January 2001

Support for groups within a formal semantics for proxy communicative acts

Marcus J. Huber

Sanjeev Kumar

Philip R. Cohen

David R. McGee

Support for Groups Within A Formal Semantics for Proxy Communicative Acts

Marcus J. Huber, Sanjeev Kumar, Philip R. Cohen, David R. McGee

Department of Computer Science and Engineering
Oregon Graduate Institute
20000 NW Walker Road
Beaverton, OR 97006, USA

{marcush, skumar, dmcgee, pcohen}@cse.ogi.edu

Keywords: Multiagent Systems, Distributed AI, Software Agents, Middle Agents, 3rd-party Performatives

Abstract

Mediation services are becoming increasingly important in multiagent systems. An agent that can act on behalf of another agent is one important example of mediation functionality commonly required. Within this paper, we define and analyze PROXY and PROXY-WEAK communicative acts that formally specify semantics for interacting with middle agents that provide proxy services. These two communicative acts are shown to have a distinctly different impact upon the mental state of the agents involved and impose significantly different levels of commitment upon the middle agents.

1 Background

A common design attribute in many general-purpose multiagent software architectures and distributed computing environments is agents or processes whose sole purpose is to help locate other agents find and communicate with them. These mediators or middle agents include the "facilitator" agents in the FIPA [FIPA, 2000] and OAA [Martin *et al*., 1999] architectures, the "proxy" agents of the DARPA CoABS Project's Grid, and the proxy web servers on a network. Within KQML [Finin *et al*., 1997], it is common for an agent to use agents to "recruit" other agents that can provide it services.

These software proxies are an increasingly important aspect of distributed computational systems and are being introduced in a wide range of domains. In many cases, the notion entails a computational process that acts on behalf of, and typically assumes full responsibility for, the activities of another computational process (which ostensibly has some limitation that requires the use of the proxy). In other cases, the proxying entity should have no real responsibility. Unlike KQML's forward [Finin *et al*., 1997], proxying does not entail simply passing on messages between entities that might not otherwise have contact with each other.

As an example of the difference in commitment levels that we are trying to support, recall the Watergate affair. President Nixon wanted the special prosecutor Archibald Cox to be fired, and asked Elliott Richardson (the Attorney General) to do so. Nixon wanted Richardson to take responsibility for the firing (i.e., Nixon performed a PROXY), rather than have Richardson tell Cox that Nixon is firing Cox (i.e., perform a PROXY-WEAK).[1]

Whereas we spend the beginning of the paper on details of the notation that we employ, the definition of key concepts, and a new definition of the INFORM speech act, the focus of the paper is devoted to the definition and analysis of two new communicative acts, PROXY and PROXY-WEAK. Their semantics is based upon prior work on the semantics of speech acts involving groups [Kumar *et al*., 2000], and should facilitate the deployment of mediation agents that provide proxying services. Our analysis will show that the two acts result in the middle agents having significantly different levels of commitments relative to the final agents, where PROXY imposes significant and PROXY-WEAK imposes very little responsibility upon the middle agents. We also show that satisfaction and successful discharge of the PROXY-WEAK speech act is semantically equivalent to the sending agents performing a speech act directly on the final target agents. As part of our analysis, we show that FIPA's speech acts of the same names suffer from a number of deficiencies, including lack of support for group interaction and misrepresentation of the sender's true intentions.

2 Preliminaries

We use a modal language with the usual connectives of a first order language with equality, as well as operators for propositional attitudes and event sequences. Full details of this modal language can be found in [Cohen and Levesque, 1990a, 1990b]. An action expression is built from variables ranging over sequences of events using constructs of dynamic logic: a;b is action composition and *p*? is a test ac-

[1] To avoid being Nixon's proxy, Richardson resigned.

tion. Mutual belief is defined in terms of unilateral mutual belief, or BMB [Cohen and Levesque, 1990b]. However, unlike the previous work, we treat BMB between two agents as a semantic primitive in this paper, as in [Kumar *et al.*, 2000]. In our model, BMB can be established by default [Katagiri, 1996].

2.1 Representing Groups

As is customary, we treat groups as simply a collection of entities. As such, we can regard a group as being defined by a membership property. This can be captured by a predicate consisting of a free variable that ranges over individuals, and in general, ranges over subgroups as well.

Notation. We will underline the entities that represent groups when we need to emphasize their group status, and use the same symbol without the underline in a functional notation to denote the associated membership predicate. For example, $\underline{\tau}$ is a group having the membership predicate $\tau(z)$ where z is a free variable. An entity without underline can be either an individual or a group.

