Formal Model of Joint Maintenance Intention*

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Abstract. Agent-oriented technique represents an exciting new means to develop complex software system. The paper presents a novel abstract concept of joint maintenance intention to represent joint constraints of social behaviors in multi-agent system. The joint maintenance intention's meaning and characteristics are discussed, the formal and rigorous semantics is defined, and some important properties are specified and proved. The abstract concept model and its theoretical results can effectively be used to specify, validate and refine multi-agent system.

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

1. Introduction

Agent is an encapsulated computational entity that is situated in some environment, and capable of flexible, autonomous actions 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, many attentions have 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 are absolutely necessary to meet global constraints and natural problem solving. The joint work among agents represents the social behavior, which is accomplished by a number of agents cooperatively. 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

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affect related 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 research is the BDI agent architecture, in which agent is composed of three cognitive components as belief, desire, and intention. 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 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 examine the joint social behaviors in multi-agent system.

Joint intention is an important abstract concept in distributed artificial intelligence to examine the social behaviors among agents in multi-agent system. It exhibits the common task and goal that multi-agent intend to jointly achieve [2,3,4,10]. 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 condition. 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.

There are many researchers investigating joint intention in the area of computer science and philosophy. The representative work is Cohen and Levesque's research [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. Other researches include Nunes, Raimo and Jennings's work [3,4,8,9,10]. Some of them extend Cohen and Levesque's theory; others investigate the joint intention from the point of philosophy. However, all of these researches do not deal with the joint maintenance problems.

For the purpose of effectively specifying the social behavior constraints, investigating the cooperation among agents in multi-agent system, we introduce a new and novel concept of joint maintenance intention. Different from the joint intention concept, the joint maintenance intention is to maintain and keep some condition and state of the system during the coordination process.

The paper is structured as follows. Section 2 informally discusses the meaning and characteristics of joint maintenance intention. Section 3 introduces the logical framework of multi-agent system. In section 4, we will define the formal and rigorous semantics of joint maintenance intention, specify and prove a number of important and essential properties. Section 5 gives a sample and demonstrates how to apply the

approach and theoretical results in practice. The final section concludes the paper, and outlines directions for future and further research.

2. Characteristics of Joint Maintenance Intention

The joint maintenance intention of agents' means that agents will work together to maintain some preposition by joint behaviors and represents the system constraints in the process of cooperation. Intuitively, the joint maintenance intention has the following properties. These properties are essential when examining the abstract concept model of joint maintenance intention, necessary to investigate the agents' social behaviors and important to specify, validate and refine multi-agent system.

- Joint action choice, which exhibits some rational choice for future joint behaviors and will restrict the agents' actions.
- Relativity, including mutual belief and cooperation during the process of joint social behaviors.
- Satisfiable, which means that the joint maintenance intention of agents is maintainable.
- Persistent, which means agents will not abandon their joint maintenance 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 maintenance intentions, and agents' joint maintenance intention should be consistent with individual agent's internal state.
- Non-conflict, which means that there are no conflicts among several joint maintenance intentions of agents.
- Consistent with belief, which means that agents' joint maintenance intention should be consistent with agents' belief. If agents have some joint maintenance intention, then they should believe that the joint maintenance intention should be maintainable.

3. 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 a branch temporal logic extended based on works in [5,6,7], which is composed of two parts: state formulas set $\boldsymbol{L_t}$ and path formulas set $\boldsymbol{L_s}$. 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,… as proposition symbol, and φ, ψ, … as formula, and x, y, … as agent symbol.

- Definition 3.1 (Syntax of Language L)
  The formal language $\boldsymbol{L}$ is the smallest closed set defined by the following rules
  - if $p \in \Phi$, then $p \in \boldsymbol{L_t}$
  - if $\psi, \varphi \in \boldsymbol{L_t}$ and $x, y \in \text{Const}_{ag}$, then $\neg\varphi$, $\psi \wedge \varphi$, $\boldsymbol{Bel}(x, \varphi)$, $\boldsymbol{MB}(x, y, \varphi)$,

AI(x,y,φ), ***MI***(x, y, φ), ***MMI***(x, y, φ), ***MMB***(x, y, φ) , ***WMC***(x, y, φ) , ***MMC***(x, y, φ), ***JMI*** (x, y, φ) $\in \boldsymbol{L_t}$

