Aspects of Protocol Conformance in Inter-agent Dialogue

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ABSTRACT

We identify different levels of conformance to a protocol (weak, exhaustive, and robust conformance) and show how conformance may be either checked *a priori* or enforced at runtime for a specific class of logic-based agents.

Categories and Subject Descriptors

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

Keywords

Agent communication protocols, Logic-based agents

1. INTRODUCTION

An agent communication *protocol* specifies the "rules of encounter" [3] governing a dialogue between agents in a multiagent system by determining which agent is allowed to say what in any given situation. It will usually allow for several alternative utterances and an agent has to choose one according to its *strategy*. The protocol is *public*, while each agent's strategy is *private*. Protocols can help to define a suitable 'social' semantics for agent communication languages in order to allow actual interoperability in open environments [2]. Instead of being related to some (virtually inaccessible) private mental state of the agent as proposed by KQML and FIPA, the meaning of a dialogue move refers to some publicly agreed and verifiable conversational state.

When considering interactions that are not necessarily cooperative (such as negotiation dialogues), it cannot be safely assumed that agents will always follow the rules specified by a particular protocol. It is then crucial to provide proper means of evaluating how well an agent is adapted to a protocol. In this extended abstract we propose the distinction of three different *levels of conformance* (weak, exhaustive, and robust conformance) and show how a simple logical representation of protocols can greatly facilitate determining whether or not an agent can be expected to conform to them. We also present a way of *enforcing* conformance at runtime for a specific class of logic-based agents. Finally, we suggest to consider the intuitive notion of an agent's *competence* to use a given protocol and put forward a preliminary definition of protocol competence which evaluates how well an agent's personal 'answer space' covers the range of legal dialogue continuations specified by a protocol.

Some of the issues discussed here are covered in greater detail in [1].

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2. PROTOCOL REPRESENTATION

A common representation formalism for communication protocols are deterministic finite automata [2]. We call a dialogue move P *legal* with respect to a protocol (represented as an automaton) and a given dialogue state S (i.e. a state of that automaton) iff there exists a state S' such that the automaton's transition function maps the pair (S, P) to S'.

We are now going to introduce an alternative representation formalism based on simple logical implications (which may be read as condition-action rules). This formalism is inspired by the representation of communication strategies for logic-based agents as sets of integrity constraints in abductive logic programming proposed in [4]. These constraints have the following form:

$$P(T) \wedge C \Rightarrow P'(T{+}1)$$

On receiving dialogue move P at time T, an agent implementing this rule would utter P' at time $T+1$, provided condition C is entailed by its knowledge base. Dropping the C on the lefthand side (which refers to an agent's private knowledge) and allowing for disjunctions on the righthand side, we can use similar rules to specify protocols:

$$P(T) \Rightarrow P'_1(T{+}1) \vee P'_2(T{+}1) \vee \cdots \vee P'_n(T{+}1)$$

We call $P'_1, \ldots, P'_n$ the *correct answers* to the *expected input* P. Unlike automata, this kind of protocol specification does not refer to any dialogue state, but only to the previous dialogue move. We call protocols that can be represented by means of such rules, with a single 'trigger' on the lefthand side, *shallow* protocols. Shallow protocols correspond to automata where the value of the transition function is independent from the current state. It appears that many (automata-based) protocols proposed in the literature are in fact shallow. Most others could be turned into shallow ones by renaming only a small number of transitions.

3. LEVELS OF CONFORMANCE

Broadly speaking, an agent is *conformant* to a given protocol if its behaviour is legal with respect to that protocol. We have found it useful to distinguish three *levels* of conformance, which we shall briefly discuss next. Note that we define the following notions on the basis of the *observable* conversational behaviour of the agents (i.e. what they utter or not) alone, without making further assumptions on how they actually come to generate these utterances. Let $\mathcal{P}$ be a protocol:

- An agent is *weakly conformant* to $\mathcal{P}$ iff it never utters any illegal dialogue moves (with respect to $\mathcal{P}$).
- An agent is *exhaustively conformant* to $\mathcal{P}$ iff it is weakly conformant to $\mathcal{P}$ and utters at least *some* dialogue move whenever required to do so by $\mathcal{P}$.
- An agent is *robustly conformant* to $\mathcal{P}$ iff it is exhaustively conformant to $\mathcal{P}$ and for any illegal dialogue moved *received* it utters a special dialogue move indicating this violation (e.g. `not-understood`).