We introduce the notation $\langle\alpha\rangle$ to denote a formula defined by the following rules:

If α is a formula without any term of the form $\underline{\tau}$, then $\langle\alpha\rangle = \alpha$

If α is a formula with term $\underline{\tau}$, and z does not appear in α, and $\tau(z)$ is the property predicate that corresponds to $\underline{\tau}$, and $\alpha(z)$ is a formula formed by replacing $\underline{\tau}$ with z in α, then $\langle\alpha\rangle = \forall z.\ \tau(z) \supset \alpha(z)$

For example,

$\langle \text{BEL x } p\rangle = (\text{BEL x } p)$, if x is an individual agent.

$\langle \text{BEL } \underline{\tau}\ p\rangle = \forall z\ \tau(z) \supset (\text{BEL z } p)$

$\langle \text{BEL } \tau\ p\rangle$ cannot be further expanded until we know whether τ is an individual or a group.

In case of ambiguity, we will mark the starting angle bracket, and the group term that it applies to, with the free variable in the superscript. For example,

$\langle^{y} \text{ BEL } \underline{\tau}^{y} (\text{BEL x } \langle^{z} \text{ BEL } \underline{\tau}^{z}\ p\rangle\ )\ \rangle =$

$\forall y\ \tau(y) \supset (\text{BEL y } (\text{BEL x } \forall z.(\ \tau(z) \supset (\text{BEL z } p))))$

If τ represents an individual agent, say x, then the superscript is dropped in the expansion.

$\langle^{y} \text{ BEL } \tau^{y}\ p\rangle = \langle \text{BEL } \tau\ p\rangle = (\text{BEL } \tau\ p) = (\text{BEL x } p)$

We will use the symbols α, β, γ, and δ to represent membership predicates, which therefore can represent either groups or individuals.

2.2 Group Beliefs

The semantics of group communication primitives based on speech acts deals with group beliefs. The simplest case is to consider the beliefs of all the members of a group when talking about group beliefs. Group belief may be defined in several ways, including inclusive belief: a group $\underline{\tau}$ believes *p* if all individuals or sub-groups that constitute the group believe *p*. The beliefs of more complex groups such as hierarchically composed organizations and institutions [Werner, 1989] can then be expressed in terms of the beliefs of an abstract group consisting of certain roles in that organization or institution.

Group BMB. An entity τ_1 has unilateral mutual belief about a proposition *p* with another entity τ_2 when τ_1 believes that there is mutual belief between itself and τ_2 about *p*. It is possible to define different variations of group BMB corresponding to the various types of group beliefs. For inclusive beliefs that we assume in this paper, we use BMB between two individuals, between an individual and a group, and between two groups as in [Kumar *et al.*, 2000].

Group Mutual Belief. Entities τ_1 and τ_2 have mutual belief about proposition *p* when both τ_1 and τ_2 have unilateral mutual beliefs about proposition *p* with respect to the other entity.

$(\textbf{MB}\ \tau_1\ \tau_2\ p) \equiv (\textbf{BMB}\ \tau_1\ \tau_2\ p) \wedge\ (\textbf{BMB}\ \tau_2\ \tau_1\ p)$

This is a straightforward generalization of the mutual belief defined for two agents in [Cohen and Levesque, 1990a].

3 Group Extension of Basic Concepts

We adopt an attempt-based semantics [Cohen and Levesque, 1990b; 199b; Smith et. al., 1998] for group communication performatives in the following definitions.

Definition 1. *PGOAL (Persistent Goal)*

$$\begin{aligned}(\text{PGOAL } \tau\ p\ q) \equiv\ & (\text{BEL } \tau\ \neg p) \wedge (\text{GOAL } \tau\ \Diamond p) \wedge \\ & (\text{KNOW } \tau\ [\text{UNTIL } [(\text{BEL } \tau\ p) \vee \\ & \quad (\text{BEL } \tau\ \Box\neg p) \vee \\ & \quad (\text{BEL } \tau\ \neg q)] \\ & \quad (\text{GOAL } \tau\ \Diamond p)]).\end{aligned}$$

Persistent goal formalizes the notion of commitment. An entity (agent or group) τ having a persistent goal *p* is committed to that goal. The entity τ cannot give up the goal that *p* is true in the future, at least until it believes that one of the following is true: *p* is accomplished, or is impossible, or the relativizing condition *q* is untrue.

Definition 2. *INTEND (Intention)*

$$\begin{aligned}(\text{INTEND } \tau\ a\ q) \equiv\ & (\text{PGOAL } \tau\ [\text{HAPPENS } \tau \\ & (\text{BEL } \tau\ (\text{HAPPENS } a))?;a]\ q)\end{aligned}$$

Intention to do an action *a* is a commitment to do the action knowingly. The entity τ is committed to being in a mental state in which it has done the action *a* and just prior to which it believed that it was about to do the intended action next.

