# Reasoning about agents' interaction protocols inside DCaseLP

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**Abstract.** Engineering systems of heterogeneous agents is a difficult task; one of the ways for achieving the successful industrial deployment of agent technology is the development of engineering tools that support the developer in all the steps of design and implementation. In this work we focus on the problem of supporting the design of agent interaction protocols by carrying out a methodological integration of the MAS prototyping environment DCaseLP with the agent programming language DyLOG for reasoning about action and change.

## 1 Introduction

Multiagent Systems (MASs) involve heterogeneous components which have different ways of representing their knowledge of the world, themselves, and other agents, and also adopt different mechanisms for reasoning. Despite heterogeneity, agents need to interact and exchange information in order to cooperate or compete not only for the control of shared resources but also to achieve their aims; this interaction may follow sophisticated communication protocols.

For these reasons and due to the complexity of agents' behavior, MASs are difficult to be correctly and efficiently engineered. Even developing a working prototype may require a long time and a lot of effort. In fact, some general aspects of the MAS can be better specified and verified using ad-hoc languages, and the prototype can involve heterogeneous agents that cannot be easily implemented using the same language[1]. The "one-size-fits-all" approach, which means using the same specification language for all the aspects of the MAS, and the same implementation language for all the agents, does not take the heterogeneity into account and represents a very rigid solution to a problem that requires as much flexibility as possible.

[1] Unless otherwise stated, by "implementation language" we mean the language used to implement the running prototype, which may be different from the language used in the final application.

According to [26], the successful industrial deployment of agent technology requires techniques that reduce the inherent risks in any new technology and there are two ways in which this can be done: presenting a new technology as an extension of a previous, well-established one, or providing engineering tools that support industry-accepted methods of technology deployment. In this paper we present an ongoing research that follows the second outlined solution, aimed at developing a "multi-language" environment for engineering systems of heterogeneous agents. This environment will allow the prototype developer to specify, verify and implement different aspects of the MAS and different agents inside the MAS, choosing the most appropriate language from a given set. In particular, the discussion will be focused on the advantages of integrating an agent programming language for reasoning about actions and change (using the language DyLOG [9,7]) into the DCaseLP [4,19,24] MAS prototyping environment.

The paper has been structured as follows: Section 2 explains the core ideas of the project, Section 3 overviews the DCaseLP environment while Section 4 introduces the DyLOG language. Finally, Section 5 outlines the integration of DyLOG into DCaseLP and discusses its outcomes in reasoning about conversation protocols; conclusions follow.

## 2 An integrated environment to engineer agent systems and to reason about interaction

The development of a prototype system of heterogeneous agents can be carried out in different ways. The "one-size-fits-all" solution consists of developing all the agents by means of the same implementation language and to execute the obtained program. If this approach is adopted, during the specification stage it would be natural to select a specification language that can be directly executed or easily translated into code, and to use it to specify all the agents in the MAS. The other solution is to specify each "view" of the MAS (that includes its architecture, the interaction protocols among agents, the internal architecture and functioning of each agent), with the most suitable language in order to deal with the MAS's peculiar features, and then to verify and execute the obtained specifications inside an integrated environment. Such a multi-language environment should, therefore, offer the means not only to select the proper specification language for each view of the MAS, but also to check the specifications exploiting formal validation and verification methods and to produce an implementation of the prototype in a semi-automatic way. The prototype's implementation should be composed of heterogeneous pieces of code created by semi-automatic translations of heterogeneous specifications. Moreover, the multi-language environment should allow these pieces of code to be seamlessly integrated and capable of interacting.

