A Negotiation Formal Model for Cooperating Agents

Ahmed Hadj Kacem and Mohamed Jmaiel

University of Sfax
LARIS Laboratory
B.P. 1088, 3018 Sfax, Tunisia
E-mail : Ahmed@fsegs.rnu.tn, Mohamed.Jmaiel@enis.rnu.tn

Abstract

The work presented in this paper constitutes a part of a global approach aiming at defining the theoretical foundations of a platform for designing and implementing Multi-Agents Systems. This paper is primarily centered around the study of the negotiation as a technique needed to support the cooperative activity within this kind of systems. Our contribution is mainly about the definition of formal models for negotiation and negotiating agent. These models enable to specify the relations between the concepts of plans, plan proposals and resource allocations, on the one hand, and concepts of roles, knowledge, beliefs and capabilities, on the other hand.

Introduction

Multi-Agent Systems (MAS) are designed and implemented with a set of agents which interact according to diversified cooperation modes, in order to enrich the collective behaviors (Wooldridge & Jennings 1995; Smith & Davis 1980). The negotiation plays a fundamental role in the cooperative activity by enabling the agents to solve conflicts which could obstruct such behaviors. Durfee et al. (Durfee & Lesser 1989) define the negotiation as a process which enhancing the agreements on the agents' points of view, by reducing inconsistencies and uncertainties. This is reached by exchanging relevant information. Also, Park et al. (Park & Birmingham 1995) describe the negotiation as a sequence of interactive communications which are necessary to solve conflicts between agents. In general, the negotiation is considered as a mechanism needed to coordinate the actions of an agent group during the problem-solving process.

The negotiation has been dealt with in several research works. Müller (Müller 1996) classified these researches into three categories. The first one concerns the studies on negotiation languages. They are interested in the communication primitives, their semantics as well as the protocols monitoring their occurrence during negotiation process. The second one includes researches on the negotiation decisions. These works are interested in algorithms needed to compare negotiation subjects, utility functions, and agents preferences. Researches, in the third category, deal with the negotiation process at high level of abstraction. They are mainly interested in semantic and behavioral aspects of the negotiation activity.

Our contribution presented in this paper belongs to the third category. It mainly concerns the study of negotiation as a technique, supporting cooperative activity within MAS. Our investigation aims at suggesting an adequate formal definition in terms of models for negotiation and negotiating agents. The study presented in this paper is an extension of a previous work defining formal models for cooperation and cooperating agents (Hadj-Kacem & Jmaiel 1999; Jmaiel & Hadj-Kacem 2000). In our opinion, such a formal definition is essential due to the lack of standards and unified definitions of concepts like cooperation and negotiation. Moreover, it is not clear at all how this concepts are related to each other. Our contribution attempts to identify these concepts and to highlight their relations. Once such a definition has been established, we can considered it as a basis for defining behavioral aspects of cooperating and negotiating agents. In this way, we will be able to analyse their behavior. At a higher level this allows to formally specify behavior of a MAS and consequently to reason about it. These models constitute a basis of a specification language for cooperating and negotiating agents. Our works belong to a global approach aiming at defining a platform for designing, in a formal manner, MAS.

In order to define a model for negotiation, we propose to highlight the links between the concepts of plan, plan proposal, resource allocation, and commitment. These concepts would be treated from the points of view of agent group and individual agent as well. This enabled us to reformulate the concepts of role and mode of cooperation specified in (Jmaiel & Hadj-Kacem 2000).

Concerning the model for negotiating agents, we propose to determine the relations between the concepts of knowledge, belief and capability. These concepts allow us to define the mental state of a negotiating agent. Moreover, we insist on the various properties of this kind of agents, such as autonomy, communication, proposal and evaluation.

This paper is organized in three sections. The first one presents the various approaches of negotiation within MAS. The second one summarizes the main concepts used to highlight the models of negotiation and negotiating agent. The last one presents a formalization of the suggested models.

State of the Art

Different negotiation techniques have been developed. These techniques are generally based on the rich diversity of the human negotiations in various contexts (Davis & Smith 1983). One of the most studied techniques is based on an organisational metaphor (Ferber 1995; Davis & Smith 1983). Mainly It deals with contract-net which was one of the most used techniques for MAS. This technique allows to coordinate the collective activities of the agents by establishing contracts. The same approach has been adopted by Cammarata et al. (S. Cammarata & Steeb 1983). They developed negotiation protocols to solve conflicts on action plans between agents which operate according to various cooperation strategies.