Definition 3. *ATTEMPT*

$$\begin{aligned}& (\text{ATTEMPT } \tau\ e\ \phi\ \psi\ t) \equiv \\ & \quad t?;[(\text{BEL } \tau\ \neg\phi) \wedge \\ & \quad (\text{GOAL } \tau\ (\text{HAPPENS } e;\Diamond\phi?)) \wedge \\ & \quad (\text{INTEND } \tau\ \ t?;e;\psi?\ (\text{GOAL } \tau\ (\text{HAPPENS } e;\Diamond\phi?)))]?;e\end{aligned}$$

An attempt to achieve ϕ via ψ is a complex action expression in which the entity τ is the actor of event *e* and just prior to *e*, the actor chooses that ϕ should eventually become true, and intends that *e* should produce ψ relative to that choice. So, ϕ represents some ultimate goal that may or may not be achieved by the attempt, while ψ represents what it takes to make an honest effort.

Definition 4. *PWAG (Persistent Weak Achievement Goal)*

$$\begin{aligned}& (\text{PWAG } \tau_1\ \tau_2\ p\ q) \equiv \\ & \quad [\neg(\text{BEL } \tau_1\ p) \wedge (\text{PGOAL } \tau_1\ p)] \vee \\ & \quad [(\text{BEL } \tau_1\ p) \wedge (\text{PGOAL } \tau_1\ (\text{MB } \tau_1\ \tau_2\ p))] \vee \\ & \quad [(\text{BEL } \tau_1\ \Box\neg p) \wedge (\text{PGOAL } \tau_1\ (\text{MB } \tau_1\ \tau_2\ \Box\neg p))] \vee \\ & \quad [(\text{BEL } \tau_1\ \neg q) \wedge (\text{PGOAL } \tau_1\ (\text{MB } \tau_1\ \tau_2\ \neg q))]\end{aligned}$$

This definition, adapted from [Smith and Cohen, 1996], states that an entity τ_1 has a PWAG with respect to another entity τ_2 when the following holds: (1) if entity τ_1 believes that p is not currently true, it will have a persistent goal to achieve p, (2) if it believes p to be either true, or to be impossible, or if it believes the relativizing condition q to be false, then it will adopt a persistent goal to bring about the corresponding mutual belief with entity τ_2.

Definition 5. *SINCERE*

Entity α is sincere with respect to entity β and proposition p if whenever α wants β to come to believe p, it wants β to come to know p. Agents may not in fact be sincere but, as with all the mental states discussed here, they are responsible for being sincere.

$$(\text{SINCERE } \alpha\ \beta) \equiv \forall e\ (\text{GOAL } \alpha\ (\text{HAPPENS } e; (\text{BEL } \beta\ p)?)) \supset (\text{GOAL } \alpha\ (\text{HAPPENS } e; (\text{KNOW } \beta\ p)?))$$

Definition 6. *TRUST*

Entity α trusts entity β for proposition p if whenever α believes that β believes p, they also come to believe p.

$$(\text{TRUSTS } \alpha\ \beta\ p) \equiv (\text{BEL } \alpha\ (\text{BEL } \beta\ p)) \supset (\text{BEL } \beta\ p)$$

Definition 7. *HAPPENING*

An action expression a is happening if one of the following is true (1) a has just been done, or (2) a is going to happen next (i.e. a is just starting), or (3) there exists some initial subsequence of a that has just been done but a has not just been done (i.e. a has started but not yet completed).

$$(\text{HAPPENING } a) \equiv (\text{DONE } a) \vee (\text{HAPPENS } a) \vee [\exists\, e\ (e \leq a) \wedge (\text{DONE } e) \wedge \neg(\text{DONE } a)]$$

3.1 REQUEST

We use a definition of the REQUEST performative with group semantics defined in [Kumar *et al.*, 2000] within our later definitions of PROXY, and so present it below. Here, α is the entity (group or individual) performing the REQUEST, β all of the recipients (including the "overhearers") of the message, and γ is the intended recipients (the intended actors or hearers).

Definition 8. *REQUEST*

$$(\text{REQUEST } \alpha\ \beta\ \gamma\ e\ a\ q\ \text{t}) \equiv (\text{ATTEMPT } \alpha\ e\ \phi\ \psi\ \text{t})$$
$$\text{where } \phi = \langle^{z}\ (\text{DONE } \gamma^{z}\ a) \wedge [\text{PWAG } \gamma^{z}\ \alpha\ (\text{DONE } \gamma^{z}\ a)\ (\text{PWAG } \alpha\ \gamma\ \langle^{w}\ \text{DONE } \gamma^{w}\ a\rangle\ q)]\ \rangle$$
$$\text{and } \psi = [\text{BMB } \beta\ \alpha\ (\text{BEFORE } e\ [\text{GOAL } \alpha\ (\text{AFTER } e\ [\text{PWAG } \alpha\ \gamma\ \phi\ q]\ )]\ )]$$

