Realizing Agent Dialogues with Distributed Protocols

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Abstract. This paper describes a protocol language which can provide agents with a flexible mechanism for coherent dialogues. The protocol language does not rely on centralised control or bias toward a particular model of agent communication. Agents can adapt the protocol and distribute it to dialogical partners during interactions.

1 Introduction

As the programming paradigm of agency evolves, more robust, diverse, and complex agents are developed. The growing heterogeneity of agent societies will increase even further as the research and development of deliberative and communicative models produce new and interesting approaches. The need for an equally adaptive means of communication between this heterogeneous multitude also grows.

Electronic Institutions [2] and other state-based approaches are not feasible for use in open multi-agent systems with dynamic or large conversation spaces. The term conversation space is used to express every possible sequence and combination of messages that can be passed between two or more agents participating in a given agent system. Protocols provide a useful framework for agent conversations and the concern that they sacrifice agent autonomy is exaggerated. In social interactions, humans and agents must willingly sacrifice autonomy to gain utility. If I want my train tickets or cup of coffee, I must follow the implicit protocol and join the queue. It is the same for software agents. If the agent must gain a resource only available by participating in an English auction, it behooves the agent to adopt the protocol necessary for participation in the auction. Whether this is done by an explicitly defined protocol or the agent learning the protocol implicitly makes no difference to the agent's behavior within the system.

Electronic Institutions take a societal approach to agent communication. Control is top-down. Administrative agents perch above the system and keep an eye on the agents as they interact inside the system. These Administrative agents regulate participating agent's dialogical activities by forcing them to adhere to the formal definition of the Electronic Institution. The institution is

defined by a set of roles for agents, a shared dialogical framework, the division of the Institution into a number of scenes and a performative structure which dictates, via a set of normative rules, the relationships between the scenes. This provides highly reliable but very constrained multi-agent systems. Electronic Institutions is only one approach to modeling interaction protocols. There are various others [6, 5]

Agent-centric approaches build systems bottom-up. These approaches attempt to pack individual agents with a model of communication which can react to a multi-agent system. Dialogical actions are not prescribed to the agent beforehand. Instead, using their model of communication agents attempt to figure out the next action to take. There are many different approaches to achieve this such as cognitive dissonance theory [12]. The concept of social commitment or obligation has been employed in [4, 19] One of the more interesting approaches is dialogue games. The papers of [13, 1, 7] all use dialogue theory and games to create flexible agent dialogues. The example given in section 4 demonstrates the use of dialogue games with the protocol language.

The protocol language described in this paper seeks a balanced approach. It utilises the useful aspects of Electronic Institutions without relying on administrative agents or statically defined protocol specifications. Agents communicate not only individual messages but the protocol and dialogue state as well. The use of protocols provides structure and reliability to agent dialogues. Yet, by describing protocols as a process rather than a fixed state-based model, the conversation space can be defined as the agent interaction progresses rather than being statically defined during the engineering process. Distributing the protocol along with the message also allows agents to communicate the social conventions of the dialogue as well as coordinate it.

Section 2 describes the protocol language and a framework for implementation. Section 3 describes how agents can adapt their protocols to create dynamic and flexible dialogues. Section 4 provides an example to illustrate the main points of the protocol language and its ability to be adapted during execution. Section 5 concludes the paper with the hazards and successes of this approach.

