Formal Semantics and Communication Strategies for Proactive Information Delivery Among Team-based Agents

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ABSTRACT

Effective human teams often benefit from proactivity through members' capability of anticipating different needs of teammates. In this paper, we focus on three issues related to the behavior of proactive information delivery. Two types of information needs are identified, the intentional semantics of *ProInform* is given, and priliminary experiments are carried out to study how different strategies for choosing *ProInform* impact team performance. The work presented in this paper provide a sound and practical framework that enables further studies regarding proactive information delivery.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Multiagent Systems*

General Terms

Theory, Experimentation

Keywords

Shared Mental Model, Proactive Information Delivery

1. INTRODUCTION

Psychological studies about human teamwork have shown that members of an effective team often use overlapping shared mental models for anticipating information needs of teammates and for offering relevant information proactively. Hence, it is highly desirable for software agents to have similar proactivity so that they can be used to better simulate, train, or support human teams for their information fusion, interpretation, and decision-makings.

Proactive information delivery requires an agent to reason about information needs of other teammates based on certain computational shared mental model, then initiate appropriate communicative acts to provide help. In this paper, we address three issues related to such proactive behavior. In section 2 we identify two types of information needs within an extended framework of the SharedPlan theory. These two types of information needs laid the foundation for developing algorithms in CAST [3] regarding how to reason about information needs dynamically. In section 3 we define the intentional semantics of *ProInform*, which is different from *inform* in that *ProInform* requires the speaker to be aware of the addressee's information needs. This formal semantics offers opportunities for extending existing agent communication protocols to support proactive teamwork. In section 4, through experimental results we study how significant different communication strategies (for choosing *ProInform*) may affect team performances.

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2. TYPES OF INFORMATION NEEDS

We distinguish two types of information needs. The first type of information need enables an agent to perform certain (complex) actions, which contributes to an agent's individual commitments to the whole team. We call this type of information need *action-performing information need*. The second type of information need allows an agent to protect a goal from potential conflicts. Knowing such information will help an agent to deal with a threat (conflict) to the goal. Thus, we call this type of information need *goal-protection information need*. The following two axiom schemas can be used for anticipating these two types of information needs, where $CBel(A,B,I,t) \triangleq (Bel(A,I,t) \wedge Bel(A,Bel(B,\neg I,t),t))$ $\vee(Bel(A,\neg I,t) \wedge Bel(A,Bel(B,I,t),t))$, and $WBel(A,I,t) \triangleq$ $(Hold(I,t) \wedge Bel(A,\neg I,t))$ $\vee(\neg Hold(I,t) \wedge Bel(A,I,t))$.

Axiom 1 (Action-performing Information Needs). $Bel(A,Int.To(B,\alpha,t,t',C_\alpha),t) \wedge$ $Bel(A,I \in pre(\alpha),t) \wedge$ $[Bel(A,unaware(B,I,t),t) \vee CBel(A,B,I,t)]$ $\Rightarrow Bel(A,InfoNeed(B,I,t',C_n),t),$ *where* $C_n = C_\alpha \wedge Bel(A,I \in pre(\alpha),t) \wedge (Bel(A,unaware(B,I,t),t) \vee CBel(A,B,I,t)).$

Axiom 1 states that agent A believes that agent B will need information I at time t' under the context C_n if A believes that (1) B intends to perform action α at time t', (2) I is a precondition of α, and (3) B does not know whether I is true, or B's belief about I is incorrect. The context C_n of the information need extends the context C_α for B's intention to perform α.

Axiom 2 (Goal-Protection Information Needs). $Bel(A,$ $Int.Th(B,\phi,t,t'',C_\phi),t) \wedge$ $Bel(A,(unaware(B,I,t') \vee WBel$ $(B,I,t')) \Rightarrow [\exists G \in TB,\alpha,t_1 > t' \cdot Do(G,\alpha,t_1,\Theta_\alpha) \Rightarrow \neg\phi],t) \wedge$ $[Bel(A,unaware(B,I,t),t) \vee CBel(A,B,I,t)]$ $\Rightarrow Bel(A,InfoNeed(B,I,t',C_n),t),$ *where* $C_n = C_\phi \wedge (Bel(A,unaware(B,I,t),t) \vee CBel(A,B,I,t)).$

Axiom 2 states that A believes that agent B will need information I at time t', if lacking information about I enables some agent in an adversary team to take some actions at a time t_1 (later than t') to destroy B's goal.

3. PROACTIVE INFORM

Following Cohen and Levesque's work[1], we treat $Attempt$ as a certain slice of mental state which could legally lead to the commitment of doing the associated event. $ProInform$ extends $Inform$ with additional requirements on the speaker's awareness of the addressee's information needs.