Intuitively, this definition says that in making a request of addressees γ, the requestors are trying to get γ to do the action a, and to form the commitment to do a relative to the requesters' commitment that they do it. More formally, by substituting for ϕ and ψ in the definition of ATTEMPT (definition 3), we obtain the goal and the intention of the REQUEST respectively. The goal of REQUEST is that the intended actors γ eventually do the action a and also have a PWAG with respect to the requesters α to do a. The intended actors' PWAG is with respect to the requesters' PWAG (towards γ) that γ does the action a. The requesters' PWAG is itself relative to some higher-level goal q. The intention of REQUEST is that all of the recipients β believe there is a mutual belief between the recipients and the requesters that before sending the REQUEST, the requesters α had a goal that after sending, the REQUEST α will have a PWAG with respect to the intended actors γ about the goal ϕ of the request. [Kumar *et al.*, 2000] have shown that the addressees γ do not quantify into α's beliefs so that α can make a request to addressees whom they might not know.

3.2 INFORM

We now present a definition of the INFORM speech act with support for the group interaction. This new definition of INFORM is a generalized version of the individual communication performatives defined in [Smith et. al., 1998].

Definition 9. *INFORM*

$$(\text{INFORM } \alpha\ \beta\ \gamma\ e\ p\ t) \equiv (\text{ATTEMPT } \alpha\ e\ \phi\ \psi\ t)$$
$$\text{where } \phi = [\text{BMB } \gamma\ \alpha\ p]$$
$$\text{and } \psi = [\text{BMB } \beta\ \alpha\ (\text{BEFORE } e\ [\text{GOAL } \alpha\ (\text{AFTER } e\ [\text{BEL } \gamma\ (\text{BEFORE } e\ [\text{BEL } \alpha\ p])])])]$$

In the definition of INFORM, the senders α have the goal that the intended recipients γ come to believe that there is mutual belief that γ believes p. The intention of INFORM is that all of the recipients β believe there is a mutual belief between the recipients and the informers that before sending the INFORM, the informers α had a goal that after sending the INFORM the intended recipients γ would believe that, before sending the INFORM, γ believed proposition p.

Using an analysis similar to that shown for REQUEST in [Kumar *et al.*, 2000], it can be shown that the recipients β, the intended recipients γ, and the senders α, never quantify into each other's beliefs. This means that the informers α does not need to know whom the individuals of β and γ are and vice versa.

4 PROXYING

The notion

of proxying involves one entity's asking another entity to do something on its behalf and typically taking responsibility for the action it was asked to do. For this paper, we define two speech acts, PROXY and PROXY-WEAK, that facilitate agents asking other agents to proxy a speech act for them, i.e., to perform a speech act to other agents on their behalf. As we will show, the PROXY speech act imposes significant commitments upon the intermediate group of agents, while the PROXY-WEAK speech act greatly reduces the burden placed upon the proxying agents. Both PROXY and PROXY-WEAK are speech acts based upon REQUEST that take a speech act as an argument – an example of composability of speech acts.

4.1 NOTATION

In the definitions to follow, we need to specify how to rewrite embedded speech acts so we first introduce some notation. In our discussions, we use the following schematic variables: *sact* ranges over speech act types, α are the senders of the speech act, β are the recipients (including the "over-hearers") of the speech act, γ are the intended recipients of the speech act, δ is the intended recipient of the speech act performed by the middle agents, *e* is an event, *a* is an action, *q* is a relativizing condition, and *t* refers to a time point.

We use a parameter substitution function that, when applied to a speech act, replaces all occurrences of the schematic variable representing the specified speech act parameter by the specified value. For the speech acts defined within this paper, we use the following abbreviations for speech act parameters: sender (s), recipient (r), intended-recipient (i), distribution (final) recipient (d), event (e), action (a), proposition (p), constraint condition (c), relativizing condition (q), and time (t). For example, *sact* = (INFORM s/α r/β i/γ e/*e* p/*on-vacation*(α) t/*t*) represents an INFORM speech act with all occurrences of the sender parameter replaced by α, all occurrences of the recipient parameter replaced by β, all occurrences of the intended recipient parameter replaced by γ, etc. In such an expression, all unreferenced speech act parameters are left unchanged.

4.2 PROXY

When performing a PROXY speech act, the senders α want the intended recipients γ to select target agents denoted by a given group descriptor δ and to perform the embedded speech act to δ. This descriptive definition is very similar to that for the FIPA PROXY communicative act [FIPA, 2000], which states, "The sender wants the receiver to select target agents denoted by a given description and to send an embedded message to them." The PROXY speech act lends itself to the deployment of middle agents within multiagent domains that can be a fully responsible proxy for other agents. As we will show, we have defined PROXY in such a manner that the individuals of the group proxying the embedded communicative act must conform to its logical preconditions.

In the definition of PROXY below:

sact is an embedded speech act that α wants γ to distribute to δ.

c is a constraint condition for distributing the embedded communicative act (*e.g.* a time deadline).

β_γ is the recipient group predicate specifying all the hearers of the embedded speech act (i.e., that from γ to δ).