2 The Protocol Language

The development of the protocol language is a reaction to Electronic Institutions [16]. Although the EI framework provides structure and stability to an agent system, it comes at a cost. Integral to EI is the notion of the administrative agents. Their task is to enforce the conventions of the Institution and shepherd the participating agents. Messages sent by agents are sent through the EI. This synchronises the conversation between the conversing agents, and keeps the administrative agent informed of the state of the interaction

An unreliable keystone makes the whole of the arch defective, just as the system is now dependent on the reliability and robustness of its administrative agent. Also, this centralisation of control runs counter to the agent paradigm of distributed processing. Within the scenes of Electronic Institutions, interaction

protocols are defined to guarantee that agents utter the proper illocutions and utter them at the appropriate time. This is defined formally by the specifications of the EI and left to the designers of individual agents to implement. It assumes that the agent's interaction protocol covers the entire conversation space before the conversation occurs. If the interaction needs of the institution change, this would require redefinition of the Institution and re-synthesis of the individual agents. Agents are also expected to know the global state of the system and their exact position within it. In EIs this is handled by an administrative agent whose job it is to synchronise the multitude of agents involved.

The protocol language addresses some of these shortcomings of EIs but retains the benefits of implementing the EI framework. Its goal is to lessen the reliance on centralised agents for synchronisation of individual participants in the system, provide a means for dissemination of the interaction protocol and to separate the interaction protocol from the agent's rationalisations to allow the dynamic construction of protocols during the interaction. By defining interaction protocols during run-time, agents are able to interact in systems where it is impossible or impractical to define the protocol beforehand. For example, negotiation dialogues where the domain of negotiation is not fixed or unknown. Another example would be diagnosis dialogues where the course of the dialogue is determined by the information sent and not a fixed sequence of messages. The protocol language defined in Figure 1 is similar to the protocol language described in [18] for which the formal semantics have been defined. The rewrite rules in figure 2 are defined in terms of these semantics.

$M \in \langle m,\mathcal{P}\rangle$ *(message)*	$m \in$ a communicative act
$\mathcal{P} \in \langle S,A^{\{n\}},K\rangle$ *(Protocol)*	$A \in \theta :: op$. *(Agent Clause)*
$\theta \in$ **agent**(r,id)	$\psi \in$ a predicate
$op \in$ null $\mid \theta \mid (op)$ *(Precedence)* $\mid M \Rightarrow \theta$ *(Send)* $\mid M \Leftarrow \theta$ *(Receive)*	
$\mid$ *op1* **then** *op2 (Sequence)* $\mid$ *op1* **or** *op2 (Choice)*	
$\mid$ *op1* **par** *op2 (Parallelism)* $\mid \psi \leftarrow M \Leftarrow \theta$ *(Consequence)*	
$\mid M \Rightarrow \theta \leftarrow \psi$ *(Prerequisite)*	

Fig. 1. The abstract syntax of the protocol

Figure 1 defines the syntax of the protocol language. An agent clause is composed of an agent definition and an operation. The agent definition individuates the agents participating in the conversation (id), and the role the agent is playing (r). Operations can be classified in three ways: actions, control flow, and conditionals. Actions are the sending or receiving of messages, a no op, or the adoption of a role. Control Flow operations temporally order the individual actions. Actions can be put in sequence (one action must occur before the other), in parallel (both action must occur before any further action), or given a choice point (one and only one action should occur before any further action). Conditionals are the preconditions and postconditions for operations. The message

passed between two agents using the protocol consists of two parts. The first is the actual illocution (m) the agent is wishing to express. The second is the full protocol ($\mathcal{P}$) itself. This is the protocol for all agents and roles involved in the conversation. This will be necessary for the dissemination of the protocol as new agents enter the system. Other aspects of the protocol are the inclusion of constraints on the dialogue and the use of roles. An agent's activities within a multi-agent system are not determined solely by the agent, rather it is the relationship to other agents and the system itself that helps determine what message an agent will send. These can be codified as roles. This helps govern the activity of groups of agents rather than each agent individually. Constraints are marked by a '$\leftarrow$'. These are requirements or consequences for an agent on the occurrence of messages or the adoption of roles. The constraints provide the agent with a shared semantics for the dialogue. These constraints communicate meaning and implication of the action to the agent's communicating partner. For example, an agent receiving a protocol with the constraint to believe a proposition s upon being informed of s can infer that the agent sending the protocol has a particular semantic interpretation of the act of informing other agents of propositions (i.e. The receiving agent is expected to believe s when informed of s). The '$\Leftarrow$' and '$\Rightarrow$' mark messages being sent and received. On the left-hand side of the double arrow is the message and on the right-hand side is the other agent involved in the interaction.