Definition 1. $ProInform(A, B, I, t, t_1, t', C_n) \triangleq Attempt(A, e, Bel(B, I, t'), \exists t'' \cdot (t \le t'' \le t_1) \wedge MB(\{A, B\}, P, t''), C_p, t, t_1)$, where $P = \exists t_b \cdot (t'' \le t_b \le t_1) \wedge Int.Th(A, Bel(B, Bel(A, I, t) \wedge Bel(A, InfoNeed(B, I, t', C_n), t), t_b), t, t_b, C_p)$, $C_p = Bel(A, I, t) \wedge Bel(A, unaware(B, I, t), t) \wedge Bel(A, InfoNeed(B, I, t', C_n), t)$.

The following theorem can be proved by using the *help* axiom in the SharedPlan theory [2]. It says that if agent A knows agent B will need information I at time t', A will try to provide help by adopting a potential intention-to.

THEOREM 1. $Bel(A, InfoNeed(B, I, t', C_n), t) \wedge Bel(A, I, t) \wedge \neg Bel(A, Bel(B, I, t'), t) \Rightarrow (\exists t_1, t_2 \cdot Pot.Int.To(A, ProInform(A, B, I, t_1, t_2, t', C_n), t, t_1, C_n \wedge Bel(A, I, t)))$.

Agents need to deal with uncertainties. As shown in theorem 1, agent A will adopt a potential intention-to regarding $ProInform$ to provide help. However, whether such potential intentions-to can be reconciled to intentions-to depends on the decision-makers' self awareness and team awareness, and the strength of these mental measure. For instance, $Bel(A, InfoNeed(B, I, t', C_n), t)$ comes from A's anticipation of B based on certain assumptions. Hence, such beliefs are actually associated with probabilities.

On the other hand, communications often carry certain cost. An agent needs to evaluate the cost and the utility of proactive communications before actually doing it. Decision-theoretic approaches can be used for an agent to reason about whether to reconcile its potential-intentions regarding $ProInform$ to intentions to do it.

4. EXPERIMENTS AND CONCLUSION

To understand how significant different communication strategies for $ProInform$ may affect team performances, we examined it in our simulated battlespace system.

The test-bed is composed of two opposing agent teams, the blue team and the red team. The goal of the blue team is to destroy the home base of the red team, while the red team tries to protect their base by attacking any approaching agents of the blue team. Agents in the blue team could play one of three roles: scout (sensing), fighter (shooting), and bomber (bombing the enemy base). The behavior of the blue team is governed by shared team plans and related teamwork knowledge, as well as certain individual plans. For instance, when informed about the location of a moving enemy, a dynamically assigned fighter will move toward that enemy and shoot at it, while the other fighters will move toward the enemy base to protect bombers from being killed. To introduce risks for communication, the enemy base has a communication-detection range. Talking inside the communication-detection range, the speaker might be detected at a certain probability.

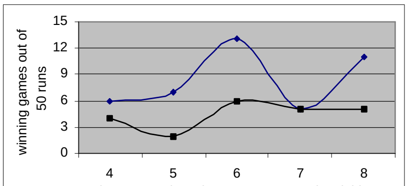

Fig.1 comm-detection range as control variable

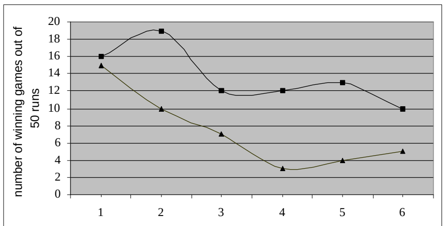

Fig.2 number of opponents as control variable

We devised two communication strategies, S_1 and S_2, for scouts in the blue team. In both S_1 and S_2, scouts need to make decisions on whether to satisfy action performing information needs, but only scous in S_2 need to make decisions on whether to satisfy goal protection information needs (i.e., scouts in S_1 always inform threats). In our experiments, the location information of detected enemies is action performing information for the fighters, as well as goal protection information for the bombers.

We run two sets of experiments, where the communication-detection range of enemy base (ranging from 4 to 8) and the number of enemy agents (ranging from 1 to 6) are used as the control variables, respectively. In each set of experiments, we randomly generated 50 initial configurations for the locations of agents in both teams, and run the experiment 50 times for each configuration.

Fig. 1 and Fig. 2 summarize the average number of successfully completed missions for the blue team. The following conclusions can be drawn from the experimental results. (1) Strategy S_2 outperforms S_1. The blue team using S_2 wins more times, which suggests that decision-theoretic communication strategies can be effective for team-based agents to decide on whether to proactively deliver needed information to teammates. (2) The number of enemy agents are more effective as control variable. As the difficulty increases, the number of success missions decrease. In both cases, as the control variable increases, the curves do fluctuate at some points. This is caused by the "grid" feature of the test-bed. The calculation of probabilities, risks, etc. are based on the distances between two agents under concern. However, the distance of two objects is approximately treated as the number of grids between them.

5. REFERENCES

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