Multiparty Proactive Communication: A Perspective for Evolving Shared Mental Models*

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Abstract

Helping behavior in effective teams is enabled by some overlapping "shared mental models" that are developed and maintained by members of the team. In this paper, we take the perspective that multiparty "proactive" communication is critical for establishing and maintaining such a shared mental model among teammates, which is the basis for agents to offer proactive help and to achieve coherent teamwork. We first provide formal semantics for multiparty proactive performatives within a team setting. We then examine how such performatives result in updates to mental model of teammates, and how such updates can trigger helpful behaviors from other teammates.

Introduction

Shared mental model (SMM) is a hypothetical construct that has been put forward to explain certain coordinated behaviors of human teams (J. A. Cannon-Bowers & Converse 1993; Sycara & Lewis 1991). Basically, a shared mental model represents each team member's model of the global team state. This representation produces a mutual awareness, with which team members can reason not only about their own situation, but also about the status and activities of teammates and progress of the team toward its goal.

A computational shared mental model enables a team of software agents to engage in effective teamwork behaviors. The scope of such a shared mental model is rather broad and includes common knowledge (beliefs) (Rao & Georgeff 1995), joint goals/intentions (Cohen & Levesque 1991), shared team structure (Yen *et al.* 2001), shared plans (Grosz & Kraus 1999), etc.

Multiparty communication (or multiparty dialogues) are conversations that involve more than two parties (Dignum & Vreeswijk 2004; Traum 2004; Kumar *et al.* 2000; Huget & Demazeau 2005), and play a major role in establishing and maintaining a shared mental model. For example, the Joint Intentions Theory (JIT) introduces a notion of *joint intention* and requires a team of agents with a joint intention to not only commit to their part in achieving a shared goal, but also to commit to informing others when the goal has been accomplished, becomes impossible to achieve, or irrelevant.

Human society is replete with examples of multiparty dialogues: posting messages to mailing lists or newsgroups, publishing webpages, and having a teleconference or videoconference. Furthermore, human teams such as a firefighter squad or a military unit often engage in multiparty dialogues via a shared communication channel to achieve a better situation awareness. Parties involved in a multiparty dialogue can assume roles other than the speaker/addressee roles in traditional two-party communication. One of the most important roles is the *overhearer*, which can be used to organize agent societies (Busetta *et al.* 2001).

Agent communication languages like FIPA (FIPA,2004) and KQML (Labrou & Finin 1997) mostly focus on two-party communication. KQML has a *broadcast* performative which is defined in terms of several simultaneous *forward* performatives. In broadcast the speaker requests the addressees to forward a message to all the agents that addressees know of. Hence, the speaker is not aware of all the final recipients of the message. Furthermore, not all of the recipients of the message know about each other because broadcast has no designated addressee.

Multiparty communication, in general, can be considered as a strong form of broadcast: a multiparty performative is a broadcast with designated receivers taking various roles that are evident to everyone involved. From this perspective, broadcast as defined in KQML is limited in its support for effective group communication because receivers of a broadcast message, not knowing whoever else is involved, cannot update their mental models about others' information awareness. Consequently, they cannot take full advantage of the broadcast message in ensuing team activities. It is thus important to formally characterize the semantics of multiparty communication performatives to better support the development of shared situation awareness in a team.

In this research, we formally define the semantics of several multiparty performatives in a team setting, where the designated addressee and overhearers are mutually known to everyone involved. The overhearers can thus monitor the interaction between the speaker and addressee and reason about their beliefs, desires, and intentions. More importantly, the overhearers can also reason about the beliefs, desires, and intentions of *other* overhearers. Such reason-

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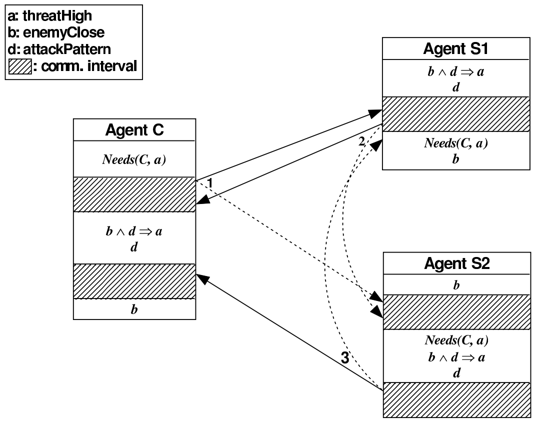