In the context of our study, we attempt to approach the negotiation from the point of view of behavioral models for negotiating agents. In the literature, we distinguish two major tendencies. According to the first one, the negotiation arises as being an inherited part of the solution generation process (Lander & Lesser 1993). It consists of specifying the proposals of solution components made by the agents until a complete solution has been reached. In order to implement the corresponding algorithm, the authors propose seven operators: *Initiate Solution* operator generates a proposal which will be evaluated by others using the *Critique Solution* operator. The generation of a feedback, in a conflict situation, is ensured by the operator *Extend Solution*. If the conflict persists, the *Relaxed Requirement Solution* operator allows, among others, the reassessment of the existing solution. The operators *Blind-Receive-Information* and *Retrieve Information* ensure an access to the knowledge base. The operator *Terminate Search* is used to indicate the end of the resolution.

The second approach considers the negotiation as a mechanism which is independent of the solution generation process. It first consists of decomposing the initial problem into a set of sub-problems which will be distributed among the cooperating agents. Each agent proceeds to plan its tasks and to be committed with others, in order to achieve them. In this context, the authors in (Park & Birmingham 1995) propose a generic structure aiming at supporting the variety of the negotiation situations. This structure consists of three models: negotiating agent model, negotiation language and protocol. The first model points out the need for maintaining, for each agent, a mental state and its associated operations. It tries to specify the behavior of agents based on their beliefs, knowledge, plans and preferences. The negotiation language defines a set of performatives such as: *Propose, Counter-Propose, Ack, Accept, Reject, Retract, Feed-Back*. The protocol of negotiation controls the interactions between agents during the negotiation process.

Negotiation Concepts

In our approach, we make use of the notion of the model in order to determine the concepts related to the negotiation within MAS. Thus, we contribute to the design of the negotiation process by specifying two models, namely:

- the model of negotiation, which is made up of three levels: global plan, local plan and resource allocation.
- the model of negotiating agent specifies the internal concepts of an agent as well as their main properties.

Negotiation Model

The process of negotiation enables to avoid any potential conflict situation. Such a mechanism is based on the generation of proposals, their evaluation and commitment in the case of agreement. We distinguish three types of proposals, namely:

- proposal for realization plan of a global goal,
- proposal to be responsible for a local goal,
- proposal for time interval to access to a shared resource.

Each proposal will be evaluated by every negotiating agent who answers whether with:

- an *acceptance* if the proposal is accepted,
- a *rejection* if the proposal is rejected and no others are made,
- or a *counter-proposal* if the proposal is rejected and an another proposal is generated.

After reaching an agreement between the agents about a proposal, a commitment will be taken to ensure its realization. There are three types of commitments corresponding to the proposals presented above.

In the following, we present, in an abstract way, the concepts needed for the qualification of a negotiation activity. This qualification is structured in three levels: global plan, local plan and resource allocation.

- A *global plan* is a decomposition of a global goal in an ordered set of local goals.
  - *Global Plan Proposal* is a suggestion of a global plan made by an agent participating in the realization of the global goal.
  - *Global Plan Commitment* is an engagement to realize a global plan accepted by all agents.
- *Local Plan* gathers the various local goals which constitute the agent role after negotiation.
  - *Local Goal Proposal* is a suggestion of an agent to take responsibility to achieve a set of local goals.
  - *Local Goal Commitment* is described by the assignment of the local goals to the appropriate agents.
- *Resource Allocation* relates to allocation of resources shared between agents.
  - *Interval Proposal* is a suggestion of a time interval to access to a shared resource.
  - *Interval Commitment* is an engagement to reserve a time interval to access to a shared resource during the local goal realization.

Negotiating agent model

The negotiating agent model expresses the individual aspects of an agent, maintaining coherence with the proposed negotiation model. Such an agent is characterized by its mental state which is the result of the interactions with its environment. This mental state plays the role of a regulator, which directs its behavior. So, certain properties characterize a negotiating agent such as communication, autonomy, reasoning, evaluation, etc. A description of these aspects, namely mental state and properties of negotiating agent, is presented in a detailed way.