- $\boldsymbol{L_t} \subseteq \boldsymbol{L_s}$
- if ψ, φ$\in \boldsymbol{L_s}$, x$\in$ Const$_{ag}$, then ¬φ, ψ∧φ, ψ ***Until*** φ, ψ***Until***$_{\forall}$ φ $\in \boldsymbol{L_s}$
- if φ$\in \boldsymbol{L}_s$, then $\boldsymbol{A}$φ$\in \boldsymbol{L_t}$

The formal model of language $\boldsymbol{L}$ is a structure $\boldsymbol{M}$ = < T, <, U_{ag}, π, [ ], B, C >, 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, and it's future may be branching. Fig.1 gives a schematic description of formal model that is a tree-like structure. U_{ag} is an agent set. π: Φ $\rightarrow \wp$(T) defines the moment set at which atomic proposition symbol is satisfied. [ ] defines the assignment to agent symbol. B: $U_{ag} \rightarrow \wp$(T×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. C: U_{ag}×T$\rightarrow \wp(\mathbf{S}_S)$ defines the choice of agent, where C(x, t) is the path set that agent chooses at moment *t* and C(x,t)$\subseteq \mathbf{S_t}$ ($\mathbf{S}_S$ and $\mathbf{S_t}$ defined as follows). To simplify, there is a model constraint: $\forall$t$\in$T, x$\in U_{ag}$: C(x, t) $\neq \varnothing$.

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 moments of *t*.

- Definition 3.2 (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 $\boldsymbol{S_t}$ the set of all paths at moment t, $\boldsymbol{S}_S$ 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 ways that the world evolves. However, such an influence is limited, because the ways that the world may evolve are 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 ways of the world.

For example, Fig.1 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 agent$_1$ and the right part represents the action of agent$_2$. At moment t_0 agent$_1$ 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 agent$_1$ take action *a*, whether the world evolves toward moment t_1 or moment t_2 is also depended on the action taken by agent$_2$. When agent$_2$ takes action *c*, then the world evolves to

moment t_1. If agent$_2$ takes action d, then the world evolves to moment t_2.

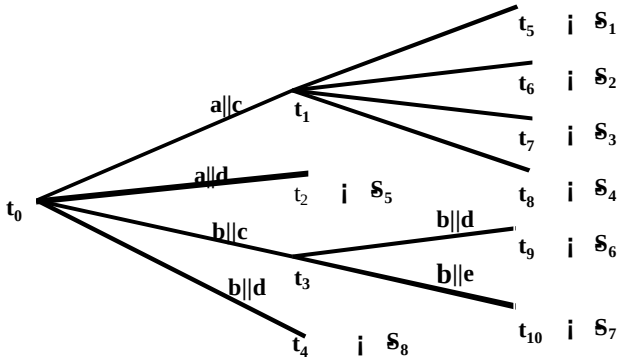


Fig. 1. The formal model of multi-agent system is a tree-like structure. The nodes represent moments, and the edges represent agents ' actions.

The satisfactory semantics of the formula in $\boldsymbol{L_t}$ 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 $\boldsymbol{L_s}$ 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 S of model M.

- Definition 3.3 (Semantics of L)
  - $M \models_t p$ iff $t \in \pi(p)$
  - $M \models_t \psi \wedge \varphi$ iff $M \models_t \psi$ and $M \models_t \varphi$
  - $M \models_t \neg\varphi$ iff $M \not\models_t \varphi$
  - $M \models_t \boldsymbol{A}\varphi$ iff $\forall S: S \in \mathbf{S_t} \Rightarrow M \models_{s,t} \varphi$
  - $M \models_t \boldsymbol{Bel}(x, \varphi)$ iff $\forall t': (t, t') \in B([x]) \Rightarrow M \models_{t'} \varphi$
  - $M \models_{s,t} \psi \wedge \varphi$ iff $M \models_{s,t} \psi ? M \models_{s,t} \varphi$
  - $M \models_{s,t} \neg\varphi$ iff $M \not\models_{s,t} \varphi$
  - $M \models_{s,t} \psi \boldsymbol{Until} \varphi$ iff $\exists t' \in S: (t \le t')$ and $(M \models_{s,t'} \varphi)$ and $(\forall t'': t \le t'' < t' \Rightarrow M \models_{s,t''} \psi)$
  - $M \models_{s,t} \psi \boldsymbol{Until}_{\forall} \varphi$ iff $\forall t' \in S: (\forall t'': t \le t'' \le t' \Rightarrow M \models_{s,t''} \neg\varphi) \Rightarrow M \models_{s,t'} \psi$
  - $M \models_{s,t} \varphi$ iff $M \models_t \varphi$, where $\varphi \in \boldsymbol{L_t}$.
  - $M \models_t \boldsymbol{MB}(x, y, \varphi)$ iff $M \models_t \boldsymbol{Bel}(x, \varphi)$ and $M \models_t \boldsymbol{Bel}(y, \varphi)$