Figure 1: Motivating example

ing will result in updates to the team's shared mental model, which triggers further helpful behaviors from overhearers. In our research, we focus on multiparty *proactive* communication; proactive communication is complementary to passive communication and alleviates several limitations of passive communications (Fan, Yen, & Volz 2005).

The rest of this paper is organized as follows: In Section 2 we discuss the motivation for our research; we give a concrete example to illustrate the difference between broadcast and multiparty communication. Specifically, we illustrate how they entail different updates to shared mental models. Section 3 gives the relevant research background. Section 4 gives the formal definition of three performatives: multiparty inform (*MP-Inform*), multiparty proactive inform (*MP-ProInform*), and multiparty indirect proactive inform (*MP-IndProInform*). In Section 5, we give some properties of *MP-IndProInform*. Section 6 discusses related work and Section 7 concludes the paper.

Motivation

Broadcast is a useful communicative action which does not require an agent to know all of the parties that can receive the broadcast message. However, it is limited for describing multi-party agent communication within a team in several ways. Broadcast is limited in maintaining a team's evolving shared mental model. More specifically, it can not be used to describe an agent communication with a designated addressee while allowing other agents to overhear the conversation. Not having a designated addressee may result in redundant replies, as multiple agents may reply to the original speaker of the broadcast. Moreover, if no agent knows the answer to the query, none of them are responsible for finding an answer to the query.

As an example, consider the agent team shown in Figure 1. Each rectangle represents an agent. The top box in each rectangle (below agent's name) represents each agent's initial beliefs. Shaded boxes represent periods of communication after which agent's beliefs are updated. The boxes further down display an agent's new beliefs established after receiving messages from other agents. Solid arrows represent communication between the speaker and the addressee; dashed arrows represent overhearing of the communicated message by an overhearer. The numbers next to the arrows represent the order in which the communications happened. A commander agent, C, needs to know *threatHigh*, yet C does not know the truth value for *threatHigh*. A scout agent, S_1, knows that *enemyClose* and *attackPattern* together can derive *threatHigh* (i.e. *enemyClose* $\wedge$ *attackPattern* $\Rightarrow$ *threatHigh*). S_1 also knows *enemyClose*, but does not know *attackPattern*. On the other hand, another scout agent, S_2, knows *attackPattern*. One desirable agent communication behavior in this case is for C to request *threatHigh* from S_1, while allowing S_2 to overhear the conversation. S_1 can respond with the knowledge to infer *threatHigh* as well as partial information needed for *threatHigh* (i.e. *enemyClose*), allowing others to overhear. Subsequently, agent S_2 realizes that the information it has (i.e. *attackPattern*) is relevant to what C needs. Hence, it can choose to proactively inform C about *attackPattern* while allowing others to overhear. This kind of communication enables agents to effectively share knowledge and information relevant to their needs by maintaining a stronger evolving shared mental model among them; for example, S_2 knows about C_s need as well as S_1's knowledge and information relevant to these needs. It is difficult to use broadcast to achieve the kind of desirable agent communication described above. This motivates us to introduce multi-party agent communicative actions and formally define their semantics.

Background

Fan, Yen, and Volz (2005) have developed a formal framework for proactive communications by introducing the notion of information need as an extension to the SharedPlans theory (Grosz & Kraus 1999). Before discussing the semantics of multiparty proactive performatives, we first briefly summarize the main concepts in this framework that we will use in this paper.

