Integrating Authority, Deontics, and Communications within a Joint Intention Framework

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ABSTRACT
Many agents are fielded within environments requiring modeling traditional organizational structures such as military hierarchies and corporations, with their associated authority relationships and a strong form of responsibility associated with the subordinate agents. Furthermore, communications between agents placed in such environments benefit from a strong, consistent semantic model to express not only the source’s goal but more importantly their intent as well. Addressing the need above, we have developed an integrated semantic framework for modeling and operationalizing authority relationships, deontic operators, and inter-agent communications based upon joint intention theory. This allows us to not only regularize the representation and reasoning components of agents but to also realize: improved coordination due to enhanced agent teamwork (persistence and robustness toward successful achievement of goals even in the face of problems); improved conformance of the behavior of each agent according to its organizational role and authority related to other organizational positions; and improved bounding of the behavior of agents when faced with the imposition of deontic operators from various sources.

1. INTRODUCTION
This paper presents a broad application of the semantics of joint intention theory (JIT) (see [3][6] as examples). A great deal of prior research on joint intention theory has been on the formal specification of the semantics of “speech acts” for agent communication languages (c.f. [3][7]). In our own work, we have focused on the “Cohen & Levesque” (C&L) formalism for joint intentions due to its strong semantic formalism and its high level of maturity in the area of agent communication languages. In this paper, we also present novel work on tying the JIT-based ACL with authority relationships and deontic operators.

2. JIT PERFORMATIVE SUITE
The prior work on JIT ACLs suffers from being spread throughout the literature and have slowly changed semantics over the years, leading to incomplete and incompatible definitions. Many performatives required to create an operational system are also missing or in a sub-optimal form. We have regularized the semantics of the basic definitions to be consistent across the entire performative suite and underlying definitions to create a single point of reference for a consistent and unified JIT-based ACL. Furthermore, we extended the prior work by adding performatives not yet found in the literature to yield a broader suite of performatives that, as a result, provides better support to multi-agent system implementers.

The performatives fall into the following general categories:

- Core: INFORM, REQUEST, SHOUT
- Specialized Core: SUBSCRIBE, QUERY, PROXY, PROXY-WEAK, STANDINGOFFER
- Team-oriented: AGREE, REFUSE, CANCEL, FAILURE, ACCEPT, REJECT, WITHDRAW, ORDER
- Utility: IMPOSSIBLE, RELFAIL, SUCCESS, ACKNOWLEDGE, NOTUNDERSTOOD

Core performatives are the most basic performatives, defined directly using the basic definition of ATTEMPT. The Core performatives are those upon which all of the other performatives are based, either using specialization or composition. Specialized Core performatives are Core performatives with specific message content expressions that are optimized to common messaging situations. Team-oriented performatives exploit the semantics of joint intention theory to form and dissolve teams of agents under various circumstances. The utility performatives are also specializations of Core performatives but are in general used in service of the operational ramifications of the semantics of the other performatives. Space limitations preclude us from giving the modal definitions of these performatives here, but see [4] for our earlier work in this area.

The performative definitions above are defined with a single, consistent semantics that have a broad range of applicability. The REQUEST and INFORM performatives will consistently be the most widely used in fielded systems because of their generality.
The specialized performatives will have more or less use depending upon the domain and situations, with for example, STANDINGOFFER being used more in cooperative environments, SUBSCRIBE in information monitoring situations, PROXY forms being used more when the multiagent community has lots of middle agents, etc. The team-oriented and utility performatives serve to simplify fielded system with their specialization to the situations commonly encountered when operating in joint intention-based teams (task acceptance and completion, cancellation, task impossibility, etc.).

3. AUTHORITY RELATIONSHIPS

The need to model organizations in which intelligent agents are associated with, or dynamically create themselves, arises often (cf. [1],[5]). One significant aspect of organizations is the authority relationship that each role/position within the organization has with respect to the other roles/positions. The level of authority each agent has over another is not likely to be identical across all relationships but will vary in degree by particular organizational position pairings. To support this variation in authority with some level of granularity in our relationship modeling, we have defined joint intention-based authority relationships with several degrees of authoritative power.

In our work, the degree of authority is based on the scope of actions and contexts that the authority relationship holds over. We have based our definitions upon the notion that agents with authority can impose that authority on others to compel them to do what they want done. We also wanted to distinguish the relationships in which agents are not necessarily in static authority relationships but may still spontaneously accept tasking from others for other reasons. Below are the authority-related definitions we have defined using joint intention semantics.

**Definition: Authority-Over**

\[\text{AUTHORITY-OVER } x y a q = \forall e. (\text{DONE } x (\text{REQUEST } x y e a \Phi)) \supset (\text{PWAG } y x (\text{DONE } y a) \Phi) \land (\text{PWAG } y x (\text{DONE } y a) \Phi)\]

where \(\Phi = [\text{MB } x y \equiv \neg \text{PROHIBITED } y a) \land q]\)

Agent \(x\) has authority over \(y\) (above) and \(y\) is obedient to \(x\) (below) with respect to action \(a\) and relativizing condition \(q\) because for every JIT REQUEST by \(x\) for \(y\) to do \(a\) in context \(q\), \(x\) will always adopt a PWAG to do \(a\) with respect to \(x\)'s PWAG that \(y\) do \(a\). Please see [4] for the notation and definitions used here.