- *Mental State* is a set of beliefs, knowledge, plans and capabilities.
  - *Beliefs* are information reported by an external event or by another agent. They describe the state of the world from the view point of an agent, and thus, the way in which it perceives its environment.
  - *Knowledge* gathers information relating to the tasks achieved by the agent as well as those concerning its environment and the other agents. They differ from beliefs by their degree of certainty.
  - *Plan* is the set of plans on which the agent is engaged to achieve. These plans can be of three types, namely: global plan, mode and local plan.
  - *Capability* describes the ability of an agent to carry out domain tasks as well as control tasks.
- *Properties* describe the essential properties of an agent, in order to be able to negotiate. Such an agent should be able to propose, to evaluate and to take decisions. In addition, a negotiating agent must be able to adapt its activities within its environment, so that it could agree with the other agents and could solve the considered conflicts.
  - *Autonomy* is an agent directed by tendencies deduced from its mental state and not by commands coming from the user or another agent.
  - *Proposing* is an agent able to propose plans for the realization of global goals, local goals and resource allocation.
  - *Evaluating* is an agent able to evaluate proposals made by other agents and to answer by an acceptance or a rejection according to its reasoning.
  - *Communicating* is characterized by its capabilities to send, receive and analyse messages.

The following section presents these two models in a formal way.

Formal definition of negotiation

This section proposes a formal definition of each concept, mentioned in the previous section, and the relations between them, as well. This formalization, which is based on a set language, enables to highlight the type of operations of the different concepts characterizing the negotiation.

In our approach, the negotiation process is carried out in three stages. A first stage consists of proposing global plans decomposing a common objective into a set of global goals. This stage ends with a total acceptance of a proposal by all the agents. Once a commitment on a global plan was made, the agents start the second stage of negotiation which ends after distributing local goals on the different agents. The last stage aims at avoiding conflicts between agents during the problem resolution by coordinating the access on the shared resources.

Formal model for negotiation

In this model we suppose the existence of the three following sets:

- $\mathcal{AG}$ is a set of all agents;
- $\mathcal{BG}$ is a set of all global goals;
- $\mathcal{BL}$ is a set of all local goals.

A *model of negotiation* is defined by a couple (Ag, Oc) such as:

$$Ag \stackrel{\text{def}}{=} \{A_1, A_2, \ldots, A_n\}$$

$$\text{where} \quad A_i \in \mathcal{AG} \quad \text{and} \quad n \geq 1 \quad (1 \leq i \leq n)$$

The set Ag denotes the agents society.

$$Oc \stackrel{\text{def}}{=} \{Bg_1, Bg_2, \ldots, Bg_m\}$$

$$\text{where} \quad Bg_i \in \mathcal{BG} \quad \text{and} \quad m \geq 1 \quad (1 \leq i \leq m)$$

The set Oc denotes the *common goal* which is made up of set of global goals.

Apart from the model of negotiation, which forms the basis for the formal definition of the negotiation, we also need the following concepts and notations:

- It is supposed that each agent has a mental state needed to create, modify, evaluate, accept or refuse proposals. The commitment on a retained proposal can update its mental state. We denote with Em_{A_i} the mental state of the agent A_i.
- We define for each agent A_i a confidence coefficient denoted with $Coef_{A_i}$. The latter associates to each agent a value describing the degree of confidence granted to its proposals. This value is obtained by a very rich mental state and a very vast expertise.
- A negotiating agent must be able, using its mental state, to evaluate the received proposals, and to submit its opinion (acceptance or refusal). For simplicity reasons, we only consider in this study the case of acceptance, since the case of refusal generally reinitializes the process of negotiation.
  - We express an acceptance of a realization plan with a predicate which takes as parameters a proposal p and the mental state of an agent A_i. We denote this predicate with $Accept(Em_{A_i}, p)$.
  - Similarly, an agent must know if another agent is able to achieve a particular local goal. We express the fact that an agent A_i accepts that a local goal b is carried out by another agent A_k, with a predicate denoted $Accept(Em_{A_i}, b, A_k)$. In this case, we say that the agent A_i has confidence, according to its mental state, in the agent A_k to reach the goal b. It is worth noting that an agent always accepts its proper proposal. That is to say an agent must be always convinced of its own proposal.

Realization Plan The process of negotiation starts with the definition of a global plan related to a global goal. This definition is the result of the negotiation of proposals for global realization plan which is suggested by the different agents.