Other operators can be derived based on the above semantics definition. ***Until*** is a "until" operator, $\boldsymbol{Until}_{\forall}$ is a weak "until" operator. $\boldsymbol{F}\varphi$ = true ***Until*** φ is an existential temporal operator. $\boldsymbol{G}$ is the dual of $\boldsymbol{F}$ and is a universal temporal operator. $\boldsymbol{A}$ is a universal path operator, $\boldsymbol{A}\varphi$ is satisfied at moment t if and only if φ is satisfied on all paths of moment t. $\boldsymbol{E}$ is the dual of $\boldsymbol{A}$, that is $\boldsymbol{E}\varphi = \neg\boldsymbol{A}(\neg\varphi)$, therefore $\boldsymbol{E}$ is an existential path operator. $\boldsymbol{Bel}(x, \varphi)$ 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 3.1 *Bel* has the following properties:
  - $\models \boldsymbol{Bel}(x, \varphi) \rightarrow \varphi$
  - $\models \boldsymbol{Bel}(x, \varphi) \rightarrow \boldsymbol{Bel}(x, \boldsymbol{Bel}(x, \varphi))$
  - $\models \boldsymbol{Bel}(x, \varphi) \wedge \boldsymbol{Bel}(x, \varphi \rightarrow \psi) \rightarrow \boldsymbol{Bel}(x, \psi)$

– if $\models \varphi$, then $\models \boldsymbol{Bel}(x, \varphi)$

4. Formal Model of Joint Maintenance Intention

We will extend the intention theory in [5,1] to establish the novel formal model of joint maintenance intention in multi-agent system, investigate the relationship between joint maintenance intention with the belief and intention of individual agents.

4.1. Definition of Basic Concept

The achievement intention of individual agent means that agent intends to achieve some preposition, 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 4.1.1 (Achievement Intention)
  $M \models_t \boldsymbol{AI}(x, \varphi)$ iff $M \models_t \boldsymbol{Bel}(x, \neg\varphi)$ and $(\forall S: S \in C(x, t) \Rightarrow M \models_{s,t} \boldsymbol{FBel}(x, \varphi))$

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, but also can help us to define the semantics of maintenance intention.

The maintenance intention of agent means that agent intends to maintain some proposition. It is the abstract representation of the system constraints in the process of social behaviors that widely exist in multi-agent system.

- Definition 4.1.2 (Maintenance Intention)
  $M \models_t \boldsymbol{MI}(x, \varphi)$ iff $(\forall S: S \in C(x, t) \Rightarrow M \models_{s,t} \boldsymbol{GBel}(x, \varphi))$

4.2. Joint Maintenance Intention

The precondition of $agent_x$ and $agent_y$ having joint maintenance intention φ is that they have the common choice, on which φ is maintained.

- Definition 4.2.1 (Common Maintenance Choice)
  $\boldsymbol{MMI}(x, y, \varphi) = \boldsymbol{MI}(x, \varphi) \wedge \boldsymbol{MI}(y, \varphi)$

Common choice of agents does not mean that they have the joint maintenance intention. In order to form joint maintenance intention, they must have relativity characteristics, viz. mutual belief maintenance intention and mutual cooperation.

- Definition 4.2.2 (Mutual Maintenance Belief)
  $\boldsymbol{MMB}(x, y, \varphi) = \boldsymbol{MB}(x, y, \boldsymbol{MI}(x, \varphi) \wedge \boldsymbol{MI}(y, \varphi))$

In order to define the semantics of joint maintenance intention, we firstly introduce and define the semantics of weak maintenance cooperation.