**Definition: Obedient-To**

\(\text{OBEIDENT-TO } y x a q = (\text{AUTHORITY-OVER } x y a q)\)

**Definition: Master**

\(\text{MASTER } x y = \forall a \forall q. (\text{AUTHORITY-OVER } x y a q)\)

**Definition: Superior**

\(\text{SUPERIOR } x y a q = (\text{AUTHORITY-OVER } x y a q)\)

**Definition: Peer**

\((\text{PEER } x y a q) = \neg (\text{AUTHORITY-OVER } x y a q) \land \neg (\text{AUTHORITY-OVER } y x a q)\)

**Definition: Helpful**

\((\text{HELPFUL } x y) = \exists a. \exists q. (\text{PEER } x y a q) \land (\text{REQUEST } x y e a q) \supset [\text{PWAG } y x (\text{DONE } y a) \land (\text{PWAG } y x [\text{DONE } y a])]\)

As can be seen by the different types of quantification, we can specify authority relationships with several levels of scoping and, therefore, authoritative power. With this characterization of authority we can specify absolute authority (Master), more narrowly focused authority related specifically to a task and a context (Superior, with multiple of these to broaden to a number of tasks given the same context, the same task in multiple contexts, etc.), and dynamic “authority” relationships in more open multiagent environments, where an agent will sometimes become subservient to another agent (Peer and Helpful).

4. DEONTICS

Deontics pertains to representing and reasoning about multiagent commitments and restrictions in the form of obligations, permissions, and prohibitions [9]. Such notions arise naturally due to institutional and organizational rules, roles, exercising of authority relationships, etc. For example within our system, rules of engagement (statements about the situations in which military forces will initiate and continue combat) explicitly use the terms “prohibited”, “may”, “may not”, etc. which easily map to deontic operators. Also, commanders associated with some of the agents in our system issue autonomy specifications to alter the behavior of our system and this, too, is in terms of what the agent’s must, may, and cannot do, also easily translatable to the basic deontic operators.

When considering how best to operationalize our deontic operators, the primary issue was how to define them in such a manner as to provide the human commanders and the agents in the system with concrete implications upon agent (and hence system) behavior (Lisse 2006); it was important that the commanders and agents clearly understood when obligations are created and discharged and give them expectations of behavior (and lack of it) given knowledge of the establishment of the deontic operators.

Joint Intention theory provides an excellent basis upon which to operationalize deontic operators because it addresses the issue of constraining behavior in appropriate circumstances and thereby also improves the accuracy of the expectations of the current and future activity of agents. Specifically, having a joint intention makes explicit what an agent is obligated to do beyond simply attempting to perform a task; the agent must persist toward successful completion of its obligation until such time as it does succeed, it becomes irrelevant, or it becomes impossible to do. Specifically, we adopted the following rule for obligation:

**Definition: Obligated**

\[\text{PWAG } y x (\text{DONE } y a) \land (\text{PWAG } y x (\text{DONE } y a) \land q) \supset (\text{OBLIGATED } y x a q)\]
That is, agent $y$ is said to become obligated to agent $x$ to do action $a$ within the context of $y$ whenever it is established that agent $y$ has a persistent goal to perform task $a$ relative to agent $x$’s persistent goal that it perform that task.

Note that the converse is not necessarily true. That is, $(\text{OBLIGATED } x y a)$ does not imply that a joint intention exists as obligations may arise from means other than by JI-based mechanisms (e.g., rules of engagement, organizational policy).

The creation of an obligation, as we have defined it, can arise in the following joint-intention situations: An agent in authority REQUESTS or ORDERS a slave (or a subordinate in the proper context) agent to perform an action; a PEER agent REQUESTS of, or SUBSCRIBES to, another agent and the requested agent explicitly AGREES to do so; A STANDINGOFFER followed by an ACCEPT is also structured to form an obligation; by being the intermediary agent of a PROXY performative will also result in an obligation as the initial contact of the intermediary agent is REQUESTed to forward another performative to the eventual destination agent.

Obligations arising from institutional norms may be created and represented directly without the need to rely upon the rule above. In other words, agents will automatically have obligations, prohibitions, etc. imposed on them based on a number of factors that will not be related to specific agents.

Definition: Prohibited

$$(\text{PROHIBITED } x y a) = (\text{OBLIGATED } x y \neg a)$$

The PROHIBITED operator says that agent $x$ is forbidden by agent $y$ from performing action $a$.

Definition: Permitted

$$(\text{PERMITTED } x y a) = \neg (\text{OBLIGATED } x y \neg a)$$

That is, agent $x$ is permitted by $y$ to perform action $a$.

During system design and development, it became apparent that in certain circumstances it was desirable that an agent acquire an explicit statement of permission to perform certain actions. To deal with this, we created the following deontic operator:

Definition: Authorized

$$(\text{AUTHORIZED } x y a) = (\text{PERMITTED } x y a) \land (\text{PERMISSION } y x a)$$

Where $(\text{PERMISSION } y x a)$ indicates that agent $x$ has received permission from $y$ regarding action $a$.

5. SUMMARY

Although severely limited in space in this paper, we have shown how a joint intention formalism, particularly the C&L formalism, can be applied to a broader range of areas than has previously ever: agent communication languages, authority relationships, and deontics operationalization.

The JIT-based ACL is novel in a number of ways. Most importantly, we have modified old performative definitions, and created many new ones, with a single consistent logical basis. We have also provided a much larger corpus of performatives than prior work, providing support for a wider range of agent applications.

We also demonstrated how joint intention semantics can be applied to model organizational authority relationships to provide varying levels in strength (breadth) of the authority relationship. Because of the basis in the joint intention formalism, the agents have explicit knowledge about the behavioral ramifications of the relationship to and from their respective authority position.

Finally, we grounded deontic concepts in joint intention theory in order to provide a strong operational semantics for obligation, permission, authorization, and prohibition. By using joint intention theory, agents are appropriately compelled or constrained in their behavior in appropriate circumstances.

6. ACKNOWLEDGMENTS

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7. REFERENCES