An agent must be able to understand the protocol, the dialogue state, and its role within the protocol. Agents need to be able to identify the agent clause which pertains to its function within the protocol and establish what actions it must take to continue the dialogue or what roles to adopt.

2.1 Implementing the Protocol Framework

A message is defined as the tuple, $\langle m,\mathcal{P}\rangle$. Where m is the message an agent is currently communicating, and $\mathcal{P}$ is the protocol written using the language described in figure 1. The protocol, in turn, is a triple, $\langle S,A^{\{n\}},K\rangle$. S is the dialogue state. This is a record of the path of the dialogue through the conversation space and the current state of the dialogue for the agents. The second part is a set of agent clauses, $A^{\{n\}}$, necessary for the dialogue. The protocol also includes a set of axioms, K, consisting of common knowledge to be publicly known between the participants. The sending of the protocol with the messages allows agents to represent the various aspects of Electronic Institutions described [2, 3]. In addition, agents themselves communicate the conventions of the dialogue. This is accomplished by the participating agents satisfying two simple engineering requirements. Agents are required to share a dialogical framework. The same is required of Electronic Institutions, and is an unavoidable necessity in any meaningful agent communication. This includes the requirements on the individual messages are expressed in a ontology understood by the agents. The issue of ontology mapping is still open, and its discussion extends beyond the scope of this paper. The second requirement obligates the agent to provide a means to

interpret the received message and its protocol. The agent must be able to unpack a received protocol, find the appropriate actions it may take, and update the dialogue state to reflect any actions it chooses to perform.

$$
\begin{array}{l}
A :: B \xrightarrow{M_i, M_o, \mathcal{P}, O} A :: E \\
\quad if \quad B \xrightarrow{M_i, M_o, \mathcal{P}, O} E \\
A_1 \; or \; A_2 \xrightarrow{M_i, M_o, \mathcal{P}, O} E \\
\quad if \quad \neg closed(A_2) \wedge A_1 \xrightarrow{M_i, M_o, \mathcal{P}, O} E \\
A_1 \; or \; A_2 \xrightarrow{M_i, M_o, \mathcal{P}, O} E \\
\quad if \quad \neg closed(A_1) \wedge A_2 \xrightarrow{M_i, M_o, \mathcal{P}, O} E \\
A_1 \; then \; A_2 \xrightarrow{M_i, M_o, \mathcal{P}, O} E \; then \; A_2 \\
\quad if \quad A_1 \xrightarrow{M_i, M_o, \mathcal{P}, O} E \\
A_1 \; then \; A_2 \xrightarrow{M_i, M_o, \mathcal{P}, O} A_1 \; then \; E \\
\quad if \quad closed(A_1) \wedge A_2 \xrightarrow{M_i, M_o, \mathcal{P}, O} E \\
A_1 \; par \; A_2 \xrightarrow{M_i, M_o, \mathcal{P}, O_1 \cup O_2} E_1 \; par \; E_2 \\
\quad if \quad A_1 \xrightarrow{M_i, M_n, \mathcal{P}, O_1} E_1 \wedge A_2 \xrightarrow{M_n, M_o, \mathcal{P}, O_2} E_2 \\
C \leftarrow M \Leftarrow A \xrightarrow{M_i, M_i - \{M \Leftarrow A\}, \mathcal{P}, \emptyset} c(M \Leftarrow A) \\
\quad if \quad (M \Leftarrow A) \in M_i \wedge satisfy(C) \\
M \Rightarrow A \leftarrow C \xrightarrow{M_i, M_o, \mathcal{P}, \{M \Rightarrow A\}} c(M \Rightarrow A) \\
\quad if \quad satisfied(C) \\
null \leftarrow C \xrightarrow{M_i, M_o, \mathcal{P}, \emptyset} c(null) \\
\quad if \quad satisfied(C) \\
agent(r, id) \leftarrow C \xrightarrow{M_i, M_o, \mathcal{P}, \emptyset} a(R, I) :: B \\
\quad if \quad clause(\mathcal{P}, a(R, I) :: B) \wedge satisfied(C)
\end{array}
$$