Proactive vs. Passive Communication

Proactive information delivery means providing relevant information to a teammate based on the anticipated needs of the teammate. Such anticipation can be derived from a shared mental model about the team structure and the teamwork process (Yen *et al.* 2001). One motivation of our study of proactive communication in the context of teamwork is that passive communication approach (ask/reply), although useful and even necessary in many cases, does have limitations. Proactive communication may provide a complementary solution (Fan, Yen, & Volz 2005). For instance, an information consumer in a team may not realize that certain information it has is already out of date. If this agent had to verify the validity of every piece of information before using it, the team could be easily overwhelmed by the amount of communication entailed by these verification messages. Proactive information delivery offers an alternative, as it shifts the burden of updating information from the information consumer to the information provider, who typically has direct knowledge about any changes. In addition, an agent, due to its limited knowledge, may not realize that it needs certain information. For instance, a piece of information may be obtained only through a chain of inferences (e.g., being fused according to certain domain-related rules). If the agent does not have all the knowledge needed to make such a chain of inferences, it simply cannot realize that it needs the information, and thus does not know enough to request it. Proactive information delivery allows teammates to assist the agent in such a circumstance.

Basics of the SharedPlans Theory

SharedPlans theory (SPT) (Grosz & Kraus 1999) formalizes collaborative activity where multiple agents, each with solutions to different pieces of a problem, work together to form a global solution. SPT defines two types of plans: *individual* or *shared*. Furthermore, plans can be *complete* or *partial*. In order to create a shared plan, agents in a team need to communicate to achieve mutual belief about intentions and capabilities of other agents. They also need to communicate when an agent fails to complete its share of a collaborative activity, or in case of resource conflict. Such communication establishes and updates a shared mental model.

Actions in SPT are either primitive or complex. Complex actions are built from primitive actions using the constructs of dynamic logic: $\alpha;\beta$ for sequential composition, $p?$ for testing, etc. All actions in SPT are intended, committed, and performed in some specific context. By convention C_α refers to context in which α is performed.

Bel and *MB* are the modal operators for belief and mutual belief, respectively. Four types of intentional attitudes are defined in SPT. *Int.To* represents an agent's adopted intention to perform an action, while *Int.Th* represents an agent's adopted intention that a proposition hold. *Pot.Int.To* (or *Pot.Int.Th*) is a potential *Int.To* (or *Int.Th*) that is not yet adopted by the agent, but may be adopted when it is reconciled with the existing intentions.

Intention operator *Int.To*$(A, \alpha, t, t_\alpha, C_\alpha)$ means that at time t, agent A intends to do action α at time t_α in the context C_α, whereas *Int.Th*(A, p, t, t', C_p) means agent A at time t intends that p hold at t' under the context C_p.

Information Need

The key issue in proactive communication is the concept of information need, formally defined in (Fan, Yen, & Volz 2005) via modal operator *InfoNeed*(A, N, t, C_n). Information need consists of an information consumer A, a need expression N, an expiry time t, and a context C_n, under which the need is valid.

An information need may state that an agent needs to know the truth value of a proposition (e.g. *Weather(Cloudy,Today)*) or an agent may want to know the values of some arguments of a predicate that would make the predicate true (e.g. *Weather(?x,Today)*).

Next, we define some functions to be used later.

- *info*(A, N) returns the information with respect to N evaluated by A.
- *has.info*(A, N) is true if agent A knows information about N.
- *hasKnow*(N) takes as input a need expression N and returns as output K, the inference knowledge regarding N.
- *Need*$_\vdash(N, K)$ takes as inputs N (a need expression) and K (inference knowledge regarding N) and returns a set consisting of the indirect need expressions, i.e. the need expressions from which N can be inferred.

Performative as attempt

Following the idea of *performative-as-attempt* (Cohen & Levesque 1990), the semantics of performatives is modeled as attempts to establish certain mutual beliefs between the speaker and the addressee. A definition of *Attempt* formally defined within the SPT can be found in (Fan, Yen, & Volz 2005). *Attempt*$(A, \epsilon, P, Q, t, t_1)$ is an attempt by agent A at time t to achieve P by time t_1 by doing ϵ while being committed to Q. Here P represents the ultimate goal that may or may not be achieved, whereas Q represents what it takes to make an honest effort (to which the agent is committed). If the attempt does not achieve P, agent may retry the attempt, try another strategy, or even drop P. However, if the attempt does not achieve Q, the agent is committed to retrying until Q is achieved, becomes irrelevant, or impossible.