Weak and exhaustive conformance can be seen as allowing or disallowing, respectively, 'silent moves'. While exhaustive conformance will be preferred in most interactions, at least to avoid confusion with lost messages, we believe that weak conformance can be useful too. The first reason is that there are examples where a lack of response can be considered to be part of the protocol (e.g. certain argumentation-based protocols where it is assumed that silence means consent). The second reason is that these two levels are conceptually different, since weak conformance only involves *not* uttering (any illegal moves), while exhaustive conformance involves uttering (some legal move). This requires substantially different approaches to checking conformance. Robust conformance is useful in open societies where one cannot safely assume that other agents will never utter any illegal moves; but this requires the agent to be able to evaluate whether received dialogue moves are legal.

The following result shows that, in the context of our shallow protocols, weak conformance can be checked without reference to the complete dialogue history:

THEOREM 1. *An agent that never utters an incorrect answer in response to an expected dialogue input of a shallow protocol $\mathcal{P}$ is weakly conformant to $\mathcal{P}$.*

This follows from the fact that, for shallow protocols, the current dialogue state is uniquely identifiable given the latest move in the dialogue, i.e. the notions of correct answer and legal move coincide.

4. CHECKING CONFORMANCE

For logic-based agents (such as those proposed in [4]) whose communication strategy is completely specified by a set of constraints of the form $P(T) \wedge C \Rightarrow P'(T+1)$, we define the notion of an agent's *answer space* as the set of protocol-constraints we get by first dropping all private conditions C and then conjoining implications with identical antecedents by collecting the corresponding consequents into a single disjunction. For example, the strategy

$$\begin{aligned} S \;=\; & \{\mathit{request}(T) \wedge \mathit{happy} \Rightarrow \mathit{accept}(T+1), \\ & \;\mathit{request}(T) \wedge \mathit{unhappy} \Rightarrow \mathit{refuse}(T+1)\} \end{aligned}$$

determines the following answer space:

$$S^* \;=\; \{\mathit{request}(T) \Rightarrow \mathit{accept}(T+1) \vee \mathit{refuse}(T+1)\}$$

We can now formulate a simple criterion that allows us to check *a priori* whether an agent will be weakly conformant to a given protocol by inspecting only the relevant parts of the agent's 'communication module':

THEOREM 2. *An agent with answer space S^* will be weakly conformant to a protocol $\mathcal{P}$ whenever $\mathcal{S}^* \models \mathcal{P}$.*

Observe, however, that the opposite direction does not hold.

5. ENFORCING CONFORMANCE

Even when an agent cannot be shown to be weakly conformant *a priori*, it may still be possible to constrain its behaviour at runtime by simply forcing it to comply to the rules of the protocol. This becomes an interesting option once we can do so in a simple and automated way.

The following result applies again to the logic-based agents of [4]:

THEOREM 3. *Given a protocol $\mathcal{P}$, an agent generating its dialogue moves from a knowledge base of the form $\mathcal{K} \cup \mathcal{P}$ will be weakly conformant to $\mathcal{P}$.*

That is, the agent could simply 'download' the appropriate protocol when entering a society and thereby guarantee conformance (and avoid possible penalties) *without* requiring any additional reasoning machinery. The intuition behind the proof of the above theorem is that the additional constraints given by $\mathcal{P}$ (together with a special rule excluding concurrent utterances) would render any 'branches' corresponding to illegal dialogue moves inconsistent and thereby actively prevent the agent from uttering such moves.

6. COMPETENT USE OF PROTOCOLS

An agent's ability to fully profit from a protocol is an important aspect of agent communication. For instance, an agent may conform to a protocol, but nevertheless use it in a very restrictive way (such that the final state could never be reached, for instance).

One may even argue that the semantics of a protocol is altered if certain dialogue moves are not available to an agent, because protocol designers assume that agents will consider the full range of possible answers. This suggests another application of the notion of *answer space* defined in Section 4: We may call an agent fully *competent* to use a protocol $\mathcal{P}$ iff its answer space $\mathcal{S}^*$ 'covers' $\mathcal{P}$. This intuitive notion of protocol competence may be regarded as complementary to the notion of conformance.

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