Observation-Based Proactive Communication in Team Cooperation

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ABSTRACT

Observation and communication are important aspects of agent teamwork. We employ the agent's observability as the major means for individual agents to reason about the environment and other team members. We focus on how to represent agents' observability and how to include it into the basic reasoning for proactive communication. The syntax and the operational semantics of observability are given. Preliminary experiments are carried out to study the effectiveness of different aspects of observability.

Categories and Subject Descriptors

I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence – Multiagent Systems

General Terms

Theory, Experimentation

Keywords

Observation, Proactive Communication

1 INTRODUCTION

In this paper, we focus on how to represent observability in an agent team, and how to include it into the basic reasoning for proactive communication [1, 2]. We define several different aspects of observability (e.g., sensing a property, sensing another agent perform an action, and believing another can sense a property or action are all different), and propose an approach to the explicit treatment of an agent's observability that aims to achieve more effective information exchange among agents. We also present an experiment that explores the effectiveness of different aspects of observability.

2 AGENT OBSERVABILITY

The syntax we use for observability is given below.

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<observability> ::= (CanSense <viewing>)*
                    (BEL <believer> (CanSense <viewing>))*
<viewing>       ::= <observer><observable> <cond>
<believer>      ::= <agent>
<observer>      ::= <agent>
<observable>    ::= <property>|<action>
<cond>          ::= (<property>|<action>)*
<property>      ::= (<property-name> <object> <args>)
<action>        ::= (DO <doer> (<operator-name> <args>))
<object>        ::= <agent>|<non-agent>
<doer>          ::= <agent>
```

To give operational semantics to observability, we need to clarify the relationships of: 1) what an agent can sense, what it actually senses, and what it believes from its sensing; 2) what an agent believes another agent can sense, what it believes another agent actually senses, and what it believes another agent believes from its sensing.

- Mapping CanSense to Sense

$$\forall a,\psi,c,t,\mathrm{CanSense}(a,\psi,c)\wedge \mathrm{Hold}_t(c)\rightarrow \mathrm{Sense}_t(a,\psi),$$

where ψ is a proposition which presents a property or an action, $\mathrm{Sense}_t(a, \psi)$ expresses that agent *a* observes ψ at time t, and $\mathrm{Hold}_t(c)$ means c holds in the world at time t. This axiom means that if the condition c holds at time t and agent *a* has the capability to observe ψ under c, then agent *a* actually does determine the truth value of ψ at time t.

- Mapping Sense to Belief

We made an analogous assumption to the one that "seeing is believing". We state it separately for properties and actions.

$$\forall a,\varphi,t,\mathrm{Sense}_t(a, \varphi)\rightarrow \text{//when sensing a property}$$
$$[\mathrm{Hold}_t(\varphi)\rightarrow \mathrm{BEL}_t(a,\varphi)]\wedge[\neg\mathrm{Hold}_t(\varphi)\rightarrow \mathrm{BEL}_t(a,\neg\varphi)],$$

which says that for any property φ sensed by agent *a*, if φ holds, agent *a* believes φ; if φ does not hold, *a* believes $\neg\varphi$.

When agent *a* senses action ϕ performed by some agent, *a* believes that the agent believed the precondition and effect:

$$\forall a,\phi,t,\mathrm{Sense}_t(a,\phi) \rightarrow \text{//when sensing an action}$$
$$\mathrm{BEL}_t(a,\mathrm{BEL}_{t-1}(\mathrm{Doer}(\phi),\mathrm{Prec}(\phi))) \wedge$$
$$\mathrm{BEL}_t(a,\mathrm{BEL}_t(\mathrm{Doer}(\phi),\mathrm{Efft}(\phi))).$$

where $\mathrm{Doer}(\phi)$, $\mathrm{Prec}(\phi)$, $\mathrm{Efft}(\phi)$ denote the doer, the precondition, and the effect of action ϕ.

- Mapping "believe CanSense" to "believe sense"

$$\forall a,b,\psi,c,t,t',\mathrm{Believe}(a, \mathrm{CanSense}(b,\psi,c))$$
$$\wedge\ \mathrm{BEL}_t(a,\mathrm{BEL}_{t'}(b,c))\rightarrow \mathrm{BEL}_t(a,\mathrm{Sense}_{t'}(b,\psi)),$$

which means that if agent *a* believes that agent *b* is able to observe ψ under condition c, and agent *a* believes c at time t', then agent *a* believes at time t that agent *b* sensed ($t'<t$), senses ($t'=t$), or will sense ($t'>t$, which requires some prediction capability for agent *a*) ψ at time t'.

- Mapping "believe sense" to "believe (another agent's) belief"

We also have two separate cases for properties and actions. When agent *a* believes agent *b* senses a property φ, *a* believes that *b* believes φ:

$$\forall a,\ b,\ \varphi,\ t,\ \mathrm{BEL}_t(a,\ \mathrm{Sense}_t(b,\ \varphi)) \rightarrow$$
$$\mathrm{BEL}_t(a,\ \mathrm{BEL}_t(b,\ \varphi)).$$

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When agent *a* believes agent *b* senses an action ϕ, *a* believes that *b* believes the doer believed the precondition at the previous time step and believes the effect at the current time step. This consequence is expressed by the following:

$$\forall a, b, \phi, t, \mathrm{BEL}_t(a, \mathrm{Sense}_t(b, \phi)) \rightarrow$$

$$\mathrm{BEL}_t(a, \mathrm{BEL}_t(b, \mathrm{BEL}_{t-1}(\mathrm{Doer}(\phi), \mathrm{Prec}(\phi)))) \wedge$$
$$\mathrm{BEL}_t(a, \mathrm{BEL}_t(b, \mathrm{BEL}_t(\mathrm{Doer}(\phi), \mathrm{Efft}(\phi)))).$$

3 PROACTIVE COMMUNICATION

We deal with communication with the 'right' agent about the 'right' thing at the 'proper' time in the following ways:

- Reasoning about what information each agent on a team will produce, and thus, what information each agent can offer others. This is achieved through: 1) analysis of the effects of individual actions in the specified team plans; 2) analysis of observability specification, indicating what and under which conditions each agent can perceive about the environment as well as the other agents.
- Reasoning about what information each agent will need in the process of plan execution. This is done through the analysis of the preconditions of the individual actions involved in the team plans.
- Reasoning about whether an agent needs to act proactively when producing some information. The decision is made in terms of: 1) whether or not the information is mutable according to information classification; 2) which agent(s) needs this information; and 3) whether or not an agent who needs this information is able to obtain the information independently according to the observation of environment and other agents' behaviors.

4 EVALUATIONS

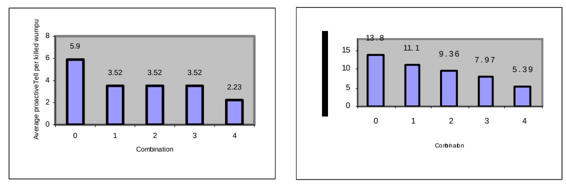
We have extended the Wumpus World problem into a multi-agent version [3]. The world is 20×20 cells and has 20 wumpuses, 8 pits, and 20 piles of gold. The goals of the team, four agents, one carrier and three fighters, are to kill wumpuses and get the gold. The carrier is capable of finding wumpuses and picking up gold. The fighters are capable of shooting wumpuses. When a wumpus is killed, agents can determine whether the wumpus is dead only by getting the message from others, who kill wumpus or see shooting wumpus action. Agents may also have sensing capabilities, defined by observability rules in their knowledge bases.

We designed two teams, Team A and Team B, and each team was allowed to operate a fixed number of 150 steps. Both teams kept all conditions the same except agents' observability. In Team A: the carrier can observe objects within a radius of 5 grid cells, and each fighter can see objects within a radius of 3 grid cells. In Team B: none of the agents have any observability beyond the basic sensing capabilities to the environment.

The experiment tested the contribution of different aspects of observability to the successful reduction of communication. These aspects are belief about observed property, belief about the doer's belief about preconditions of observed action, belief about the doer's belief about effects of observed action and belief about another's belief about observed property. For simplify, we call them belief1, belief2, belief3 and belief4 correspondently. We used Team B, as reference to evaluate the effectiveness of different combinations of observability with Team A. We named this test combination 0, since there is none of such four beliefs involved in. For Team A, we tested another 4 combinations of these beliefs to show the effectiveness of each, in terms of Average Communication Per Wumpus Killed (ACPWK). These combinations are:

0. Team B, which involves none of beliefs.
1. In Team A, for each agent, leave off "Believe CanSense" rules and do not process belief2 and belief3 when maintaining beliefs after observation. Therefore every agent only has belief1 about the world.
2. Keep every condition in comb. 1, except for enabling the belief2 process.
3. Enabling the belief3 process in comb. 2.
4. Add "Believe CanSense" rules into comb. 3. This combination tests the effect of belief4 as well as show effectiveness of the beliefs as a whole.

Each combination is run in 5 randomly generated worlds. The average results of these runs are presented in Fig. 1, in which one bar shows ACPWK for one combination.



(a) *Tell* (b) *Ask*

Fig. 1. Average communication per killed wumpus in different combinations

The results of this experiment indicate three things. First, belief1 and belief4 have a strong effect on the efficiency of both *Tell* and *Ask*. Therefore, CanSense / "Believe CanSense" a property, the observability from which these two beliefs generated, can be generally applied to dual parts communication involving both *Tell* and *Ask*. Second, belief2 and belief3 have weak influence on the efficiency of *Tell*, this suggests that CanSense an action may be applied to communication which incurs more *Ask* than *Tell*, such as goal-directed communication. Third, these beliefs work best together, because each of them provides a distinct way for agents to get information from the environment and other agents. Furthermore, they complement each other's relative weakness, so using them together better serves the effectiveness of communication as a whole.

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