(a) Proposal for a Global Plan A proposal for global plan is a decomposition of a global goal in a non empty set of local goals. At this stage, it should be noted that a global plan does not make any association between agents and suggested local goals. A proposal of a global goal is a subset of $\mathcal{BL}$:

$$\{b_1, b_2, \ldots, b_l\} \quad \text{where } b_i \in \mathcal{BL} \text{ and } l \geq 1 \ (1 \leq i \leq l)$$

During the process of negotiation, an agent A_i can propose a global achievement plan for a global goal Bg_j. The set of the proposals relating to Bg_j which can be submitted by the agent A_i is denoted with:

$$PG(A_i, Bg_j) \quad \text{where } (1 \leq i \leq n) \text{ and } (1 \leq j \leq m)$$

The set of the proposals for global achievement plans for the global goal Bg_j is defined as follows:

$$PG(Bg_j) \stackrel{\text{def}}{=} \bigcup_{i=1}^{n} PG(A_i, Bg_j)$$

(b) Global Plan Commitment A proposal for a global plan will be subject of commitment if it is accepted by all agents of the society. This proposal belongs to the set defined by:

$$PGEng \stackrel{\text{def}}{=} \{Pg \in PG(Bg_j) | AcceptTot(Ag, Pg)\}$$

(c) Global Plan Acceptance This can be reached according to two cases:

- all the agents accept the same proposal;
- the agents are in conflict (no proposal can satisfy the first case). In this case, the agent which has the highest confidence coefficient will impose its proposal.

Let A_i be an agent of the society, Bg_j a global goal and Pg_{ij} a proposal belonging to the set $PG(A_i, Bg_j)$.

$AcceptTot(Ag, Pg_{ij})$ iff

$(\forall A_k \in Ag \backslash \{A_i\}\ Accept(Em_{A_k}, Pg_{ij}))$ or
$(\forall A_k \in Ag \backslash \{A_i\}\ Coef_{A_i} > Coef_{A_k})$

Local Goal Distribution The first step of the negotiation considers only the decomposition of a global goal in a set of local goals. The next step distributes the retained achievement plan on the agents of the society. Indeed, it affects to each agent the set of local goals which it has to be achieved.

(a) Local Goal Proposal For the achievement of a global goal (after definition of the global plan) the agents diffuse their proposals for responsibility of local goals (who does what). Each proposal is a subset of the selected global plan. Let Bg_j be a global goal, Pg an accepted global plan belonging to $PGEng(Bg_j)$, and A_i an agent. *A proposal for responsibility* of local goal made by the agent A_i relative to Pg is, in the fact, a subset of Pg. The set of these proposals is denoted with $PL(A_i, Pg)$. The set of the proposals for responsibility of the local goals of all the agents is the union of submitted proposals. This set is denoted by $PL(Pg)$. Hence:

$$PL(Pg) = \bigcup_{i=1}^{n} PL(A_i, Pg)$$

It should be noted that each local goal, belonging to the plan of resolution, must be part of at least one proposal for a local plan.

(b) Local Goal Commitment A local goal will be subject of the negotiation when it is proposed to be of the responsibility of at least two agents. Formally:
Let b a local goal in $PL(Pg)$. The local goal b is considered as subject of negotiation if and only if:

$$\exists A \subseteq Ag.\ |A| \geq 2 \text{ and } b \in \bigcap_{A_i \in A} PL(A_i, Pg)$$

The set A is regarded as the set of agents that proposed to deal with the local goal b as part of the global plan Pg. We denote with $Aneg(b, Pg)$ the set of all agents who proposed the goal b as part of Pg:

$$Aneg(b, Pg) \stackrel{\text{def}}{=} \{A_i \in Ag | b \in PL(A_i, Pg)\}$$

(c) Local Goal Acceptance The conflict between agents must be solved by the agents of the society which select the appropriate agent for carrying out a local goal, according to their mental states (knowledge on competences of the various agents) or according to the coefficients of confidence. Total acceptance of a local goal can be reached either:

- depending on the mental state, i.e. the agent which is ready to achieve the goal.
- or according to the confidence coefficient assigned to each agent.

