An Agent Intentional Structure based on Cooperation Ontology

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ABSTRACT
If multi-agent systems are to become widely accepted as a basis for large scale applications, adequate agent concepts will be essential. To address this issue, we show in this paper that agents need to have communication concepts and organization concepts. We argue that instead of the usual approach of starting from a set of intentional states, the intentional structure should be deduced in terms of interaction. To this end, we come up with ontologies related to communication and organization. Unlike most previous work, the presented study shows a new way to combine agent and ontology technologies. Indeed, ontologies have established themselves as a powerful tool to enable knowledge sharing, and a growing number of applications have benefited from the use of ontologies as a means to achieve semantic interoperability among heterogeneous, distributed systems. Ontologies are used in this paper as natural arguments to belief-goal-role agents. We illustrate the concepts by the well known prey/predator example.

Keywords
BDI agent, communication, organization, intentional stance

1. INTRODUCTION
Artificial intelligence (AI) has emphasized building "stand-alone systems" that can solve problems with minimal help from other systems (computer or human). These systems have traditionally been brittle, in the sense that they fail miserably when presented with problems even slightly outside of their range of expertise[2].
Accordingly, the recent years have witnessed a large interest in agent-oriented approaches to developing systems. With the explosion of interest in intelligent agents and multi-agent systems, a great many architectures have been developed. There is even some debate about exactly what constitutes an agent in the agents community (and more generally, the AI community).
The purpose of this paper is to establish how these different models stand in relation to each other and contemporary concepts of agency, and in particular it presents a new approach which is different from most known in AI field: while the Belief-Desire-Intention architecture draws its inspiration from the philosophical theories of Bratman [3] who argues that intentions as well as beliefs and desires play a significant and distinct role in practical reasoning, the presented approach stresses the interaction aspect to deduce the intentional structure of an agent.
Actually, the conception of multi-agent systems covers many meanings each referring to a peculiar trend in research. These trends can be grouped in two standpoints: *individual*[1] conception and *mass* conception.
Individual conception :
This point of view gathers all researchers who think that the solution goes only through the formal representation of an agent model [1] (agents as intentional systems). Accordingly, this consists in formalizing the mental state of an agent (its Beliefs, its Desires, its Intentions). Ascribing mental propositions to a system amounts to adopting what is commonly known as the intentional stance. These intentional notions constitute abstractions that give a familiar way of describing, explaining and predicting the behaviour of complex systems. This familiarity is due mainly to the fact that in popular psychology, the behaviour of a human being is explained through the attribution of the so-called propositions such as beliefs and desires. Most researchers work along those lines including Shoham [4], Georgeff and Rao [8], Cohen and Levesque [10], Jennings and Wooldridge [11].
In our opinion, the proposed theories mask cooperation which is one of the main forces of multi-agent systems: we have the impression that their agents are isolated. Although there are situations where an agent can operate usefully by itself, the increasing interconnection and networking of computers is making such situations rare. Modern computing platforms and information environments are distributed, large, open, and heterogeneous. Computers are no longer stand-alone systems, but become tightly connected both with each other and their users.
Mass conception :
this point of view gathers people who consider that we should first think about interaction, then deduce the intentional structure of the agents and not the contrary. It is based on the fact that multi-agent systems interest lies effectively in the collective action and its capacity to articulate the individual to the collective through the intermediary of the cognitive agent structure. This mass conception emphasizes the interaction structures (cooperation, negotiation, action coordination, …) and the organizations that follow from (roles, authority hierarchies, …).
Unlike individual conception, this approach does not mask the original aspect of multi-agent systems which is cooperation.
Cooperation is often presented as one of the key concepts which differentiates multi-agent systems from other related disciplines such as distributed computing, object-oriented systems, and expert systems [16].
Our approach is in keeping with the latter standpoint. Indeed, starting from the study of cooperation in multi-agent systems [12], we have identified the underlying concepts of an agent. These concepts consist of *beliefs* and *goals* as communication concepts and *roles* as concepts related to organization.
We support the idea that communication as well as organization are mainstays of cooperation.
In this paper, we use a two steps approach:
– Conceptualization which consists in focusing our attention on the system structures that seems relevant to the problem to

[1] This term was used by Ferber in [1].

be solved. Then, describing informally those structures in a language called conceptualization language.

- formal specification which consists in the formalization of the conceptualization. This definition is consistent with the usage of ontology .