Definition 10. *PROXY*

(PROXY α β γ *e* δ *c* (*sact* s/γ r/β_γ i/δ) *q t*) $\equiv$
(REQUEST α β γ *e* (*c*?;(*sact* s/γ r/β_γ i/δ)) *q t*)

PROXY is defined as a request by the sender for an intermediary entity to perform a specified speech act to a final target entity if the condition c is met.

An example of PROXY in use is shown below, where a chairman says, "Would somebody request the board members in the hall to come inside before we vote?"

(PROXY
chairman <u>people in room</u> one_person_in_room
e <u>board_members</u>
(REQUEST
one_person_in_room <u>people in hall</u>
<u>board_members</u>
e' come_into_room (goal chairman vote) t')
(before we vote) t)

The PROXY act is a REQUEST that has been shown to satisfy the condition that the involved groups do not quantify into each others' individual beliefs [Kumar *et al.*, 2000]. However, in the previous analysis of REQUEST, it was assumed that the content of the REQUEST was opaque. Because we have now introduced nested speech acts, the opacity assumption is no longer valid. It can be shown, though, that the semantics of the third-party speech act still respects the criteria given in [Kumar *et al.*, 2000] for group communication.

In the theorems below, let *H* be the action of the middle agents γ honoring a PROXY. With respect to the definition of PROXY above, it means that γ just performed the requested action, *c*?;(*sact* s/γ r/β_γ i/δ), where *sact* is the speech act to be proxied. We can now establish the following results about the mental states of the middle agents.

Theorem 1a: After middle agents honor a PROXY of a REQUEST to do action *a*, they become committed to the final recipients doing action *a*. Formally,

$\models$ (DONE α (PROXY α β γ *e* δ *c*
(REQUEST γ β_γ δ *e*' *a q*' *t*') *q t*)); *H*)
$\wedge$ (SINCERE γ δ [PWAG γ δ ϕ *q*])
$\supset$ (PGOAL γ $\langle^{z}$ DONE δ^{z} *a*$\rangle$ *Q*)

where, *Q* is some relativizing condition and ϕ is the goal of the PROXY (definitions 10, 8).

Proof sketch: The middle agents γ have just honored the proxy. Hence, (DONE γ (REQUEST γ β_γ δ *e*' *a q*' *t*')) is true. From the definition of request as an ATTEMPT (definition 8), the intention of this REQUEST is ψ, where

ψ = [BMB β_γ γ (BEFORE *e*' [GOAL γ
(AFTER *e*' [PWAG γ δ ϕ *q*])])],

ϕ = $\langle^{z}$ (DONE δ^{z} *a*) $\wedge$ *P*$\rangle$, and P represents the PWAG conjunct in ϕ.

From the definition of ATTEMPT (definition 3), we see that (INTEND γ t?; *e*';ψ? …) must have been true just before γ did the request action, i.e. γ must have had an intention to bring about a BMB between all the recipients and themselves that before γ made the request, they had the goal that after the request is done, they will have a PWAG with final recipients δ about ϕ. Using the usual assumption that agents are sincere in their communication, γ must have the PWAG with final recipients δ about ϕ after they do the REQUEST action because sincere agents cannot intend to bring about BMB about a proposition they believed to be false. Therefore, (PWAG γ δ ϕ *q*) is true after the request *e*' is done. Since γ has just done the request action, they do not yet believe that the final recipients δ have done the action *a*. That is, $\neg$(BEL γ $\langle^{z}$ (DONE δ^{z} *a*) $\wedge$ *P*$\rangle$) is true. Therefore, from the definition of PWAG (definition 4), we see that the first disjunct

[$\neg$(BEL γ *p*) $\wedge$ (PGOAL γ *p*)] is true, where

$p = \langle^{z}$ (DONE δ^{z} a) $\wedge$ $P\rangle$

Substituting for p in the PGOAL conjunct above, we get

(PGOAL γ $\langle^{z}$ (DONE δ^{z} a) $\wedge$ $P\rangle$)

If an agent is committed to the conjunction $p1 \wedge p2$, it must be committed to each of $p1$ and $p2$ relativized to the original commitment. Therefore,

(PGOAL γ $\langle^{z}$ (DONE δ^{z} a) $\wedge$ $P\rangle$)
$\supset$ (PGOAL γ $\langle^{z}$ DONE δ^{z} $a\rangle$ Q)
where, Q = (PGOAL γ $\langle^{z}$ (DONE δ^{z} a) $\wedge$ $P\rangle$)

This proves the desired result.