$AcceptTot(Ag, A_i, b, Pg)$ iff
$A_i \in Aneg(b, Pg)$ and
$((\forall A_k \in Ag \backslash (Aneg(b, Pg))\ Accept(Em_{A_k}, b, A_i))$ or
$(\forall A_l \in (Aneg(b, Pg) \backslash \{A_i\})\ Coef_{A_i} > Coef_{A_l}))$

After negotiation, we assign to each agent a set of local goals called *Role*, defined as follows:

$$Role(A_i, Pg) \stackrel{\text{def}}{=} \{b \in Pg | AcceptTot(Ag, A_i, b, Pg)\}$$

It is obvious that the roles of the agents must be pairwise disjunct, in order to ensure an optimal cooperation.

Resources Distribution In the problem solving process, agents generally access not only to local resources, but also to shared resources. The access to shared resources can involve simultaneous accesses, to the same resource, which can generate conflicts. In order to cure these anomalies, it is necessary that each agent reserves the needed resources during a set of time intervals.

(a) Notations For the formal description of the process of negotiation for allocating shared resources we suppose the existence of the following sets:

- $\mathcal{I}$ denotes the set of all time intervals;
- $\mathcal{R}$ denotes the set of shared resources;

We denote with $Uses(A_i, b, r, I)$ the predicate which indicates that the agent A_i, uses the resource r during the time interval I while resolving the local goal b.
Let A_i be an agent, Pg a global plan. We define the set of the intervals, allocated by an agent A_i within the framework of the global plan Pg, as:

$$IntR(A_i, Pg) \stackrel{\text{def}}{=} \{(I,r) \in \mathcal{I} \times \mathcal{R} | \exists b \in Role(A_i, Pg).Uses(A_i, b, r, I)\}$$

(b) Interval Proposal We denote with $PI(A_i, Pg)$ the set of proposals for interval allocations of resources needed by the agent A_i to realize local goals as part of the resolution plan Pg. An agent submits a proposal in term of resources allocation intervals with respect to global plan. An agent should not propose intervals which overlap intervals allocated for global plan not yet completed :

$$PI(A_i, Pg) \stackrel{\text{def}}{=} \{(I,r) \in IntR(A_i, Pg) | \forall A_k \in Ag, I' \in \mathcal{I}. Reserv(A_k, I', r) \Rightarrow I \cap I' = \emptyset\}$$

(c) Interval Commitment A proposal for a resource allocation is subject of negotiation if the same resource is proposed by two different agents for time intervals which overlap. We denote the set of resource allocations which are subject of negotiation with $NegInt(Ag, Pg)$. It is defined as:

$(I,r) \in NegInt(Ag, Pg)$ iff
$\exists A_i, A_j \in Ag, I' \in \mathcal{I}. i \neq j$ and $(I,r) \in PI(A_i, Pg)$ and
$(I',r) \in PI(A_j, Pg)$ and $I \cap I' = \emptyset$

A Commitment on an interval of resource allocation is made with a real reservation of the resource during the interval indicated after a total agreement of the proposal by all agents.

$$Reserv(A_i, I, r) \text{ iff } AcceptTot(Ag, A_i, I, r)$$

(d) Allocation Acceptance A total agreement of a proposal for a resource allocation can be reached either by a correspondence between the mental state of each agent and the proposal, or by using the confidence coefficient if none of the proposals can satisfy the first case.

$AcceptTot(Ag, A_i, r, I)$ iff
$(\forall A_k \in Ag \backslash \{A_i\}\ Accept(A_i, r, I, Em_{A_k}))$ or
$(\forall A_l \in EngIR(r, I)\ Coef_{A_i} > Coef_{A_l})$

where
$EngIR(r, I) \stackrel{\text{def}}{=} \{A \in Ag | \exists Pg \in PG.(I,r) \in PI(A, Pg)\}$

(e) Local Plan For every agent, the process of negotiation enables to specify a local plan defined in term of roles and resource allocations:

$$Plan(A_i, Pg) \stackrel{\text{def}}{=} (Role(A_i, Pg), Res(A_i, Pg))$$

where
$Res(A_i, Pg) \stackrel{\text{def}}{=} \{(I,r) | \exists b \in Role(A_i, Pg).$
$Uses(A_i, b, I, r)$ and $Reserv(A_i, I, r)\}$

We denote with $Plans$ the set of all the possible plans.