The more complexity associated with the latter solution is proportional to the advantages it gives in respect to the former. In particular, by allowing different specification languages for modeling different aspects of the MAS, *it provides the flexibility needed to describe the MAS from different points of view.* More-

over, by allowing different specification languages for the internal architecture and functioning of each agent, *it respects the differences existing among agents*, namely the way they reason and the way they represent their knowledge, other agents, and the world. Clearly, this solution also has some drawbacks in respect to the former. The coherent integration of different languages into the same environment must be carefully designed and implemented by the environment creators, who must also take care of the environment maintenance. It must be emphasized that the developer of the MAS does not have to be an expert of *all* the supported languages: he/she will use those he/she is more familiar with, and this will lead to more reliable specifications and implementations.

Although solid and complete environments that focus on the integration of heterogeneous specification and implementation languages in a seamless way do not exist yet, some interesting results have already been achieved with the development of prototypical environments for engineering heterogeneous agents. Just to cite some of them, the AgentTool development system [2] is a Java-based graphical development environment to help users analyze, design, and implement MASs. It is designed to support the Multiagent Systems Engineering (MaSE) methodology [12], which can be used by the system designer to graphically define a high-level system behavior. The system designer defines the types of agents in the system as well as the possible communications that may take place between them. This system-level specification is then refined for each type of agent in the system. To refine the specification of an agent, the designer either selects or creates an agent's architecture and then provides detailed behavioral specification for each component in such architecture. Zeus [30] is an environment developed by British Telecommunications for specifying and implementing collaborative agents, following a clear methodology and using the software tools provided by the environment. The approach of Zeus to the development of a MAS consists of analysis, design, realization and runtime support. The first two stages of the methodology are described in detail in the documentation, but only the last two stages are supported by software tools. DCaseLP (Distributed CaseLP, [4,19,24]) integrates a set of specification and implementation languages in order to model and prototype MASs. It defines a methodology which covers the engineering stages, from the requirements analysis to the prototype execution, and relies on the use of AUML (Agent UML, [6]) not only during the requirements analysis, but also to describe the *interaction protocols* followed by the agents. The description of other prototyping environments can be found starting from the UMBC Web Site (`http://agents.umbc.edu`) and following the path `Applications and Software, Software, Academic, Platforms`. The reader can refer to [13] for a comparison between some of them, including the predecessor of DCaseLP (CaseLP).

In respect to the existing MAS prototyping environments, DCaseLP stresses the aspect of *multi-language support* to cope with the heterogeneity of both the views of the MAS and the agents. This aspect is usually not considered in depth, and this is the reason why we opted to work with DCaseLP rather than with other existing environments.

The choice of AUML to represent interaction protocols in DCaseLP is motivated by the wide support that it is obtaining from the agent research community. Even if AUML cannot be considered a standard agent modeling language yet, it has many chances to become such, as shown by the interest that both the FIPA modeling technical committee (`http://www.fipa.org/activities/modeling.html`) and the OMG Agent Platform Special Interest Group (`http://www.objs.com/agent/`) demonstrate in it.

In DCaseLP, interaction protocols can be described using UML and/or AUML, and can be animated by creating agents whose behavior adheres to the given protocols. The idea of translating UML and AUML diagrams into a formalism and check their properties by either animating or formally verifying the resulting code is shared by many researchers working in the agent-oriented software engineering field [20,25,28]. We followed an animation approach to check that the interaction protocols produced during the requirement specification stage are the ones necessary to describe the system requirements and, moreover, that they are correct. The "coherence check" is done by comparing the results of the execution runs with the interaction specification [4]. Despite its usefulness, this approach does not straightforwardly allow the formal proof of properties of the resulting system *a priori*: indeed, a key issue in the design and engineering of interaction protocols, that DCaseLP does not address, is the use of *formal methods* to verify properties of the interactions occurring between the agents. For instance, in the line of [21], it would be interesting to perform validation tests, i.e. to check the coherence of the AUML description with the specifications derived from the analysis. To this aim, it is possible to use model checking techniques [10]. Another kind of verification that could be executed (a priori as well) is the conformance test, i.e. a test that verifies if the implementation is coherent with the AUML specification. Moreover, when using a declarative language for the implementation, it is also possible to exploit reasoning techniques to prove further properties of the interaction.