Theorem 1b: Just before middle agents honor a PROXY of an INFORM for some proposition p, they are required to believe p. Formally,

$\models$ (DONE α (PROXY α β γ e δ c
(INFORM γ β_γ δ e' p t') q t); H)) $\wedge$
(SINCERE γ δ p)
$\supset$ (BEFORE e' [BEL γ p])

Proof sketch: We use similar arguments as in the proof of theorem 1a. γ has just honored the PROXY by performing the embedded INFORM. From the definition of INFORM as an ATTEMPT (definition 9), the intention part of INFORM is

ψ = [BMB β_γ γ (BEFORE e' [GOAL γ
(AFTER e' [BEL δ (BEFORE e' [BEL γ p])])])]

Since the INFORM has just been done, the middle agents γ must have had the intention to bring about BMB that before performing the INFORM, γ believed p. Therefore, by the sincerity assumption, γ must have believed p (i.e., (BEFORE e' [BEL γ p]) is true. This proves the desired result.

4.3 PROXY-WEAK

Next, we try to define a form of proxy that we will call PROXY-WEAK that removes the "strong" requirement of precondition conformance upon the intermediary agents γ and, which upon satisfaction and successful performance, provides third-party speech act semantics. Unlike PROXY of a REQUEST to do an action a, the PROXY-WEAK of a request should not commit the middle agents to the final recipients doing action a. And, unlike PROXY of an INFORM for proposition p, the PROXY-WEAK of an INFORM should not require the middle agents to believe p.

Perhaps most importantly, PROXY-WEAK should satisfy the requirements of a third-party performative [Cohen and Levesque, 1990b] – the successful execution of the PROXY-WEAK and subsequent embedded speech act should be equivalent to the senders' performing a speech act directly to the final (possibly unknown) group of agents, *even when going through the proxy*. We start with a definition corresponding essentially to FIPA's definition of PROXY-WEAK [FIPA, 2000] and, after finding that it has significant flaws, define a version that we believe captures the key aspects.

Definition 11a. *PROXY-WEAK* (incorrect)

(PROXY-WEAK α β γ e δ c ($sact$ s/γ r/β_γ i/δ e/e') q t) $\equiv$
(REQUEST α β γ e
[c?;(INFORM γ β_γ δ e'
(GOAL α (DONE γ ($sact$ s/γ r/β_γ i/δ e/e'))) t')] q t)

Essentially, the middle agents say "α wants me to do *sact*." Since the middle agents γ always perform an INFORM in honoring PROXY-WEAK, from theorem 1b the following is true:

(BEFORE e' [BEL γ (GOAL α
[DONE γ ($sact$ s/γ r/β_γ i/δ)])])

That is, before performing the INFORM to δ, γ believed that α wanted it to perform *sact*. However, by performing a PROXY-WEAK, the goal of α was *not* that γ does *sact*, but rather that γ perform an INFORM regarding the *sact*. This misrepresents α's goals to δ and is therefore incorrect.

The above definition also does not result in performance of a third-party performative by the proxy agents. To illustrate this point, consider the Nixon example given earlier. Suppose Nixon (α) performs a PROXY-WEAK on Richardson (γ) with *sact* being the performative for 'fire' and Cox being the target agent (δ). According to the above definition of PROXY-WEAK, Richardson can satisfy Nixon's PROXY-WEAK by performing an INFORM to Cox corresponding in natural language to Richardson's saying to Cox, "Nixon wants me to fire you". However, this INFORM does not result in Cox's getting fired by Nixon. The key here is that performatives are accomplished in virtue of their being uttered and here Richardson's utterance does not result in 'fire' being performed by Nixon. The next definition addresses this limitation.

Definition 11b. *PROXY-WEAK*

(PROXY-WEAK α β γ e δ c
($sact$ s/α r/β_γ i/δ e/$e;e'$ t/t') q t)
$\equiv$ (REQUEST α β γ e [c?;(INFORM γ β_γ δ e' θ t')] q t)

where θ = (HAPPENING ($sact$ s/α r/β_γ i/δ e/$e;e'$ t/t'))

In other words, PROXY-WEAK of a speech act *sact* is a REQUEST to INFORM that the speech act *sact* is happening using the two acts – the sender's and the intermediary's. The two actions are $e;e'$, where e' is the very act of informing this fact – hence γ's act of performing the INFORM also completes α's speech act to δ. Using this definition of PROXY-WEAK, Richardson will satisfy Nixon's PROXY-WEAK by saying, in natural language, "Nixon hereby fires you". Here 'fires' is used as a third party performative – it is a performative because saying so in the right situation makes it so. We note that by the definition of PROXY-WEAK as a REQUEST, when the middle agents γ accept the REQUEST, they have a PWAG with senders α about performing the INFORM act with respect to the senders' PWAG that γ does the INFORM. From the definition of PWAG (definition 4), γ will establish a mutual belief to that effect after performing the requested INFORM. The PROXY-WEAK is discharged successfully when this mutual belief is established. This is evident from the next two theorems.