A protocol term is decided to be closed, meaning that it has been covered by the preceding interaction, as follows:

$$
\begin{array}{l}
closed(c(X)) \\
closed(A \; or \; B) \leftarrow closed(A) \vee closed(B) \\
closed(A \; then \; B) \leftarrow closed(A) \wedge closed(B) \\
closed(A \; par \; B) \leftarrow closed(A) \wedge closed(B) \\
closed(X :: D) \leftarrow closed(D)
\end{array}
$$

$satisfied(C)$ is true if C can be solved from the agent's current state of knowledge. $satisfy(C)$ is true if the agent's state of knowledge can be made such that C is satisfied. $clause(\mathcal{P}, X)$ is true if clause X appears in the dialogue framework of protocol $\mathcal{P}$, as defined in Figure 1.

Fig. 2. Rules for expanding an agent clause

Figure 2 describes rules for expanding the received protocols. Details can be found in [14]. A similar language for web services is described in [15]. An agent

receives a message of the form specified in figure 1. The message is added to the set of messages, M_i, currently being considered by the agent. The agent takes the clause, C_i, from the set of agent clauses received as part of $\mathcal{P}$. This clause provides the agent with its role in the dialogue. The agent then expands C_i by the application of the rules in figure 2. The expansion is done with respect to the different operators encountered in the protocol and the response to M_i. The result is a new dialogue state, C_n; a set of output messages, O_n and a subset of M_i, which is the remaining messages to be considered,M_n. The result is arrived at by applying the rewrite rules. The sequence would be similar to figure 3. C_n is then sent as part of $\mathcal{P}$ which will accompany the sending of each message in O_n.

$$\langle C_i \xrightarrow{M_i, M_{i+1}, \mathcal{P}, O_i} C_{i+1}, \ldots, C_{n-1} \xrightarrow{M_{n-1}, M_n, \mathcal{P}, O_n} C_n \rangle$$

Fig. 3. Sequence of rewrites

2.2 Features of the Protocol

Several features of the protocol language are useful for agents capable of learning and adapting to the multi-agent system in which they participate. Sending the dialogue state during the interaction provides agents with several advantages. It is no longer necessary for an administrative agent to shepherd the interaction. The sending of the protocol with the message uses the 'hot potato' approach to communication. The interaction is coordinated by which agent currently 'holds' the protocol. The reception of a message would cue an agent to action. The sending of the protocol provides a means for disseminating the social conventions for the dialogue. The most common approach is to use specifications to be interpreted by individual engineers. The protocol directly communicates the social conventions and expectations an agent has for the dialogue. Agents with the ability to learn could use the received protocol to plan ahead or modify its own social conventions to be able to communicate with other agents. The protocol language is strictly concerned with the interaction level of communication. The semantics of the language does not depend on any assumptions about the agent's internal deliberative model. All requirements for the interaction are publicly specified with the protocol. Agents with different models of deliberation are able to communicate [10].

3 Means of Adaptation

Protocols are traditionally seen as a rigid ordering of messages and processing to enable a reliable means of communication. Agent-centric approaches have tended

to avoid their use, lest agents be reduced to nothing more than remote function calls for the multi-agent system. The control over agent interactions within an electronic institutions is indeed intrusive. The administrative agents of electronic institutions have complete control. The sequence of messages are dictated but also the roles an agent may adopt and the actions an agent must take within and outside of the context of the dialogue.