Formal Model for Negotiating Agent

Mental State The set of knowledge or facts of an agent A_i is denoted by $Facts_{A_i}$. To each fact ψ the agent A_i assigns, by applying a function CC_{A_i}, a coefficient of certainty denoted $CC_{A_i}(\psi)$. This is because an agent is not always sure of the truth of any given fact. The value $CC_{A_i}(\psi)$ is always between 0 and 1. According to this value we distinguish two types of facts:

- **Knowledge** are facts whose coefficient of certainty equals 1.
$$\mathcal{K}_{A_i} \stackrel{\text{def}}{=} \{\psi | \psi \in Facts_{A_i} \text{ and } CC_{A_i}(\psi) = 1\}$$
A knowledge is a fact of which the agent is sure of its truth.
- **Beliefs** are facts whose coefficient of certainty is strictly lower than 1.
$$\mathcal{B}el_{A_i} \stackrel{\text{def}}{=} \{\psi | \psi \in Facts_{A_i} \text{ and } CC_{A_i}(\psi) < 1\}$$
A belief is a fact of which the agent is not sure of its truth. Consequently, it cannot be considered as knowledge.

The mental state of an agent is made up of knowledge and beliefs. We denote with Em_{A_i} the current mental state of the agent A_i, defined as:

$$Em_{A_i} \stackrel{\text{def}}{=} \mathcal{K}_{A_i} \cup \mathcal{B}el_{A_i}$$

We denote with $\mathcal{E}m$ the set of mental states of the all agents.

Negotiating Agent Properties In order to be able to conclude a process of negotiation, an agent has to be equipped with a suitable set of capabilities. We pay a particular attention to the capability of communication. Besides, an agent must also be able, using its mental state, to generate and evaluate proposals. Finally, an agent has to be autonomous in order to make decisions concerning the updating of its own working plan. We denote with Cap_{A_i} the set of functionalities that an agent A_i can achieve. A capability is represented, according to its nature, by a function, a relation or an elementary primitive (operation). The essential capabilities needed for the negotiation are presented formally as follows:

- **Communication** is the capability of exchanging information of various types: data, facts or proposals for global plans, local plans or resource allocations. This capability is ensured by two primitives, namely *Send* and *Receive*:
  - The primitive *Send* enables an agent to submit a message of any type to another agent. The submitting agent must specify the name of the receiver agent, the information type and the message to be sent.

- The primitive *Receive* allows the reception of messages already sent by another agent.

An agent A_i is said to be *Communicating* if it has among its capabilities the primitives *Send* and *Receive*.

- **Proposal** is the capability to generate proposals or counter-proposals, using the mental state and the already made proposals. We denotes with $\mathcal{P}$ the set of all the proposals ($PG \cup PL \cup PI$) and $2^{\mathcal{P}}$ the of all subsets of $\mathcal{P}$. An agent A_i is known as *Proposing* if has the capabilities *Propose, CounterPropose*, and *Evaluate*, defined as follows:

$$Proposing(A_i) \stackrel{\text{def}}{=} \exists Propose,\ CounterPropose,\ Evaluate \in Cap_{A_i}$$

where

$$\begin{array}{ll} Propose: & \mathcal{E}m \times (\mathcal{BG} \cup PG \cup PL) \longrightarrow \mathcal{P} \\ & (e_i, Bg/Pg/Pl) \mapsto Pg/Pl/Pi \\ CounterPropose: & \mathcal{E}m \times (\mathcal{BG} \cup PG \cup PL) \times 2^{\mathcal{P}} \longrightarrow \mathcal{P} \\ & (e_i, Bg/Pg/Pl, Ep) \mapsto Pg/Pl/Pi \\ Evaluate: & \mathcal{E}m \times \mathcal{P} \longrightarrow \{Accept, Reject\} \end{array}$$

Propose defines, using the mental state and the global goal, global plan, or local plan, respectively, a proposal for a global plan, a local plan or a resource allocation.

- **Autonomy** is the capability to generate and modify its own working plan. At the end of the process of negotiation, an agent should define the tasks which it must carry out in order to achieve the goals specified in its role. According to resource allocations over the time axis, it defines the sequence of tasks to be carried out. These tasks constitute the agenda which is described by a sequence of pairs $(task, time)$. An agent is said to be *Autonomous* if it is able to create and modify its agenda according to its mental state and to its plan. Formally:

$$Agenda \stackrel{\text{def}}{=} \{[(task_1, t_1), \ldots, (task_n, t_n)]| \\ task_i \in \mathcal{T}asks \text{ and } t_i \in \mathcal{T}ime\}$$

$$Autonomous(A_i) \stackrel{\text{def}}{=} \\ \exists CreateAgenda,\ UpdateAgenda \in Cap_{A_i}$$

where

$$\begin{array}{ll} CreateAgenda: & Plan \times \mathcal{E}m \longrightarrow Agenda \\ & (p, e) \mapsto a \\ UpdateAgenda: & Plan \times \mathcal{E}m \times Agenda \longrightarrow Agenda \\ & (p, e, a) \mapsto a' \end{array}$$