Theorem 2a: When the middle agents successfully discharge a PROXY-WEAK performed to them, the original senders believe that they have performed the embedded speech act even though they may not have observed the middle agents’ act directly and only know that it was done. Formally,

$$
\begin{aligned}
\models\ & [\mathrm{DONE}\ (\mathrm{PROXY\text{-}WEAK}\ \alpha\ \beta\ \gamma\ e\ \delta\ \mathit{SACT}\ q\ t);\\
& \qquad (\mathrm{MB}\ \alpha\ \gamma\ (\mathrm{DONE}\ (\mathrm{INFORM}\ \gamma\ \beta_\gamma\ \delta\ e'\ p\ t')))?\ ] \wedge\\
& (\mathrm{SINCERE}\ \alpha\ \beta\ [\mathrm{PWAG}\ \alpha\ \beta\ \phi\ q])\\
& \supset (\mathrm{BEL}\ \alpha\ (\mathrm{DONE}\ \alpha\ \mathit{SACT}))
\end{aligned}
$$

where, $\mathit{SACT} = (\mathit{sact}\ \mathrm{s}/\alpha\ \mathrm{r}/\beta_\gamma\ \mathrm{i}/\delta\ \mathrm{e}/e;e'\ \mathrm{t}/t')$,
$p = (\mathrm{HAPPENING}\ (\mathit{sact}\ \mathrm{s}/\alpha\ \mathrm{r}/\beta_\gamma\ \mathrm{i}/\delta\ \mathrm{e}/e;e'\ \mathrm{t}/t'))$, and
ϕ is the goal of the PROXY-WEAK (definitions 11b, 8).

Proof sketch: By performing a PROXY-WEAK, the senders α requested the middle agents γ to inform the final recipients δ that *p*. (1) From the usual assumption of sincerity, α cannot make that REQUEST unless α believes that *p*. (2) When γ establishes the mutual belief that the INFORM has been done, α believes that the event *e*' (i.e. the INFORM event) has been done. From (1) and (2), α believes that the event sequence *e;e*' is happening and also believes that the event *e*' has just been done. So α believes that the event sequence *e;e*' has just been done and hence believes that the action *SACT* represented by the event sequence *e;e*' has just been done. This establishes the desired result.

Theorem 2b: When the middle agents satisfy a PROXY-WEAK performed on them, the final recipients will come to believe that the original sender has performed the embedded speech act on them provided that they trust the middle agents. Formally,

$$
\begin{aligned}
\models\ & [\mathrm{DONE}\ (\mathrm{PROXY\text{-}WEAK}\ \alpha\ \beta\ \gamma\ e\ \delta\ \mathit{SACT}\ q\ t);\\
& \qquad (\mathrm{INFORM}\ \gamma\ \beta_\gamma\ \delta\ e'\ p\ t')] \wedge\\
& (\mathrm{TRUSTS}\ \delta\ \gamma\ p) \wedge (\mathrm{SINCERE}\ \gamma\ \ \delta\ p)\\
& \supset (\mathrm{BEL}\ \delta\ (\mathrm{DONE}\ \mathit{SACT}))
\end{aligned}
$$

where $\mathit{SACT} = (\mathit{sact}\ \mathrm{s}/\alpha\ \mathrm{r}/\beta_\gamma\ \mathrm{i}/\delta\ \mathrm{e}/e;e'\ \mathrm{t}/t')$, and
$p = (\mathrm{HAPPENING}\ (\mathit{sact}\ \mathrm{s}/\alpha\ \mathrm{r}/\beta_\gamma\ \mathrm{i}/\delta\ \mathrm{e}/e;e'\ \mathrm{t}/t'))$

Proof sketch: By assumption of sincerity, the middle agents γ believes the proposition being informed. The final recipients δ trust the middle agents γ. (1) Therefore, δ also believes the proposition being informed i.e. δ believes that *p*. (2) The final recipients δ have just received the INFORM from the middle agent. Therefore, δ believes that the event *e*' (i.e. the INFORM event) has been done. From (1) and (2), δ believes that the event sequence *e;e*' is happening and also believes that the event *e*' has just been done. So it believes that the event sequence *e;e*' has just been done and hence believes the action *SACT* represented by the event sequence *e;e*' has just been done. This establishes the desired result.

In the following theorems, let *H*' be the action of the middle agents γ honoring a proxy-weak message i.e. γ performs the requested INFORM action.

Theorem 3a: After middle agents honor a PROXY-WEAK of a REQUEST to do action *a*, they do *not* become committed to the final recipients doing action *a*. Formally,

$$
\begin{aligned}
\models\ & (\mathrm{DONE}\ \alpha\ (\mathrm{PROXY\text{-}WEAK}\ \alpha\ \beta\ \gamma\ e\ \delta\ c\\
& \qquad\qquad (\mathrm{REQUEST}\ \alpha\ \beta_\gamma\ \delta\ e'\ a\ q'\ t')\ q\ t);\ H')\\
& \not\supset (\mathrm{PGOAL}\ \gamma\ \langle^{z}\ \mathrm{DONE}\ \delta^{z}\ a\rangle\ Q)
\end{aligned}
$$

where, *Q* is some relativizing condition.