The protocol language of this paper does not follow this tradition. It is designed to bridge the gap separating the two approaches to agent interaction. The language is capable of representing the scenes and performative structure of electronic institutions, but it is not limited to electronic institution's inflexible model of agent interaction. The protocol language and the process of sending the protocol during execution provides agents with a means of adaptation.

In the electronic institution model, the protocol does not exist within the participating agents. It is retained by the institution itself, and designers must engineer agents that will strictly conform to the protocol which will be dictated by the administrative agents. Our approach delivers the protocol to the participating agents. Individual agents are given providence over the protocol they receive. This returns the power of the interaction to the participating agents. For example, the protocol received is not required to be the protocol that is returned.

The protocol, as described so far, already allows for a spectrum of adaptability. At one extreme, the protocol can be fully constrained. Protocols at this end of the spectrum would be close to the traditional protocols and electronic institutions. By rigidly defining each step of the protocol, agents could be confined to little more than remote processing. This sacrifice allows the construction of reliable and verifiable agent systems. At the other extreme, the protocols would be nothing more than the ordering of messages or even just the statement of legal messages(without any ordering) to be sent and received. Protocols designed this way would be more akin to the way agent-centric designers envisage agent communication. Agents using these protocols would be required to reason about the interaction to determine the next appropriate step in the dialogue. Though the protocol language is expressive enough for both extremes of the spectrum, the bulk of interactions are going to be somewhere in the middle. A certain amount of the dialogue will need to be constrained to ensure a useful dialogue can occur. This allows agents to express dynamic and interesting dialogues.

The protocol language is flexible enough to be adapted during run-time. Yet, protocols modified indiscriminately would return us to the problem facing the agent-centric approach. We would have a model for flexible communication, but no structure or conventions to ensure a meaningful dialogue can take place. It is necessary to constrain any adaptation in a meaningful way. By the examination of patterns and standards of an agent-centric approach, protocols can be construct to have points of flexibility. Portions in the dialogue can be adapted without losing the benefits of a protocol-based approach. The example below employs the rules for playing a dialogue game, the protocol language, and an

amendment to the rewrite rules to allow a more dynamically constructed protocol.

4 Example

Figure 4 shows the agent clauses needed to play an Information-seeking dialogue game similar to the one defined in [11]. The dialogue game rules are simplified to clarify its implementation within the protocol. There are countless variations on the rules for any one type of dialogue game. This illustrates a continuing problem with agent-centric communication design. It is not a trivial requirement to ensure agents within a system are employing the same communicative model. This is the same with dialogue games. Subtle differences could break the dialogue. By the use of the protocol, agent can communicate their 'house' rules for the game. The rules for this particular game are as follows:

1. The game begins with one agent sending the message *question(p)* to another agent.
2. Upon receiving a *question(p)* message, an agent should evaluate p and if it is found to be true, the agent should reply with *assert(p)* else send an *assert(null)* which is a failure message.
3. Upon receiving an *assert(p)*, an agent should evaluate the assertion, then the agent can send an *accept(p)* or *challenge(p)* depending on whether the agent's acceptance attitude will allow.
4. Upon receiving a *challenge(p)*, an agent should send an *assert($\mathcal{S}$)*. $\mathcal{S}$ is a set of propositions in support of p.
5. For each proposition in $\mathcal{S}$, repeat steps 3 and 4.
6. The game is over when all propositions have been accepted or no further support for a proposition can be offered.

Rule one is satisfied by an agent taking up the role of the 'seeker'. This provides the agent with the legal moves necessary to play that side of the information-seeking dialogue game. The other agent will receive the *question(p)* message along with the protocol of figure 4. The agent identifies the clause which it should use. In this example, the clause playing the 'provider' role. It is necessary to use constraints to fully satisfy the second rule. Part of the rule states an agent sending an *assert(p)* depends on its knowledge base and its assertion attitude, otherwise an *assert(null)* is sent. The constraint *verify(p)* is assumed to be satisfiable by the agent. The agent is free to satisfy the constraint how it prefers. This could range from a simple function call to a complex belief logic with identity evaluation. The protocol only states what conditions must be satisfied, not how. The recursive steps are handled by the roles of *eval* (evaluate) and *def* (defend) which are similarly constrained. Finally, the termination rule for the game is written as the last line in the 'evaluate' role. No more messages are sent when the remainder of the set of propositions is empty.