This approach is applied for communication as well as organization.

This paper is organised as follows. In the next section, we present an ontology for communication. Section 3 provides an organization ontology. Section 4 identifies the agent concepts. We illustrate our work with the well known prey/predator problem.

2. COMMUNICATION ONTOLOGY

Although communication is not universally assumed in multi-agent systems research, we argue that it is fundamental to the everyday process of cooperation. Communication in multi-agent systems as for human beings, is the basis of interaction and social organization. Communication consists of a set of psychological and physical processes relating the sender to the addressee(s) in order to reach some goals [7][2]. This definition emphasize three underlying dimensions to communication: *physical* dimension, *psychological* dimension, and *social* dimension. The physical dimension deals with all the required physical means to support communication such as: physical connections. The psychological dimension takes mainly into account mental factors which can be in the beginning or in the end of the communicative action. Finally, the social dimension deals with the set of conventions adopted as a guiding line by a group e.g., communication protocols.

The goal of this section is to derive the underlying concepts to a communication model appropriate to multi-agent systems.

Let C be a communication model. C is based on speech act theory[17]: the communications are defined as operators which can change the mental state of agents [6].

2.1 Beliefs

In more traditional AI terms, an agent's beliefs are its knowledge. Beliefs change due to the external environment of the agent, his communication with the others and his proper reasoning. Beliefs are acquired through perception, communication, deduction, and prediction.

The concept of belief is an essential element of C. Indeed, beliefs can be a subset of the propositions that agents exchange. Generally, communication depends on the beliefs and the application domain.

Example 1.

- In the prey/predator problem, the prey's position on the grid is a predator's belief. Whenever the prey gets into the perception field of a predator (hence he *believes* knowing its position), he communicates this information to the other predators.
- A communication can be due to the fact that a predator believes not knowing the prey's position. In this case, he sends a request to his colleagues asking for the prey's position.

[2] We adopt this definition because we think that it is appropriate to multi-agent systems problematics.

2.2 Goals

A goal is an underlying concept to the psychological level of a communication. It refers to a potential state of the world to which the agent belongs. The achievement of a goal is at the beginning of an agent behaviour (including his communicative actions). A goal may be *local* or *global* and can be expressed in terms of the agent beliefs.

Example 2.

For a predator, getting closer to a prey from the southern side is a local goal which helps reaching the global goal consisting in the capture of the prey. This local goal can be expressed in terms of the following beliefs: the prey's position and the predator's position on the grid.

2.3 Actions

As previously stated, a communication is defined as a speech act and a-fortiori as an action. Accordingly, an action is the basic element of a communication model. Actions are interactions between an agent and the external world. An agent can perform at a point of time one of the following actions:

- *physical* actions are interactions between agents and the spatial environment,
- *communicative* actions are interactions between agents. They can be *emission* or *reception* actions,
- *private* actions are internal functions of an agent. They correspond to an agent exploiting its internal computational resources, and
- *decision* action can generate communicative, physical and private actions. A decision action can also update the agent's beliefs. We assume that the agent's goals are modified only after a negotiation with the other agents.

The actions to execute are determined by the resolution methods and communication protocols.

We denote by APH the set of physical actions, APR the set of private actions, ACO the set of communicative actions such that $ACO = ACOE \cup ACOR$ where $ACOE$ is the set of emission actions and $ACOR$ is the set of reception actions, τ a decision action, which an agent can execute.

Example 3.

- In the prey/predator game, moving on the grid is a physical action.
- informing another predator is a communicative action.

Concerning the actions execution, an agent use an interaction paradigm (e.g. an agenda). The interaction paradigm implicitly defines the metaphors used by the agents to interact and cooperate among each other [5].

2.4 Message

In the definition of communication, three dimensions have been distinguished among which the psychological dimension (whose concepts are beliefs, goals, and actions) and the physical dimension (which support communication). The transition step between the afore mentioned dimensions is message production.

In a multi-agent universe, a message is a specification of a speech act to which we can add the physical processes of communication which support message transmission. Practically, a message can be considered as a four attributes structure: elocution force, propositional content, sender, and routing. Figure 1 represent an example of this structure according to the prey/predator problem.

Force : *inform* Propositional content : *the position of the prey is* (x_0, y_0) Sender : *predator 1* Routing : *predator 2*

Figure 1. a message

3. ORGANIZATION ONTOLOGY

Whenever we have to deal with task distribution and well-knit interaction between agents in a multi-agent system, the basic problem is an organizational issue i.e. deciding who will do what and when [13].