One step in this direction is to integrate the ability of *reasoning* about the agent interaction protocols, into DCaseLP. To achieve this, we propose to implement AUML sequence diagrams into the DyLOG programming language, and then to integrate DyLOG into DCaseLP. The choice of DyLOG is motivated by our interest in the aspects of specification, that are related to *communication* between agents; in fact, the DyLOG language includes a fully integrated "communication kit", that allows not only to specify both communicative acts and conversation protocols, but also to reason upon the latter. Moreover, it is possible to prove in a formal way that a DyLOG implementation is *conformant* to the AUML specification of an interaction protocol, according to the definitions given in [8] (i.e. that all the conversations that it produces respect the protocol specification) and to partially automate the implementation process. Section 5 briefly illustrates the translation procedure. DyLOG also allows reasoning about the conversations defined by a protocol, basically to check if there is a conversation after whose execution a given set of properties holds. This characteristic can be exploited to determine which protocol, from a set of available ones, satisfies a

goal of interest, and also to compose many protocols for accomplishing complex tasks. After proving desired properties of the interaction protocols, the developer can animate them thanks to the facilities offered by DCaseLP, discussed in Section 3.

This integration of DyLOG into DCaseLP is a *methodological integration*: it extends the set of languages supported by DCaseLP during the MAS engineering process and augments the verification capabilities of DCaseLP, without requiring any real integration of the DyLOG working interpreter into DCaseLP. Nevertheless, DyLOG can also be used to directly specify agents and execute them inside the DCaseLP environment, in order to exploit the distribution, concurrency, monitoring and debugging facilities that DCaseLP offers. This *physical integration* of DyLOG into DCaseLP is briefly discussed in Section 5.

## 3 The DCaseLP environment

DCaseLP is a prototyping environment where agents specified and implemented in a given set of languages can be seamlessly integrated. It provides an agent-oriented software engineering methodology to guide the developer during the analysis of the MAS requirements, its design, and the development of a working MAS prototype. The methodology is sketched in Figure 1. Solid arrows represent the information flow from one stage to the next one. Dotted arrows represent the iterative refinement of previous choices. The first release of DCaseLP did not realize all the stages of the methodology. In particular, as we have pointed in last section, the stage of properties verification was not addressed. The integration of DyLOG into DCaseLP discussed in Section 5 will allow us to address also the verification phase. The tools and languages supported by the first release of

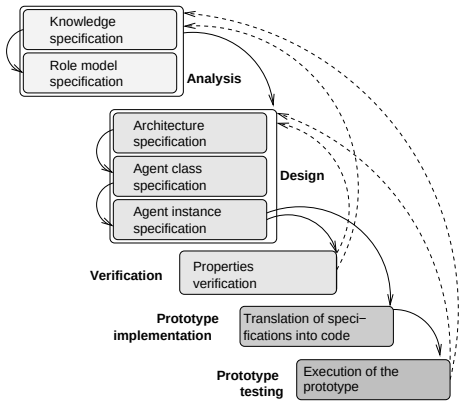


**Fig. 1.** DCaseLP's methodology.

DCaseLP, discussed in [24,4], included UML and AUML for the specification of

the general structure of the MAS, and Jess [23] and Java for the implementation of the agents.

DCaseLP adopts an existing multi-view, use-case driven and UML-based method [5] in the phase of requirements analysis. Once the requirements of the application have been clearly identified, the developer can use UML and/or AUML to describe the interaction protocols followed by the agents, the general MAS architecture and the agent types and instances. Moreover, the developer can automatically translate the UML/AUML diagrams, describing the agents in the MAS, into Jess rule-based code. In the following we will assume that AUML is used during the requirements analysis stage, although the translation from AUML into Jess is not fully automated (while the translation from pure UML into Jess is).