Similar protocols can be written to express the other atomic dialogue types. Real world dialogues rarely consist of a single dialogue game type. [8] formally

$$
\begin{array}{l}
agent(infoseek(P,B),A) :: \\
\quad agent(provider(P,A),B)\ or \\
\quad agent(seeker(P,B),A). \\
\\
agent(seeker(P,B),A) :: \\
\quad question(P) \Rightarrow agent(provider(P,A),B)\ then \\
\quad\ assert(P) \Leftarrow agent(provider(P,A),B)\ then \\
\quad\quad agent(eval(P,B),A)\ or \\
\quad\ assert(null) \Leftarrow agent(provider(P,A),B). \\
\\
agent(provider(P,A),B) :: \\
\quad question(P) \Leftarrow agent(seeker(P,B),A)\ then \\
\quad\ (assert(P) \Rightarrow agent(seeker(P,B),A) \leftarrow verify(P)\ then \\
\quad\quad agent(def(P,A),B))\ or \\
\quad\ assert(null) \Rightarrow agent(seeker(P,B),A). \\
\\
agent(eval([P|R],B),A) :: \\
\quad accept(P) \Rightarrow agent(def([P|R],A),B) \leftarrow accept(P)\ or \\
\quad \left(\begin{array}{l} challenge(P) \Rightarrow agent(def([P|R],A),B)\ then \\ \quad assert(\mathcal{S}) \Leftarrow agent(def([P|R],A),B)\ then \\ \quad\ agent(eval(\mathcal{S},B)A) \end{array}\right) \\
\quad then \\
\quad\quad \left(\begin{array}{l} null \leftarrow R = []\ or \\ agent(eval(R,B),A) \end{array}\right). \\
\\
agent(def([P|R],A),B) :: \\
\quad accept(P) \Leftarrow agent(eval([P|R],B),A)\ or \\
\quad \left(\begin{array}{l} challenge(P) \Leftarrow agent(eval([P|R],B),A)\ then \\ \quad assert(\mathcal{S}) \Rightarrow agent(eval([P|R],B),A) \\ \leftarrow\ justify(P,\mathcal{S}) \end{array}\right) \\
.
\end{array}
$$

Fig. 4. The agent clauses for the information-seeking protocol

describe several combinations of dialogue types. *Iteration* is the initiation of a dialogue game immediately following the finishing of another dialogue game of the same type. *Sequencing* is the similar to iteration except that the following dialogue game can be of any type. In *Parallelisation* of dialogue games, agents make moves in more than one dialogue game concurrently. *Embedding* of dialogue games occurs when during play of one dialogue game another game is initiated and played to its conclusion before the agents continue playing the first. The example involves two agents; a doctor and a patient. The patient is trying to find out whether the proposition 'patient is ill' is true (i.e. looking for a diagnosis). This is the perfect scenario to play an information-seeking dialogue game and to use the dialogue game protocol. Figure 5 and 6 shows the dialogue state as it is rewritten during the course of the dialogue.

$$agent(infoseek(\text{“}patient\ is\ ill'', doctor), patient) :: agent(seeker(\text{“}patient\ is\ ill'', doctor), patient) \quad (1)$$

$$agent(infoseek(\text{“}patient\ is\ ill'', doctor), patient) :: question(\text{“}patient\ is\ ill'') \Rightarrow agent(provider(\text{“}patient\ is\ ill'', patient), doctor) \quad (2)$$

$$agent(infoseek(\text{“}patient\ is\ ill'', doctor), patient) :: question(\text{“}patient\ is\ ill'') \Rightarrow agent(provider(\text{“}patient\ is\ ill'', patient), doctor)\ then\ assert(null) \Leftarrow agent(provider(\text{“}patient\ is\ ill'', patient), doctor). \quad (3)$$