The semantics of elementary performatives is given by substituting appropriate formula for P and Q in the definition of *Attempt*. Proactive inform (*ProInform*) is a proactive performative in which the speaker not only believes in the information communicated but also believes the addressee needs the information. *ProInform* is different from the existing performatives (e.g. *Inform* (Fan, Yen, & Volz 2005)) in two ways. First, *ProInform* is *anticipation driven*, i.e. the speaker anticipates the addressee's information need prior to performing the communicative act. Second, *ProInform* allows for exchange of anticipated *information need* as well as the exchange of information. Hence, a reply to *ProInform* could involve confirming/rejecting the need.

Multiparty Proactive Performatives

In this section, we define three performatives regarding multiparty communication that can contribute to maintaining a team's evolving shared mental model: (1) multiparty inform (*MP-Inform*), (2) multiparty *proactive* inform (*MP-ProInform*), and (3) multiparty indirect proactive inform (*MP-IndProInform*). *MP-ProInform* and *MP-IndProInform* deal with situations that the provider agent has *full* or *partial* knowledge regarding consumer's information need.

Multiparty Inform

Multiparty inform (*MP-Inform*) is an extension of the *Inform* performative to multiparty settings. Since *MP-Inform* is a multiparty performative, agents involved in *MP-Inform* can assume different roles such as speaker, addressee, and overhearer. The speaker of *MP-Inform* intends to inform the addressee (a single agent) while the overhearers (possibly multiple agents) monitor the conversation. Hence, unlike *Inform* in which only the addressee will know about the speaker's intention, in *MP-Inform* the *overhearers* will also know about the speaker's intention. *MP-Inform* is defined as an attempt by the speaker to establish a mutual belief with the addressee and the *overhearers* about the speaker's intention to let the addressee know the speaker knows the information communicated. Formally,

Def. 1 *MP-Inform*$(A, B, \{O_1, \ldots, O_n\}, \epsilon, p, t, t_\alpha) \equiv$
$(t < t_\alpha)?$; *Attempt*$(A, \epsilon, P, Q, C_p, t, t_\alpha)$, where
$P =$*MB*$(\{A, B, O_1, \ldots, O_n\}, p, t_\alpha)$, and
$Q = \exists t''.(t \leq t'' < t_\alpha) \wedge$ *MB*$(\{A, B, O_1, \ldots, O_n\}, \psi, t'')$, and
$\psi = \exists t_b.(t'' \leq t_b < t_\alpha) \wedge$ *Int.Th*$(A,$*Bel*$(B,$*Bel*$(A, p, t), t_b), t, t_b, C_p)$.

Assuming reliable communication, it is easy to establish the mutual belief about ψ; agent B (agent O_i) believes in ψ upon receiving (overhearing) a message with content ψ from A. The addressee can either accept the communicated information (reply *MP-Accept*), or reject it (reply *MP-Reject*). *MP-Accept* and *MP-Reject* are defined as a *MP-Inform*; Hence, they can also be overheard by the overhearers.

Upon overhearing the conversation between the speaker and the addressee (*MP-Inform* followed by addressee's reply), the overhearers – in addition to the speaker and the addressee – can update their beliefs about the information communicated, resulting in an updated shared mental model for the team.

In the following, we use $Done(A, \alpha, t, \Theta)$ to denote the successful performance of performative α by agent A at time t under constraints Θ. By successful performance of a performative we mean the honest goal of the performative has been achieved.