The Jess code obtained from the translation of AUML diagrams must be manually completed by the developer with the behavioral knowledge which was not explicitly provided at the specification level. The developer does not need to have a deep insight into rule-based languages in order to complete the Jess code, since he/she is guided by comments included in the automatically generated code. The agents obtained by means of the manual completion of the Jess code are integrated into the JADE (Java Agent Development Framework, [22]) middle-ware. JADE complies with the FIPA specifications [15] and provides a set of graphical tools that support the execution, debugging and deployment phases. The agents can be distributed across several machines and can run concurrently. By integrating Jess into JADE, we were able to easily monitor and debug the execution of Jess agents thanks to the monitoring facilities that JADE provides.

A recent extension of DCaseLP, discussed in [19], has been the integration of tuProlog [29]. The *choice* of tuProlog was due to two of its features:

1. it is implemented in Java, which makes its integration into JADE easier, and
2. it is very light, which ensures a certain level of efficiency to the prototype.

By extending DCaseLP with tuProlog we have obtained the possibility to execute agents, whose behavior is completely described by a Prolog-like theory, in the JADE platform. For this purpose, we have developed a library of predicates that allow agents specified in tuProlog to access the communication primitives provided by JADE: asynchronous send, asynchronous receive, and blocking receive (with and without timeout). These predicates are mapped onto the corresponding JADE primitives. Two predicates for converting strings into terms and vice-versa are also provided, in order to allow agents to send strings as the content of their messages, and to reason over them as if they were Prolog terms.

A developer who wants to define tuProlog agents and integrate them into JADE can do it without even knowing the details of JADE's functioning. An agent whose behavior is written in tuProlog is, in fact, loaded in JADE as an ordinary agent written in Java. The developer just needs to know how to start JADE.

## 4 Interaction protocols in DyLOG

Logic-based executable agent specification languages have been deeply investigated in the last years [3,16,11,9]. In this section we will briefly recall the main features of DyLOG, by focussing on how the communicative behavior of an agent can be specified and on the form of reasoning supported (details in [9,7]).

DyLOG is a high-level logic programming language for modeling rational agents, based on a modal theory of actions and mental attitudes where *modalities* are used for representing *actions*, while *beliefs* model the agent's internal state. It accounts both for atomic and complex actions, or procedures. Atomic actions are either world actions, affecting the world, or mental actions, i.e. sensing and communicative actions producing new beliefs and then affecting the agent mental state. Complex actions are defined through (possibly recursive) definitions, given by means of Prolog-like clauses and by action operators from dynamic logic, like sequence ";", test "?" and non-deterministic choice "∪". The action theory allows coping with the problem of reasoning about complex actions with incomplete knowledge and in particular to address the temporal projection and planning problem in presence of sensing and communication.

Intuitively, DyLOG allows the specification of rational agents that reason about their own behavior, choose courses of actions conditioned by their mental state and can use sensors and communication for obtaining fresh knowledge. The agent behavior is described by a *domain description*, which includes, besides a specification of the agents initial beliefs, a description of the agent behavior plus a *communication kit* (denoted by $\mathsf{CKit}^{ag_i}$), that encodes its *communicative behavior*. Communication is supported both at the level of *primitive speech acts* and at the level of *interaction protocols*. Thus, the communication kit of an agent $ag_i$ is defined as a triple $(\Pi_{\mathcal{C}}, \Pi_{\mathcal{CP}}, \Pi_{\mathcal{S}get})$: $\Pi_{\mathcal{C}}$ is a set of laws defining precondition and effects of the agent speech acts; $\Pi_{\mathcal{CP}}$ is a set of procedure axioms, specifying a set of interaction protocols, and can be intended as a library of *conversation policies*, that the agent follows when interacting with others; $\Pi_{\mathcal{S}get}$ is a set of sensing axioms for acquiring information by messages reception.