Fig. 5. The progression of the dialogue state for the patient

$$agent(infoseek(\text{“}patient\ is\ ill'', patient), doctor) :: agent(provider(\text{“}patient\ is\ ill'', patient), doctor) \quad (1)$$

$$agent(infoseek(\text{“}patient\ is\ ill'', patient), doctor) :: question(\text{“}patient\ is\ ill'') \Leftarrow agent(seeker(\text{“}patient\ is\ ill'', doctor), patient)\ then\ assert(null) \Rightarrow agent(seeker(\text{“}patient\ is\ ill'', doctor), patient). \quad (2)$$

Fig. 6. The progression of the dialogue state for the doctor

The patient begins the dialogue by taking the initial agent clause of *infoseek* which stands for information-seeking. This step is labeled *1.* The agent applies the rewrite rules to expand the seeker role and sends the *question* to the doctor agent, step *2.* The doctor receives the message and the protocol. The applies the rewrite rules and finds the only instantiation that is possible is the unfolding of the provider role. It applies the rewrite rules and comes to the *verify* constraint which it is unable to satisfy. It cannot determine the truth value of the proposition and is unwilling to defend the proposition. It takes the other half of the *or* operator and sends the *assert(null).* Let us assume the doctor agent is a bit more clever. It cannot currently assert that the patient is ill. It has a knowledge-base and an inference engine that allows it to figure whether the proposition is true or not, and it needs some more information from the patient. The particular kind of information would depend on each patient consultation. If this diagnosis scenario was part of an electronic institution, the institution would have to represent in a state diagram every possible permutation of a diagnosis scenario. This is not practical, if not impossible.

Instead, the doctor agent can use the patterns of dialogue games to structure the interaction but allow adaptations to handle any run-time dialogical needs that may arise. In the example, the doctor agent needs to ask about a different proposition before it can answer the patient's original query. This is achieved by an additional rewrite rule shown in figure 7.

$$A \xrightarrow{M_i, M_o, \mathcal{P}, O} A \; then \; B$$
$$if \quad clause(P, B) \wedge isa(B, dialogue - type)$$

$$isa(infoseek, dialogue - type).$$

Fig. 7. Additional rewrite rule

This allows the agent to graft the infoseek agent clause between any term in the protocol. These rewrites can be expanded further to represent other dialogue combinations as well as domain specific rewrite rules. Figure 8 shows the sequence of dialogue states for the doctor agent capable of embedding information-seeking games. The expansions and dialogue begin the same, but rather than just sending the *assert(null)*. The agent inserts the agent definition *agent (infoseek ("patient has a fever"),patient),doctor)*. The next instance of a information-seeking dialogue is begun. The moves of the embedded dialogue game are in bold text. In this instance the patient plays the provider role and the doctor plays the seeker. The game is finished by the patient asserting "patient has a fever". The doctor, now knowing this proposition to be true, has enough knowledge to assert the original proposition posed by the patient's first question. The first information-seeking game also concludes successfully by the doctor making the diagnosis and asserting the proposition "patient is ill" is true.