Organization in animal or human societies deals with task distribution and work division according to the proper skills of each agent member. Next, we draw the key concepts related to organization. An organizational model defines how to dispatch the tasks between cooperative agents and their possible relations.

3.1 The problem

A problem is defined by a set of tasks. Each task can be optional or compulsory according to the resolution strategy (see § 3.4). A task is an ordered set of actions which allows to reach a goal.

Definition 3.1 [A problem]
Let $T=\{t_1, t_2, \ldots, t_i, \ldots, t_n\}$ be a set of tasks defining the problem to be solved,
T_C: a restriction of T to compulsory tasks, and
T_O: a restriction of T to optional tasks, and
$T = T_C \cup T_O$ and $T_C \cap T_O = \varnothing$.

The distinction between compulsory tasks and optional ones can be justified by the fact that it is a better way to simulate the reality.

Example 4.
The prey/predator problem includes the following compulsory tasks: "follow the prey", "communicate the prey's position once it is seen". To this set, we can add the following optional tasks: "communicate the predator's position at each step", or "communicate the distance covered by the predator".

3.2 Role

In a cooperation framework, it is necessary to define the respective roles that the agents play in a resolution process. The role characterizes the responsibilities which would be attributed to an agent i.e., the tasks he is charged with. An agent's role is defined by a subset of compulsory tasks and a subset of optional tasks.

Definition 3.2 [An agent role]
Let a be an agent, T_C^a be the compulsory tasks of a, T_O^a be the optional tasks of a. The role of the agent a is defined by r_a such that: $r_a = < T_C^a, T_O^a >$.

3.3 Cooperation mode

The concept of cooperation mode has been previously stated in [9]. A cooperation mode specify the responsabilities attributed to the partners taking part in a collective activity. A cooperation mode is defined by an n-uplet representing the respective roles of the agents.

Example 5.
In the prey/predator game, once the prey's position is known by all the predators, the cooperation mode related to this situation is: <"surround the prey from the south", "surround the prey from the north", "surround the prey from the east", "surround the prey from the west">.

The relevance of a cooperation mode is measured by the cooperation strategy which will be described in the following paragraph.

3.4 Cooperation strategy

In a distributed problem solving, each agent member of the system is able to process a set of tasks by applying some resolution methods within his competences.

Agent competences can be complementary or redundant. For the same tasks, an agent may be more competent than another (he puts into practice a resolution method more efficaciously). For other tasks, the agents can have different methods but there is no way to determine a priori which method is the most efficient. Accordingly, to select an agent to achieve a task, the resolution context should be taken into account. Hence, a dynamic distribution of tasks seems to be more appropriate than a static distribution. If the abilities of the agents are redundant, then they can play the same role. In this case, an agent should be selected to accomplish each role. According to the context, we can specify different indications concerning the way the choice is done: for example, in the case of system-human cooperation, we can indicate that the user must play all the decision roles even if the system is competent to accomplish such roles.

We call a cooperation strategy, a process which determines the appropriate cooperation mode to a given situation. In this case, we talk about *dynamic organization*[3].

Example 6.
In the prey/predator game, a cooperation mode where an agent's role is "getting closer to a prey from the north" can be substituted for a cooperation mode where the same agent play the following role: "getting closer to a prey from the east". It is because of the respective positions of the predators on the grid, that the cooperation strategy administer this transition in cooperation mode.

In order to guarantee the coherence of an organizational model, some properties should be verified. We don't address those properties in this paper, but we think that they are closely related to the application domain.

[3] Mike Wooldridge & al., support the idea of dynamic organization when they talk about reactive or on-fly cooperation [14].

4. AGENT CONCEPTS

Cooperation is perhaps the paradigm example of social activity in both real and artificial social systems; it is certainly the best studied process in multi-agent systems research [15].

A conceptualization of cooperation has been presented so far. Indeed, two aspects have been mentioned as mainstays of cooperation: communication and organization. Concerning communication, the terminology includes the concepts of beliefs, goals, actions and a message. Organization is dynamic because of the concept of cooperation strategy.

Obviously, an organizational structure in which roles distribution is dynamic increase communication cost, but can give better results for some complex problems. A static structure doesn't cope with the environment hazards and limits the possible configurations that can occur in the resolution process[4].