Speech acts are represented as atomic actions with preconditions and effect on $ag_i$'s mental state, of form $\mathsf{speech\_act}(ag_i, ag_j, l)$, where $ag_i$ (sender) and $ag_j$ (receiver) are agents and $l$ (a fluent) is the object of the communication. Effects and preconditions are modeled by a set of effect and precondition laws. We use the modality $\Box$ to denote such laws, i.e. formulas that hold *always*, after every (possibly empty) arbitrary action sequence.

We refer to a mentalistic approach, which is also adopted by the standard FIPA-ACL [14], where communicative actions affect the internal mental state of the agent. Some authors have proposed a *social approach* to agent communication [27], where communicative actions affect the "social state" of the system, rather than the internal states of the agents. The social state records the social facts, like the *permissions* and the *commitments* of the agents, which are created and modified along the interaction. Different approaches enable different types of properties to be proved [18]. For instance the mental approach is not well suited for the verification of an "open" multi-agent system, where the history of

communications is observable, but the internal states of the single agents may not be observable [27]. However, DyLOG is a language for specifying an *individual, communicating agent*, situated in a multi-agent context. In this case it is natural to have access to the agent internal state and we are interested in proving different kind of of properties about communication. Basically, based on a representation of the effects and preconditions of the interactions on the agent mental state, we want to perform *hypothetical reasoning* about the effects of conversations on the agent mental state, in order to find conversation plans which are proved to respect protocols and to achieve some desired goal. Therefore the semantic of the speech acts is specified based on mental states, taking the point of view of the agent. A DyLOG agent has a twofold representation of each a speech act: one holds when it is the sender, the other when it is the receiver. As an example, let us define the semantics of the *inform* speech act within the DyLOG framework:

a) $\Box(\mathcal{B}^{Self} l \wedge \mathcal{B}^{Self}\mathcal{U}^{Other} l \supset \langle \mathsf{inform}(Self, Other, l)\rangle \top)$
b) $\Box([\mathsf{inform}(Self, Other, l)]\mathcal{M}^{Self}\mathcal{B}^{Other} l)$
c) $\Box(\mathcal{B}^{Self}\mathcal{B}^{Other} authority(Self, l) \supset [\mathsf{inform}(Self, Other, l)]\mathcal{B}^{Self}\mathcal{B}^{Other} l)$
d) $\Box(\top \supset \langle \mathsf{inform}(Other, Self, l)\rangle \top)$
e) $\Box([\mathsf{inform}(Other, Self, l)]\mathcal{B}^{Self}\mathcal{B}^{Other} l)$
f) $\Box(\mathcal{B}^{Self} authority(Other, l) \supset [\mathsf{inform}(Other, Self, l)]\mathcal{B}^{Self} l)$

In general, for each action $a$ and agent $ag_i$, $[a^{ag_i}]$ is a universal modalities ($\langle a^{ag_i}\rangle$ is its dual). $[a^{ag_i}]\alpha$ means that $\alpha$ holds after every execution of action $a$ by agent $ag_i$, while $\langle a^{ag_i}\rangle\alpha$ means that there is a possible execution of $a$ (by $ag_i$) after which $\alpha$ holds. Therefore clause (a) states *executability preconditions* for the action $\mathsf{inform}(Self, Other, l)$: it specifies the mental conditions that make the action executable in a state. Intuitively, it states that $Self$ can execute an inform act only if it believes $l$ (we use the modal operator $\mathcal{B}^{ag_i}$ to model the beliefs of agent $ag_i$) and it believes that the receiver ($Other$) does not know $l$. It also considers possible that the receiver will adopt its belief (the modal operator $\mathcal{M}^{ag_i}$ is defined as the dual of $\mathcal{B}^{ag_i}$, intuitively $\mathcal{M}^{ag_i}\varphi$ means the $ag_i$ considers $\varphi$ possible), clause (b), although it cannot be certain about it -autonomy assumption-. If agent $Self$ believes to be considered a trusted *authority* about $l$ by the receiver, it is also confident that $Other$ will adopt its belief, clause (c). Since executability preconditions can be tested only on the $Self$ mental state, when $Self$ is the receiver, the action of informing is considered to be *always* executable (d). When $Self$ is the receiver, the effect of an inform act is that $Self$ will believe that $l$ is believed by the sender ($Other$), clause (e), but $Self$ will adopt $l$ as an own belief only if it thinks that $Other$ is a trusted authority, clause (f).