- Definition 4.2.3 (Weak Maintenance Cooperation)
  $\boldsymbol{WMC}(x, y, \varphi) = (\boldsymbol{Bel}(x, \neg\varphi) \wedge \neg \boldsymbol{Bel}(x, \boldsymbol{Bel}(y, \neg\varphi)) \rightarrow \boldsymbol{AI}(x, \boldsymbol{MB}(x, y, \neg\varphi))) \wedge (\boldsymbol{Bel}(x, \boldsymbol{AF}\neg\varphi) \wedge \neg \boldsymbol{Bel}(x, \boldsymbol{Bel}(y, \boldsymbol{AF}\neg\varphi)) \rightarrow \boldsymbol{AI}(x, \boldsymbol{MB}(x, y, \boldsymbol{AF}\neg\varphi)))$

$\boldsymbol{AF}\neg\varphi$ means that $\neg\varphi$ will be satisfied on all paths. $\boldsymbol{WMC}(x, y, \varphi)$ denotes that $agent_x$ have weak maintenance cooperation with $agent_y$ with regard to φ. It is satisfied, if and only if, when $agent_x$ knows that φ is not satisfied and does not know that $agent_y$ knows φ is not satisfied, then $agent_x$ intend to let two sides mutual know φ is not satisfied, and when $agent_x$ knows that $\neg\varphi$ will be satisfied and does not know that $agent_y$ knows $\neg\varphi$ will be satisfied, then $agent_x$ intend to let two sides mutual know $\neg\varphi$ will be satisfied. Based on the weak maintenance cooperation, the semantics of mutual maintenance cooperation is defined as follows.

- Definition 4.2.4 (Mutual Maintenance Cooperation)
  $M \models_t \boldsymbol{MMC}(x, y, \varphi)$ iff $(\forall S: S \in C(x,t) \Rightarrow M \models_{s,t} (\boldsymbol{MB}(x, y, \boldsymbol{WMC}(x, y, \varphi) \wedge \boldsymbol{WMC}(y, x, \varphi))) \boldsymbol{Until} \neg \boldsymbol{MI}(x, \varphi))$ and $(\forall S: S \in C(y,t) \Rightarrow M \models_{s,t} (\boldsymbol{MB}(x, y, \boldsymbol{WMC}(x, y, \varphi) \wedge \boldsymbol{WMC}(y, x, \varphi))) \boldsymbol{Until} \neg \boldsymbol{MI}(y, \varphi))$

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

- Definition 4.2.5 (Joint Maintenance Intention)
  $\boldsymbol{JMI}(x, y, \varphi) = \boldsymbol{MMI}(x, y, \varphi) \wedge \boldsymbol{MMB}(x, y, \varphi) \wedge \boldsymbol{MMC}(x, y, \varphi)$

The above definition shows that $agent_x$ and $agent_y$ have joint maintenance intention φ, if and only if, they have common choice on which φ will be maintained, and they mutually believe that they have the common choice, and they know they will cooperate with each other during the process of maintaining joint intention. According to the semantics definition, a number of important properties of joint maintenance intention can be specified and proved.

According to the above semantics definition, we can obtain and prove a number of important properties of joint maintenance intention, enumerated in section 2.

- Theorem 4.2.1 $\models JMI(x, y, \varphi) \rightarrow MB(x, y, \varphi)$

The theorem shows the condition that agents will accept or drop joint maintenance intention. $agent_x$ and $agent_y$ have joint maintenance intention φ, only if, they mutually believe that φ holds. The theorem can be proved according to definition of ***JMI***, ***MMB*** and ***MI***.

- Theorem 4.2.2 (self-consistent)
  $\models \neg (\boldsymbol{JMI}(x, y, \varphi) \wedge \boldsymbol{JMI}(x, y, \neg\varphi))$

The theorem shows that at any moment agents cannot have joint maintenance intention φ and $\neg\varphi$ at the same time. The theorem can be proved by theorem 4.2.1and theorem 3.1.

- Theorem 4.2.3 (consistent with maintenance intention)
  $\models \neg (\boldsymbol{JMI}(x, y, \varphi) \wedge (\boldsymbol{MI}(x, \neg\varphi) \vee \boldsymbol{MI}(y, \neg\varphi)))$

The theorem shows that agent's joint maintenance intention is consistent with its internal maintenance intention. It can be proved according to theorem 4.2.1 and theorem 3.1, together with semantics definition of ***MI.***

- Theorem 4.2.4 (satisfiable)

$\models$ ***JMI***(x, y, φ) ® ***MB***(x, y, ***EG***φ)

EGφ means that there exists a path on which φ is always satisfied. Agent's joint maintenance intention should be satisfiable, or in other words, maintainable. If $agent_x$ and $agent_y$ have joint maintenance intention φ, then $agent_x$ and $agent_y$ should mutually believe that φ is maintainable. The theorem can be proved according to semantics definition of ***JMI***, ***MMB***, ***MI,*** and the model constraint: $\forall t \in T,\ x \in U_{ag}$: $C(x, t) \neq \varnothing$ in section 3.