Proof sketch: From definition 11b, note that the middle agent(s) γ perform an INFORM — γ never perform the embedded ($\mathit{sact}\ \mathrm{s}/\alpha\ \mathrm{r}/\beta_\gamma\ \mathrm{i}/\delta\ \varepsilon/e;e'\ \tau/\mathrm{t}'$). Therefore, when the *sact* is a REQUEST, γ do not have the goal and intentions of ($\mathrm{REQUEST}\ \alpha\ \beta_\gamma\ \delta\ e'\ a\ q'\ t'$). In particular, from the definition of REQUEST (definition 8) γ do not have any PWAG with δ for doing *a* and hence are not committed to δ doing *a*.

Theorem 3b: After middle agents honor a PROXY-WEAK of an INFORM for some proposition *p*, they are *not* required to have believed *p*. Formally,

$$
\begin{aligned}
\models\ & (\mathrm{DONE}\ \alpha\ (\mathrm{PROXY}\ \alpha\ \beta\ \gamma\ e\ \delta\ c\\
& \qquad\qquad (\mathrm{INFORM}\ \alpha\ \beta_\gamma\ \delta\ e'\ p\ t')\ q\ t)\ );\ H'\ )\\
& \not\supset (\mathrm{BEFORE}\ e'\ [\mathrm{BEL}\ \gamma\ p])
\end{aligned}
$$

Proof sketch: Similar to the proof of theorem 3a where *sact* is an INFORM.

5. Discussion

FIPA has defined proxy communicative acts with a similar intent as ours [FIPA, 2000]. There are several significant differences between our approach and that of FIPA, however. First, FIPA’s PROXY and PROXY-WEAK are defined as an INFORM between the sending agent and the middle agent, while ours is defined using a REQUEST to the middle agents. This is significant in that the middle agent within FIPA is not expected to do anything, while in our definition the middle agents are expected to perform a subsequent speech act if they honor the request.

Second, FIPA defines their equivalent of PROXY-WEAK in terms of an INFORM of an intent by the original sender to have the middle agent do an action. The FIPA definition therefore misrepresents the sending agent’s intentions to the target agent similar to the shortcoming discussed for our definition 11a for PROXY-WEAK.

Third, FIPA does not support communication between more than a pair of agents at a time, one sender and one receiver. FIPA’s ACL semantics are ill-defined for cases of communication to, from, or between groups of agents.

In summary, the PROXY and PROXY-WEAK communicative acts defined in this paper provide speech acts that support agents interacting with middle agents that can act on their behalf. Our analysis has shown that the two acts result in the middle agents having significantly different levels of commitments relative to the final group, where PROXY imposes significant and PROXY-WEAK imposes very little responsibility upon the middle agents. We also have shown that the PROXY-WEAK speech act results in the correct embodiment of third party performative semantics, where we obtain the equivalence of the sending agents performing a speech act directly on the final target agents even while going through proxies.

References

Cohen, P.R., and Levesque, H.J. Intention is Choice with Commitment, *Artificial Intelligence*, 42(3), 1990(a).

Cohen, P.R., and Levesque, H.J. Performatives in a Rationally Based Speech Act Theory. *Proc. of the 28th Annual Meeting of the Assoc. for Comp. Linguistics*, 1990(b).

Finin, T., and Labrou, Y. A proposal for a new KQML Specification, TR CS-97-03, CSEE Dept., UMBC, Baltimore, MD, 1997.

FIPA ACL Specification. http://www.fipa.org/, 2000.

Katagiri Y. Belief Coordination by Default. *International Conference on Multi-Agent Systems*, pages 142-149, 1996.

Kumar, S., Huber, M.J., McGee D.R., Cohen, P.R., and Levesque, H.J. Semantics of Agent Communication Languages for Group Interaction. *AAAI*, pages 42-47, 2000.

Martin, D.L., Cheyer, A.J., and Moran, D.B., The Open Agent Architecture: A Framework for Building Distributed Software Systems, *Applied Artificial Intelligence*, vol. 13, pages 91-128, 1999.

Smith, I.A., and Cohen, P.R. Toward a Semantics for an Agent Communications Language Based on Speech-Acts. *Proc. of AAAI*, 1996.

Smith, I.A., Cohen, P.R., Bradshaw, J. M., Greaves, M., and Holmback, H. Designing Conversation Policies Using Joint Intention Theory. *Proc. of ICMAS*, 1998.

Werner, E. Cooperating agents: A Unified Theory of Communication and Social Structure, in *Distributed Artificial Intelligence*, Gasser, L., and Huhns, M.N. (eds.), Morgan Kaufmann, Publishers, San Mateo, California. 1989.