Theorem 1 Successful performance of *MP-Inform* act establishes a mutual belief between the speaker, the addressee, and the overhearers, that the speaker believes the informed proposition.[1]

Multiparty Proactive Inform

Multiparty proactive inform (*MP-ProInform*) is an extension of the *ProInform* to multiparty settings. Unlike *ProInform*, in *MP-ProInform* the *overhearers* will also know about the speaker's intention. *MP-ProInform* is defined as an attempt by the speaker to establish a mutual belief with the addressee and the *overhearers* about the speaker's intention to let the addressee know (1) the speaker knows the information communicated (2) the speaker knows the addressee *needs* the information. Formally,

Def. 2 *MP-ProInform*$(A,B, \{O_1, \ldots ,O_n\}, \epsilon,I,N,t,t_\alpha, t',C_n) \equiv$
$(t < t_\alpha < t')?$; *Attempt*$(A, \epsilon, p_1, p_2, C_p, t, t_\alpha)$, where
$p_1 =$*Bel*(B, I, t'), and
$p_2 = \exists t''.(t \leq t'' < t_a) \wedge$ *MB*$(\{A, B, O_1, \ldots, O_n\}, Q, t'')$,
$Q = \exists t_b.(t'' \leq t_b < t_a) \wedge$ *Int.Th*$(A,$*Bel*$(B, \psi, t_b), t, t_b, C_n)$,
$\psi =$*Bel*$(A,$*InfoNeed*$(B,N,t',C_n), t) \wedge$ *Bel*$(A, I =$*info*$(A,N), t)$

The addressee can reply in four ways:

1. Accept both the information and the information need (*multiparty strong accept* or *MP-SAccept*).
2. Accept the information and reject the information need (*multiparty weak accept* or *MP-WAccept*).
3. Reject the information and accept the information need (*multiparty weak reject* or *MP-WReject*).
4. Reject both the information and the information need (*multiparty strong reject* or *MP-SReject*).

[1]Proof of the theorems are omitted due to lack of space

The replies are defined as a *MP-Inform*; Hence, they can also be overheard by the overhearers.

Following the communication between the speaker and the addressee (*MP-ProInform* followed by addressee's reply), all the team members can update their beliefs regarding the speaker and addressee's beliefs about the information communicated and the information need, resulting in an updated shared mental model for the team.

MP-ProInform, unlike *MP-Inform*, is *need driven*, i.e. the speaker is aware of the addressee's information need prior to performing the communicative act. Furthermore, like *ProInform*, *MP-ProInform* allows for exchange of *information need* as well as the exchange of information between the speaker, the addressee and the *overhearers*.

Multiparty Indirect Proactive Inform

Oftentimes the provider agent is aware of consumer's information need, yet it cannot fully satisfy the information need. Given that the provider has the information need's inference knowledge, the provider can infer the *indirect information needs* of the consumer. Indirect information needs are the relevant information necessary to derive the needed information using certain inference knowledge. If the provider is aware of any indirect information need, the provider can proactively inform the consumer about (1) the consumer's information need, (2) the information need's inference knowledge, and (3) the consumer's indirect information need. The consumer needs the inference knowledge for synthesizing its information need from the relevant information received from different agents. We will next clarify such a situation with an example.

Example 1: Suppose a commander agent C and two scouts S_1 and S_2 are members of a team (Figure 2). The information need of C is *threatHigh*. Initially, C neither knows *threatHigh*, nor that it *needs threatHigh*. Agent S_1 knows that C needs *threatHigh* and that C does not know *threatHigh*. Agent S_1 does not know *threatHigh* but it knows *enemyClose*. Furthermore, S_1 has the inference knowledge regarding *threatHigh*, i.e. *enemyClose* $\wedge$ *attackPattern* $\Rightarrow$ *threatHigh* – no other agent has this inference knowledge. Agent S_2 neither knows *threatHigh*, nor that C needs *threatHigh*; S_2 only knows *attackPattern* (and that C does not know *attackPattern*).

There are two difficulties in the example discussed: (1) C (or S_2) is not aware of C's information need, and (2) even though S_2 knows *attackPattern*, which can be used to infer *threatHigh*, S_2 does not have the knowledge to relate *attackPattern* to C's needs. The proposed solution is illustrated in Figure 2.

- First, agent S_1 proactively informs C about C's information need (i.e. *threatHigh*), the inference knowledge regarding *threatHigh* (i.e. *enemyClose* $\wedge$ *attackPattern* $\Rightarrow$ *threatHigh*), and *enemyClose* (message 1).
- Second, upon receiving message 1, agent C accepts the information communicated (message 2). Agent S_2 overhears the messages and learns about the C's information need (i.e. *threatHigh*), the inference knowledge regarding *threatHigh*, and the relevant information (i.e. *enemyClose*).