Conclusion

This article is centered around the study of the negotiation as a technique needed to support the cooperative activity in a MAS. Thus, we have initially presented the concepts related to the negotiation model such as proposals, their evaluations as well as the generated commitments. In the second step, a model for negotiating agent is given. This model describes the agent's mental state and the properties needed to support negotiation. It should be noted that a system of negotiating agent, based on the suggested model, has been implemented.

This study constitutes a part of a global approach aiming at defining a platform for designing and implementing multi-agent systems. At the current state of this work, a formal validation of the models is essential at the semantic level as well as at the behavioral one. Thus the validated models can be used in two different ways:

- as basis for a detailed analysis for the behavior of a set of negotiating agents.
- as a formalism for specifying a negotiating agent system.

Acknowledgment: The authors are gratefully thankful for Monia Loulou and Amira Rgaieg for their valuable contributions concerning the specification and the implementation of the negotiating agent system.

References

Chainbi, W.; Jmaiel, M.; and Hamadou, A. B. 1998a. Conception, behavioral semantics and formal specification of multi-agent systems. In *Proceedings of the 4th Australian Workshop on Distributed Artificial Intelligence*, volume 1544 of *Lecture Notes in Artificial Intelligent.*

Chainbi, W.; Jmaiel, M.; and Hamadou, A. B. 1998b. A new approach to the conception and the behavioral semantics of a multi-agent system. In *Proceedings of the 2nd IEEE International Conference on Intelligent Processing Systems.*

Davis, R., and Smith, R. G. 1983. Negotiation as a metaphor for distributed problem solving. *Artificial Intelligence* 20(1).

Decker, K. 1987. Distributed problem-solving techniques : A survey. *IEEE transactions on systems, man, and cybernetics* 17(5):729–740.

Durfee, E. H., and Lesser, V. 1989. Negotiating task decomposition and allocation using partial global planning. *Distributed Artificial Intelligence* 2(1):229–244.

Ferber, J. 1995. *Les systèmes multi-agents. Vers une intelligence collective.* InterEdition.

Hadj-Kacem, A., and Jmaiel, M. 1999. Towards a formal definition of the cooperation among multi-agent systems. In *Proceedings of the first IFAC Workshop on Multi-Agent-Systems in production.*

Hadj-Kacem, A. 1996. Les SBC coopératifs, vers une architecture fondée sur une formalisation du contrôle. In *Proceedings du 10ème Congrès Reconnaissance des Formes et Intelligence Artificielle.*

Jmaiel, M., and Hadj-Kacem, A. 2000. A formal definition of cooperation and agency among multi-agent systems. In *Proceedings International conference on Artificial and Computational Intelligence for Decision, Control and Automation in Engineering and Industrial Applications.*

Jmaiel, M. 1996. Specification of communication protocols using temporal logic. *Journal of Systems and Software, Special Issue on Software Engineering for Distributed Systems* 33(3):299–312.

Lander, S. E., and Lesser, V. 1993. Understanding the role of negociation in distributed search among heterogeneous

agents. In *Proceedings of the thirteen International Joint Conference on Artificial Intelligence*, 438–444.

Müller, H. J. 1996. *Negotiation principles*. England: John Wiley & sons.

Park, S., and Birmingham, W. P. 1995. Toward a unified framework for multiagent negotiation. In *Proceedings of the international Conference on Intelligent Computer Communication*, 105–122.

S. Cammarata, D. M., and Steeb, R. 1983. Strategies of cooperation in distributed problem solving. In *Proceedings of the IJCAI83*.

Smith, R. G., and Davis, R. 1980. Frameworks for cooperation in distributed problem solving. *IEEE transactions on Systems, Man and Cybernetic* 11(1).

Wooldridge, M., and Jennings, N. R. 1995. Intelligent agents: Theory and practice. *Knowledge Engineering Review* 10(2).