respectively. The theorem can be proved by semantics of *JAI*, *MAB*, *AI*, and theorem 4.1.

Persistency is another important property of joint achievement intention. The joint achievement intention has the following persistency axiom.

Axiom 5.2.1 (Persistency Axiom)

$$A(JAI(x, y, \phi) \rightarrow JAI(x, y, \phi) \text{ Until}_{\vee} (MB(x, y, \phi) \vee MB(x, y, \neg EF\phi)))$$

The above axiom shows that if agent_x and agent_y have the joint achievement intention ϕ , then agent will persistently hold the joint achievement intention until they know that ϕ is satisfied or is impossible to achieve. In order to make the axiom sound, some constraint is imposed on the formal model: $\forall t \in T; S \in \mathbf{S}_{\Sigma}; x, y \in U_{ag}: M \models_t JAI(x, y, \phi) \Rightarrow$

$$(\forall t' \in S: (\forall t'' : t \leq t'' \leq t' \Rightarrow M \models_{t''} \neg (MB(x, y, \phi) \vee MB(x, y, \neg EF\phi)))) \Rightarrow M \models_{t'} JAI(x, y, \phi)$$

6. Conclusion

The paper explains the significance and importance of making research on the joint achievement intention, analyzes the existing work and its limitations, discusses the characteristics of joint achievement intention. Based on the logical framework of multi-agent system, the new semantics of joint achievement intention is defined, a number of important properties are specified and proved. Different from existing work, the semantics definition of joint achievement intention is not based on the possible world accessible relation, but on the choice of world evolving paths in the formal model. We don't incorporate the modification strategy of joint achievement intention into its semantics definition. Such a semantics definition clearly captures and describes the basic and essential characteristics of joint achievement intention.

The theorem framework of joint achievement intention can effectively support analysis and design of multi-agent system, especially investigation of social behaviors of multi-agent system. The further work includes to specify and validate the interaction behaviors and cooperation model based on the theorem framework.

Reference

1. P.R.Chen, H.J.Levesque. Intention is choice with commitment. *Artificial Intelligence*, 1990, 42(2-3) : 213~261.
2. P.R.Chen and H.J.Levesque. Teamwork. *Nous*, 21, 1991.
3. Raimo Tuomela. Collective and joint intention. *Proceeding of cognitive theory of social action*, 1998.
4. Raimo Tuomela. Philosophy and distributed artificial intelligence: The case of joint intention. *Foundation of distributed artificial intelligence*, John Wiley&Sons, 1996: 487~504.
5. Mao Xinjun, Wang Huaiming. The intention theory of agent computing in multi-agent system, *Journal of software*, 1999, 10(1): 43~48.
6. Singh M P. Multiagent System: A Theoretical framework for Intentions, Know-how, and Communications. Berlin, Heidelberg: Springer-Verlag, 1994.
7. B.Chellas. Modal logic: an introduction. Cambridge University Press, Cambridge, MA,1980.
8. B. Dunin-Keplicz and R.Verbrugge. Collective Commitment. In *Proceeding of the second international conference on multi-agent system*, Menlo Park,CA,1996.
9. Panzarasa, P and N.R.Jennings. Social mental shaping: Modelling the impact of sociality on the mental state of autonomous agents. *Computational Intelligence*, 2001.
10. N.R.Jennings. Specification and implementation of belief-desire-joint intention architecture for collaborative problem solving. *Journal of Intelligent and Cooperative Information Systems*, 1993, 2 (3): 289~318.
11. N.R.Jennings. Building complex software system: the case for an agent-based approach. *Communication of ACM*, 2001.