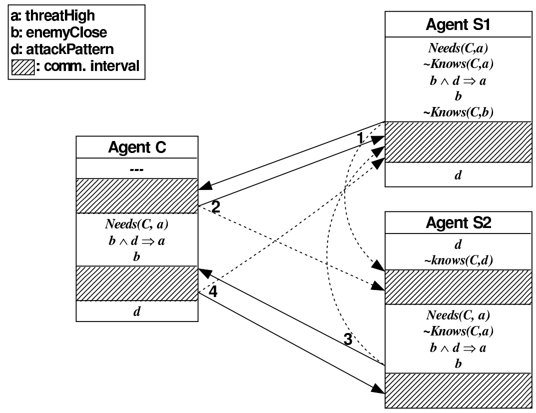

Figure 2: Multiparty proactive communication

- Third, since S_2 now knows that *attackPattern* is necessary to infer *threatHigh*, it will proactively inform C about *attackPattern* (message 3).
- Fourth, upon receiving message 3, agent C accepts the information communicated (message 4). Agent S_1 will overhear messages 3 and 4 and updates its beliefs.

The example just discussed is different from the Motivation section example in that agent C is *not* aware of its own information need (e.g. due to lack of knowledge), whereas agent S_1 has anticipated C's information need. Since C is not aware of its information need, it cannot possibly ask for its information need. Such situations can be addresses via proactive communication based on anticipated need of a teammate.

To capture the semantics of such situations we formally define a new performative, multiparty indirect proactive inform (*MP-IndProInform*). *MP-IndProInform* is defined as an attempt by the speaker to establish a mutual belief with the addressee and the *overhearers* about the speaker's intention to let the addressee know (1) the speaker knows addressee's information need, (2) the speaker knows information need's inference knowledge, and (3) the speaker knows the indirect information need of the addressee. Formally,

Def. 3 $\textit{MP-IndProInform}(A,B,\{O_1,\ldots,O_n\},\epsilon,I,IN,K,N,t,t_\alpha,t',C_n) \equiv$ $(t < t_a < t')?$; $\textit{Attempt}(A,\epsilon,p_1,p_2,C_p,t,t_\alpha)$, where
$p_1 = \textit{Bel}(B,I,t')$, and
$p_2 = \exists t''.(t \le t'' < t_a) \wedge \textit{MB}(\{A,B,O_1,\ldots,O_n\},Q,t'')$, and
$Q = \exists t_b.(t'' \le t_b < t_\alpha) \wedge \textit{Int.Th}(A,\textit{Bel}(B,\psi,t_b),t,t_b,C_n)$,
$\psi = \textit{Bel}(A,\textit{InfoNeed}(B,N,t',C_n),t) \wedge$
$\textit{Bel}(A,K = \textit{hasKnow}(N),t) \wedge$
$\textit{Bel}(A,IN \in \textit{Need}_\vdash(N,K),t) \wedge \textit{Bel}(A,I = \textit{info}(A,IN),t)$

The addressee can accept or reject any combination of the speaker's beliefs regarding the information need, information need's inference knowledge, and the indirect information need. Therefore, the addressee can reply in eight possible ways (definitions of replies are omitted due to lack of space). The replies are defined as a *MP-Inform*; Hence, they can also be overheard by the overhearers.

Following the communication between the speaker and addressee (*MP-IndProInform* followed by addressee's reply), team members can update their beliefs regarding information need of the original addressee, information need's *inference knowledge*, and the original addressee's indirect information need, resulting in an updated shared mental model for the team. Thus, *MP-IndProInform* not only allows for the exchange of information and information need, but also allows for the exchange of *inference knowledge* regarding the information need. Such inference knowledge enables the overhearers to provide different pieces of information necessary to satisfy the information need, triggering further helpful behaviors from the overhearers.

Properties of MP-IndProInform

We give a desired agent behavior regarding multiparty proactive communication. The first two theorems show the mental states of the overhearers, whereas the last theorem shows how such mental state can lead to helpful behavior.

