Protocol Conformance for Logic-based Agents

Ulle Endriss\textsuperscript{1}, Nicolas Maudet\textsuperscript{2}, Fariba Sadri\textsuperscript{1} and Francesca Toni\textsuperscript{1}

\textsuperscript{1} Department of Computing, Imperial College London
Email: \{ue,fs,ft\}@doc.ic.ac.uk

\textsuperscript{2} School of Informatics, City University, London
Email: maudet@soi.city.ac.uk
Motivation

- Communication is a central issue in multiagent systems.

- A “conventional” protocol specifies the range of possible follow-ups available to each agent during a dialogue.

- By referring to a protocol (rather than the agents’ mental states) we can give a “social” semantics to the interactions occurring in a multiagent system.

- In open agent societies, public protocols and agent’s private strategies may not always match ⇒ conformance checking.

- We propose a logic-based representation for protocols which facilitates checking an agent’s conformance to a given protocol a priori, on the basis of the agent’s (logic-based) specification.
Talk Outline

• Protocols as finite state machines
• Protocols as sets of integrity constraints
• Levels of conformance to a protocol
• Logic-based agents
• Checking and enforcing conformance
• Conclusion and future work
Automata-based Protocol Representation

The *continuous update protocol* (Pitt & Mamdani, IJCAI-1999):

We call a dialogue move $P$ legal wrt. a protocol $\mathcal{P}$ and a given dialogue state $Q$ iff there exists a state $Q'$ such that the automaton's transition function maps the pair $(Q, P)$ to $Q'$. 
Logic-based Protocol Representation

The same protocol, expressed as two sets of integrity constraints (each corresponding to one of the two subprotocols):

\[
\mathcal{P}_A : \quad START(T) \Rightarrow inform(T+1) \\
\text{acknowledge}(T) \Rightarrow inform(T+1) \lor end(T+1) \\
end(T) \Rightarrow STOP(T+1)
\]

\[
\mathcal{P}_B : \quad inform(T) \Rightarrow acknowledge(T+1) \lor end(T+1) \\
end(T) \Rightarrow STOP(T+1)
\]
Shallow Protocols

• In general, our protocol rules have the following form:

\[ P(T') \Rightarrow P_1'(T+1) \lor P_2'(T+1) \lor \cdots \lor P_n'(T+1) \]

We call the dialogue moves on the righthand side of a protocol constraint correct answers wrt. the expected input given on the lefthand side.

• We call protocols that can be represented by means of our integrity constraints, with a single “trigger” on the lefthand side, shallow protocols.

• Many automata-based protocols in the literature are either shallow or could be made shallow by renaming only a small number of transitions, i.e. our very simple representation formalism is appropriate.
Levels of Conformance

We may distinguish three levels of conformance to a given communication protocol \( \mathcal{P} \):

- An agent is \textit{weakly conformant} to \( \mathcal{P} \) iff it never utters any illegal dialogue moves (wrt. \( \mathcal{P} \)).

- An agent is \textit{exhaustively conformant} to \( \mathcal{P} \) iff it is weakly conformant to \( \mathcal{P} \) and utters at least \textit{some} dialogue move whenever required to do so by \( \mathcal{P} \).

- An agent is \textit{robustly conformant} to \( \mathcal{P} \) iff it is exhaustively conformant to \( \mathcal{P} \) and for any illegal dialogue move received from another agent it utters a special dialogue move indicating this violation (e.g. not-understood).
Logic-based Agents

Sadri et al. (ATAL-2001) have introduced a class of agents based on abductive logic programming.

In this framework, an agent’s communication strategy is a set of integrity constraints of the following form:

\[ P(T) \land C \Rightarrow P'(T+1) \]

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 (private) knowledge base.
Checking Conformance

When checking conformance to a given protocol $\mathcal{P}$, we may distinguish two concepts:

- checking conformance of an actual dialogue \textit{at runtime} (easy)
- checking conformance of an agent \textit{a priori}, on the basis of the agent’s specification (hard)

The latter may also involve problematic \textit{privacy} issues.
Response Space

Abstracting from the private conditions $C$ referred to in an agent’s strategy $S$, we define its response space $S^*$ as follows:

$$\{P(T) \Rightarrow \bigvee \{P'(T+1) \mid [P(T) \land C \Rightarrow P'(T+1)] \in S\} \mid P \in \mathcal{L}\}$$

with $\bigvee \{\} = \bot$

Here’s a simple example:

$$S = \{\text{inform}(T) \land \text{happy} \Rightarrow \text{acknowledge}(T+1), \quad \text{inform}(T) \land \text{unhappy} \Rightarrow \text{end}(T+1)\}$$

$$S^* = \{\text{inform}(T) \Rightarrow \text{acknowledge}(T+1) \lor \text{end}(T+1)\}$$
Checking Conformance a priori

We obtain a useful criterion for weak conformance:

**Theorem:** An agent with response space $S^*$ will be weakly conformant to a protocol $\mathcal{P}$ whenever $S^* \models \mathcal{P}$.

Note that checking *exhaustive* conformance *a priori* is more difficult and requires reference to the agent’s private knowledge . . . (see our forthcoming ESAW-2003 paper for details)
Enforcing Conformance

Checking conformance \textit{a priori} may not always be possible:

- the precise protocol may not be known at design time
- checking conformance requires meta-level reasoning (theorem proving by the system designer, not by the agent itself)
- our theorem only specifies a sufficient (not a necessary) condition for conformance

Agents may simply “download” a protocol $\mathcal{P}$ to guarantee their own conformance to it (and to avoid possible penalties):

\textbf{Theorem:} An agent generating its moves from a knowledge base of the form $\mathcal{K} \cup \mathcal{P}$ will be weakly conformant to $\mathcal{P}$.

Note that enforcing \textit{exhaustive} conformance in a meaningful manner would be impossible!
Conclusion

• Logic-based agents and protocols help bridging the gap between the specification and the implementation of multiagent systems.

• We have introduced a new logic-based representation formalism for communication protocols.

• Our shallow protocols are essentially as expressive as automata-based protocols, but checking conformance does not require access to the dialogue history.

• We have given a simple criterion for checking conformance a priori (generally a very difficult problem).

• We have shown how agents may enforce their own conformance at runtime (not a difficult problem) without requiring any additional reasoning machinery (that’s the interesting bit).
Future Work

• Possible extensions to our protocol representation formalism:
  – more than two dialogue partners
  – concurrent communication
  – reference to past events
  – reference to the content of a dialogue move (rather than just the communicative act)

• To develop concrete interaction protocols.
  – we are particularly interested in negotiations over resources

• An agent that is known to be conformant to a given protocol is not necessarily a competent user of that protocol.
  – see our forthcoming ESAW-2003 paper for some initial ideas