5 Conclusions

The protocol language described in the paper is expressive enough to represent the most popular approaches to the agent communication. It is able to capture the various aspects of Electronic Institutions such as the scenes, performative structure, and normative rules. This enables agents to have structured and meaningful dialogues without relying on centralised control of the conversation. The language is also capable of facilitating agent-centric approaches to agent communication. Agents pass the protocol to their dialogical partners to communicate the social conventions for the interaction. Agents can adapt the received protocols to explore dynamic conversation spaces. The protocol language in this paper is not seen as a replacement for either model of agent communication. Instead, it synthesizes the two approaches to gain the advantages of both. Protocols are used to coordinate and guide the agent's dialogue, but agents are able

$$agent(infoseek(\text{“}patient\ is\ ill''), patient), doctor) ::$$
$$question(\text{“}patient\ is\ ill'') \Leftarrow agent(seeker(\text{“}patient\ is\ ill'', doctor), patient)\ then$$
$$agent(infoseek(\text{“}patient\ has\ a\ fever'', patient), doctor).$$

(2)

$$agent(infoseek(\text{“}patient\ is\ ill'', patient), doctor) ::$$
$$question(\text{“}patient\ is\ ill'') \Leftarrow agent(seeker(\text{“}patient\ is\ ill'', doctor), patient)\ then$$
$$\mathbf{question}(\text{“}\mathbf{patient\ has\ a\ fever}'')$$
$$\Rightarrow \mathbf{agent}(\mathbf{provider}(\text{“}\mathbf{patient\ has\ a\ fever}'', \mathbf{doctor}), \mathbf{patient})$$

(3)

...

$$agent(infoseek(\text{“}patient\ is\ ill'', patient), doctor) ::$$
$$question(\text{“}patient\ is\ ill'') \Leftarrow agent(seeker(\text{“}patient\ is\ ill'', doctor), patient)\ then$$
$$\mathbf{question}(\text{“}\mathbf{patient\ has\ a\ fever}'') \Rightarrow$$
$$\mathbf{agent}(\mathbf{provider}(\text{“}\mathbf{patient\ has\ a\ fever}'', \mathbf{doctor}), \mathbf{patient})\ then$$
$$\mathbf{assert}(\text{“}\mathbf{patient\ has\ a\ fever}'') \Leftarrow$$
$$\mathbf{agent}(\mathbf{provider}(\text{“}\mathbf{patient\ has\ a\ fever}'', \mathbf{doctor}), \mathbf{patient})\ then$$
$$assert(\text{“}patient\ is\ ill'') \Rightarrow agent(seeker(\text{“}patient\ is\ ill'', doctor), patient).$$

Fig. 8. The progression of the dialogue state for the doctor with embedding

to adapt the protocol by using an agent-centric model for communication. The use of this communicative model constrains transformation to the agent clauses in meaningful ways. The run-time delivery provides the mechanism for communicating the protocol as well as any adaptations that are made. We are developing FIPA compliant agents which uses the ACL library and the protocol language. It is hoped that the verifiability and semantic problems associated with FIPA's ACL can be mitigated by the use of the protocol language to communicate the performative's semantics during their use.

This approach does raise new issues which have not been addressed in this paper. One issue concerns restricting changes to the protocols. There are certainly dialogues where certain agents will be restricted from modifying the protocols or dialogue which require portions of the protocol to remain unchanged. There is also the issue of malicious agents. An agent could attempt to modify the dialogue state or the protocol in some dubious manner. The publicness of the protocol would certainly impede the naughty agent from gaining much from this activity, but the issue still needs to be addressed more fully. There is also some concerns with the amount of data being transmitted and the possibility of situations which do not require transmission of the dialogue state or the agent clauses. For example, agents who routinely communicate together or are known to maintain the dialogue state themselves. This remains for future work along with develop-

ment of a vocabulary of generic transformations which can be proved *a priori* or verified to retain semantic and syntactical continuity of the protocols.

The protocol language has already been shown to be useful for a number of agent purposes. A scheduling program has been developed using the protocol written in Prolog and using LINDA. A Java-based agent framework also exists which uses an XML representation of the protocols. Separating the protocol from the deliberative and communicative models of agency makes definition and verification simpler tasks. Tools have already been developed which use model-checking for automatic verification [17]. The protocol language has been used to implement the generic dialogue framework of [8] and the negotiation game described in [9].

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