Protocol Conformance for Logic-based Agents

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Motivation

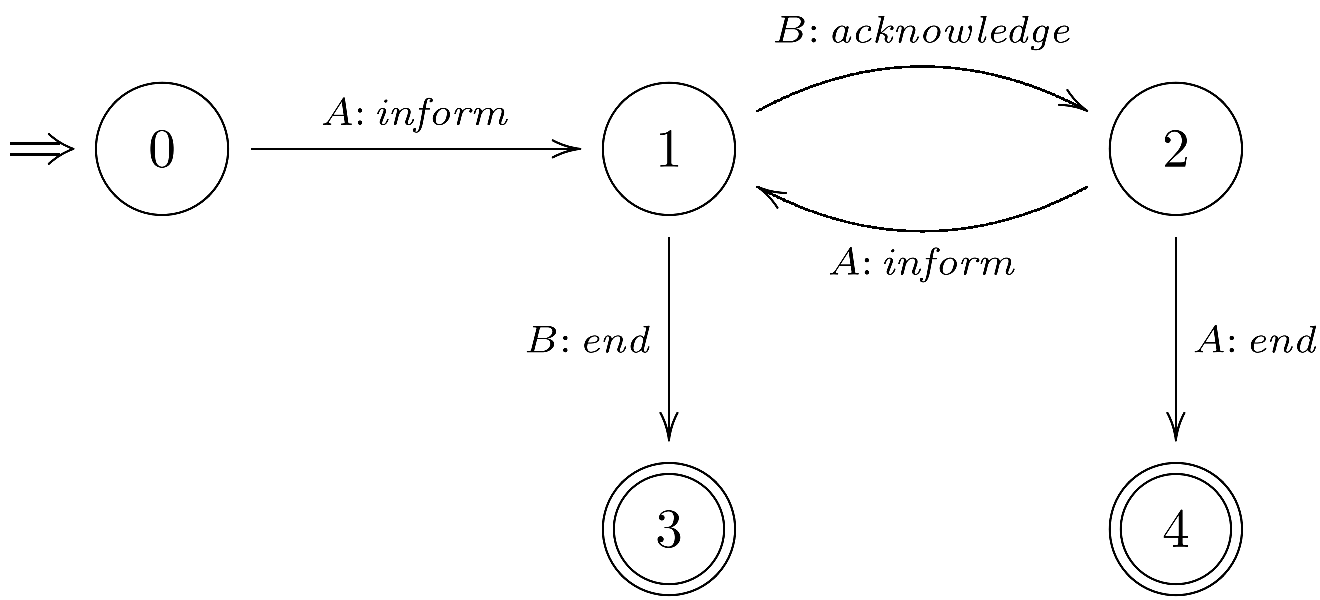
- Communication is a central issue in multiagent systems.
- A "conventional" *protocol* specifies the range of possible follow-ups available to each agent during a dialogue.
- By referring to a protocol (rather than the agents' mental states) we can give a "social" semantics to the interactions occurring in a multiagent system.
- In open agent societies, *public protocols* and agent's *private strategies* may not always match $\Rightarrow$ *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):

$$\begin{aligned}
\mathcal{P}_A: \quad & \mathit{START}(T) \Rightarrow \mathit{inform}(T{+}1) \\
& \mathit{acknowledge}(T) \Rightarrow \mathit{inform}(T{+}1) \vee \mathit{end}(T{+}1) \\
& \mathit{end}(T) \Rightarrow \mathit{STOP}(T{+}1)
\end{aligned}$$

$$\begin{aligned}
\mathcal{P}_B: \quad & \mathit{inform}(T) \Rightarrow \mathit{acknowledge}(T{+}1) \vee \mathit{end}(T{+}1) \\
& \mathit{end}(T) \Rightarrow \mathit{STOP}(T{+}1)
\end{aligned}$$

Shallow Protocols

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

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

  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 *weakly conformant* to $\mathcal{P}$ iff it never utters any illegal dialogue moves (wrt. $\mathcal{P}$).
- 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 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:

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

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 (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 *at runtime* (easy)
- checking conformance of an agent *a priori*, on the basis of the agent's specification (hard)

The latter may also involve problematic *privacy* issues.

Response Space

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

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

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

Here's a simple example:

$$\begin{aligned} \mathcal{S} \quad &= \quad \{\mathit{inform}(T) \wedge \mathit{happy} \Rightarrow \mathit{acknowledge}(T{+}1), \\ &\qquad \mathit{inform}(T) \wedge \mathit{unhappy} \Rightarrow \mathit{end}(T{+}1)\} \\ \mathcal{S}^* \quad &= \quad \{\mathit{inform}(T) \Rightarrow \mathit{acknowledge}(T{+}1) \vee \mathit{end}(T{+}1)\} \end{aligned}$$

Checking Conformance a priori

We obtain a useful criterion for weak conformance:

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

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 *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):

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 *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