Theorem 2 Successful performance of *MP-IndProInform* with respect to I, N, and K establishes a mutual belief between the speaker, addressee, and overhearers that the speaker believes (1) N is the information need of addressee, (2) K is the inference knowledge regarding N, and (3) I is the indirect information need of addressee regarding N.

Theorem 3 Successful performance of a *MP-IndProInform* with respect to I, N, and K followed by a successful *MP-SAccept-K* by the addressee establishes a mutual belief between the speaker, the addressee, and the overhearers that (1) N is the information need of the addressee, (2) K is the inference knowledge for N, and (3) I is an indirect information need regarding N.

Theorem 4 If after overhearing a *MP-IndProInform* followed by a *MP-SAccept-K* between agents D and B, an overhearer, A, believes IN is an indirect information need of B, A will consider helping B with *MP-IndProInform*.

Discussion and Related Work

Even though it is possible to model multiparty communications with a series of parallel two-party communications, such parallel communications are limited in evolving a team's shared mental model. Since each communication in parallel two-party communications involves two agents only (not the whole team), the overhearers cannot form any shared mental model on the beliefs of other overhearers. This not only reduces the team's shared mental model – which may affect team's performance – but also may result in redundant communications – e.g., two agents may simultaneously respond to the original speaker.

Agent communication languages, like KQML (Labrou & Finin 1997) and FIPA ACL (FIPA,2004), mostly focus on two-party dialogues. Dignum and Vreeswijk discuss the issues that arise when moving from two-party to multiparty dialogues and propose a testbed for multiparty dialogues based on the idea of blackboard systems (2004). Traum further discusses the issues in multiparty dialogues (2004). Huget and Demazeau propose a communication server for multiparty communication (2005), which depicts different modes for communication. Kumar *et al.* consider two-party dialogues as special case of multiparty dialogues and formally define a

Request performative that handles both two-party and multiparty conversations (2000). To the best of our knowledge, (Kumar *et al.* 2000) provide the only work in the literature on the *semantics* of multiparty performatives. In this paper, we take a further step by providing the semantics of multiparty *proactive* performatives.

Kaminka *et al.* use overhearing for plan recognition (2002). Gutnik and Kaminka model overhearing and propose algorithms for *conversation recognition* – identifying the conversations that took place in a system given a set of overheard messages (2004). Novik and Ward employ overhearing to model interactions between pilots and air traffic controllers (1997). Busetta *et al.* define an overhearing architecture in which an overhearer monitors the conversation between some service agents (2001). Suggester agents subscribe to the overhearer and are informed by overhearer when certain information is communicated between the service agents. The suggester agents can then give appropriate information to the service agents proactively. Aiello *et al.*, further propose an interaction language between the overhearer and suggester (2002). Our research leverages overhearing in providing a specific helpful behavior, namely proactive information delivery in a multiparty setting. Moreover, unlike other approaches our research focuses on the mental states of participants in a conversation, which enables the participants to infer the information needs of their teammates and provide help.

Summary

Helpful behavior in effective teams is enabled by an overlapping shared mental model, which is established and updated by the team members. Multiparty proactive communication is essential for establishing and maintaining such a shared mental model. In this paper, we provide formal definitions for multiparty proactive performatives within a team setting. First, we formally defined a multiparty inform performative that can increase awareness about teammates' mental states via other teammates *overhearing* the conversations. We then formally defined two multiparty proactive performatives that deal with situations that the provider has *full* or *partial* knowledge regarding consumer's information need. We then examined the effect of performatives on the mental model update of teammates and how these updates trigger helpful behaviors from teammates.

Multiparty proactive communication enables a team of agents to share not only relevant information but also relevant knowledge, initiating additional helpful behaviors. The work in this paper not only can serve as a formal specification for designing agent teams that support proactive information exchange, but also can offer opportunities for extending existing agent communication protocols to support multiparty proactive communication. Moreover, the work is useful in other areas such as mobile peer to peer systems (e.g. in distributed query processing) or for achieving multiparty agreement in multiagent systems (Wan & Singh 2005).

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