- Theorem 4.2.5 (consistent with belief)

  $\models \varnothing$ **(*JMI*(x, y, φ) ∧ (*Bel*(x, Ø*EG*φ) ∨ *Bel*(y, Ø*EG*φ)))**

Ø***EG***φ means that there is no path on which φ will always be satisfied. The above theorem denotes that agent's joint maintenance intention should be consistent with individual agent's belief. It is impossible for agent that it has joint maintenance intention and at the same time believes that φ is not maintainable. The theorem can be proved by theorem 4.2.4 and theorem 3.1.

- Theorem 4.2.6 (non-conflict)

  $\models$ ***JMI***(x, y, φ) ∧ ***JMI***(x, y, ψ) → ***EG***(φ ∧ ψ)

The theorem describes that if $agent_x$ and $agent_y$ have the joint maintenance intention φ and ψ, then there exist a path on which φ and ψ always hold. The theorem can be proved according to the semantics of ***JMI***, ***MMB***, ***MI***, and theorem 3.1.

- Theorem 4.2.7 (Consistent with achievement intention)

  $\models \neg$ (***JMI***(x, y, φ) ∧ (***AI***(x, ¬φ)∨ ***AI***(y, ¬φ)))

The theorem shows that agent's joint maintenance intention is consistent with its internal achievement intention. It can be proved according to theorem 3.1, together with semantics definition of ***JMI*** and ***AI.***

- Axiom 4.2.1 (Persistent)

  A(***JMI***(x, y, φ) → ***JMI***(x, y, φ) $\mathbf{Until}_{\forall}$ (***MB***(x, y, Øφ) ∨ ***MB***(x, y, Ø***EG***j)))

The axiom shows that if $agent_x$ and $agent_y$ have joint maintenance intention φ, then they will hold the joint maintenance intention until they mutual believe that Øφ already holds or Øφ will be satisfied. In order to make the axiom sound, constraint is imposed on the formal model:

$\forall t \in T;\ S \in \mathbf{S}_S;\ x,y \in U_{ag}$: $M \models_t$ ***JMI***(x, y, φ) ⇒
$(\forall t' \in S : (\forall t'' : t \le t'' \le t' \Rightarrow M \models_{t''} \neg(\ $***MB***(x, y, Øφ) ∨ ***MB***(x, y, Ø***EG***φ))) ⇒
$M \models_{t'}$ ***JMI***(x, y, φ))

5. Application: A Case Analysis

The theorem framework of joint maintenance intention can effectively support analysis, specification and design of multi-agent system, especially investigation of social behaviors. The contribution given in the paper can be used to specify the high-level cooperation constraints in multi-agent system, validate their consistency with individual agent's internal state, and furthermore refine the specification to obtain the agents ' low-level cognitive component description. For example, two robot agents are assigned task to move object from one place to another place, and at the same time some restrictions are imposed on the cooperative agents, i.e., they must move the

object horizontally and stably in the process of cooperation. Obviously, such restrictions describe the system requirement, and will restrict the system's further design and implementation.

Fortunately, such a requirement can be specified formally and rigorously according to joint maintenance model as ***JMI***(x, y, φ), where φ representing that object is stable and horizontal. Furthermore, the theoretical results can be used to validate the consistency among a number of system specifications and find the problems in the system analysis and descriptions. If $agent_x$ has some achievement intention as ***AI***(x, ¬φ) in the process of cooperation with $agent_y$ to move object horizontally and stably, then the two specifications are inconsistent and conflict according to theorem 4.2.7. The related agents' internal cognitive specification can be further refined according the system requirement specification and the formal model, e.g., according to semantics definitions and theoretical results theorem1-7. If $agent_x$ and $agent_y$ have the joint the maintenance intention ***JMI***(x, y, φ), then the related agents should have maintenance intention φ, i.e., ***MI***(x, φ) and ***MI***(y, φ).

6. Conclusion

The paper explains the significance and importance of making research on the joint maintenance intention, analyzes and discusses the meaning and characteristics of joint maintenance intention. Different from joint intention, the joint maintenance intention is the abstract representation of system constraints during coordination process in multi-agent system. Based on the logical framework of multi-agent system, the semantics of joint maintenance intention is defined, a number of important properties are specified and proved. Different from existing work, the semantics definition of joint maintenance 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 maintenance intention into its semantics definition. Such a semantics definition clearly captures and describes the basic and essential characteristics of joint maintenance intention. The further work includes to execution model of agent incorporated with joint maintenance intention, specify and validate the interaction behaviors and cooperation model based on the theorem framework.

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