Multi-agent systems put into practice a set of techniques and concepts allowing some concrete (e.g. robots) or abstract (software) entities called "agents" to cooperate according to some cooperation modes. By focusing on interaction and individual satisfaction, multi-agent systems ban thinking in a centralized or global way[5]. Hence, we keep from our previous study the following concepts for an agent: *beliefs* and *goals* as communication concepts and *roles* as concepts related to organization.

5. CONCLUSION

The agent metaphor comes packaged with a number of powerful psychological abstractions such as Beliefs, Desires, and Intentions. The work presented explores a particular type of rational agent: a Belief-Goal-Role agent. This making up of the intentional structure of an agent was subject to argumentation in this paper. The development of an ontology for cooperation has ended in identifying beliefs, goals as communication concepts and roles as organization concepts. Unlike most previous work, the presented study shows a new way to combine agent and ontology technologies. Indeed, ontologies have established themselves as a powerful tool to enable knowledge sharing, and a growing number of applications have benefited from the use of ontologies as a means to achieve semantic interoperability among heterogeneous, distributed systems. Ontologies are used in this paper as natural arguments to belief-goal-role agents.

Finally, we think that the study presented in this paper open new perspectives on the realization of agent systems. The ontology developed for communication as well as for organization draws its inspiration from the widely recognized fact that interaction is the most important single characteristic of complex systems. Many researchers believe that in future, computation itself will be understood chiefly as a process of interaction.

[4] In certain kinds of problems, a static structure may be more appropriate than a dynamic one. Such discussion is beyond the scope of this paper; it can be addressed apart in another study with more details. Generally, and according to the essence of multi-agent systems, a dynamic structure can respond better to complexity.

[5] Accordingly, it is forbidden to talk about cooperation mode (see section 3) whenever we talk about agent systems.

6. REFERENCES

[1] Ferber, J. Les systèmes multi-agents: un apercu général. T.S.I, Volume 16, 1997.

[2] Durfee, E.H. The Distributed Artificial Intelligence Melting Pot. IEEE Trans. On SMC, Vol. 21, No 6, November, 1991.

[3] Bratman, M.E. Plans, and Practical Reasons. Harvard university press, Cambridge, MA, 1987.

[4] Shoham, Y. Agent Oriented Programming. Artificial intelligence, 60 (1), 1993.

[5] Bandinelli, S., and Di Nitto, E., and Fuggetta, A. Supporting cooperation in the SPADE-1 environment. IEEE trans. On Software engineering, Vol. 22, No 12, December 1996.

[6] Konolige, K., and Nilson, N.J. Multiple agent planning systems. AAA'80, pp 138-142.

[7] Anzieu, D., and Martin, J.Y. La dynamique des groupes restreints. Ed. puf, 1968.

[8] Rao, A.S., and Georgeff, M.P. An abstract architecture for rational agents. In R. Fikes and e. Sandwall editors, Proceedings of Knowledge Representation And Reasoning (KR&R-91), page 473-484. Morgan Kauffmann Publishers: San Mateo, CA, April 1991.

[9] Soubie, J.L., and Kacem, A.H. Modèles de cooperation homme/système intelligent. Systèmes coopératifs : de la modélisation à la conception, ed. Octares, 994.

[10] Cohen, P.R., and Levsque, H.J. Intention is choice with commitment. Artificial Intelligence, 42, pp. 213-261, 1990.

[11] Wooldridge, M., and Jennings, N.J. Agent theories, Architectures, and Languages: A Survey. LNAI 890, Springer-Verlag, 1994.

[12] Chainbi, W., Cooperation in Multi-agent Systems. Internal report, Fseg-Sfax, April 1997.

[13] Gasser, L. Distribution and Coordination of Tasks Among Intelligent Agents. Scandinavian conference on artificial intelligence (SCAI'88), pp 189-192.

[14] Wooldridge, M., and Haddadi, A. Making it up as they go along: A Theory of Reactive Cooperation. LNAI 1441, Springer-Verlag, June 1998.

[15] D'Inverno, M., and Luck, M., and Wooldridge, M. Cooperation Structures. IJCAI-97, Nagoya, Japan, August 1997.

[16] Doran, J.E., and Franklin, S., and Jennigs, N.R., and Norman, T.J. On cooperation in multi-agent systems. The Knowledge Engineering Review, 12(3), 309-314, 1997.

[17] Austin, J.L. How to do things with words. Oxford University Press,1962