DyLOG supports also the representation of *interaction protocols* by means of procedures, that build on individual speech acts and specify communication patterns guiding the agent communicative behavior during a protocol-oriented dialogue. Formally, protocols are expressed by means of a collection of procedure axioms of the action logic of the form $\langle p_0\rangle\varphi \subset \langle p_1\rangle\langle p_2\rangle \ldots \langle p_n\rangle\varphi$, where $p_0$ is the procedure name the $p_i$'s can be $i$'s speech acts, special sensing actions

for modeling message reception, test actions (actions of the form $Fs?$, where $Fs$ is conjunction of belief formulas) or procedure names [2]. Each agent has a subjective perception of the communication with other agents; for this reason, given a protocol specification, we have as many procedural representations as the possible roles in the conversation (see example in the next section).

Message reception is modeled as a special kind of sensing action, what we call *get message actions*. Indeed, from the point of view of an individual agent receiving a message can be interpreted as a query for an external input, whose outcome cannot be predicted before the actual execution, thus it seems natural to model it as a special case of sensing. The *get message actions* are defined by means of inclusion axioms, that specify a finite set of (alternative) speech acts expected by the interlocutor.

DyLOG allows reasoning about agents' communicative behavior, by supporting techniques for proving existential properties of the kind "given a protocol and a set of desiderata, is there a specific conversation, respecting the protocol, that also satisfies the desired conditions?". Formally, given a DyLOG domain description $\Pi_{ag_i}$ containing a $\mathsf{CKit}^{ag_i}$ with the specifications of the interaction protocols and of the relevant speech acts, a *planning* activity can be triggered by *existential queries* of the form $\langle p_1\rangle\langle p_2\rangle \ldots \langle p_m\rangle Fs$, where each $p_k$ $(k = 1, \ldots, m)$ may be a primitive speech act or an interaction protocol, executed by our agent, or a get message action (in which our agent plays the role of the receiver). Checking if the query succeeds corresponds to answering to the question "is there an execution of $p_1, \ldots, p_m$ leading to a state where the conjunction of belief formulas $Fs$ holds for agent $ag_i$?". Such an execution is a plan to bring about $Fs$. The procedure definition constrains the search space.

Actions in the plan can be speech acts performed or received by $ag_i$, the latter can be read as the *assumption* that certain messages will be received from the interlocutor. The ability of making assumptions about which message (among those foreseen by the protocol) will be received is necessary in order to actually build the plan. Depending on the task that one has to execute, it may alternatively be necessary to take into account all of the possible alternatives that lead to the goal or just to find one of them. In the former case, the extracted plan will be *conditional*, because for each get_message it will generally contain many branches. Each path in the resulting tree is a linear plan that brings about $Fs$. In the latter case, instead, the plan is linear.

## 5 Integrating DyLOG into DCaseLP to Reason about Communicating Agents

Let us now illustrate, by means of examples, the advantages of adding to the current interaction design tools of DCaseLP the possibility of converting AUML sequence diagrams into a DyLOG program. Figure 2 represents the resulting architecture. DyLOG is placed between the verification and the prototype stage. In

[2] For sake of brevity, sometimes we will write these axioms as $\langle p_0\rangle\varphi \subset \langle p_1; p_2; \ldots; p_n\rangle\varphi$.

fact, being based on computational logic, we can exploit it both as implementation language and for verifying properties. In the first DCaseLP release, AUML

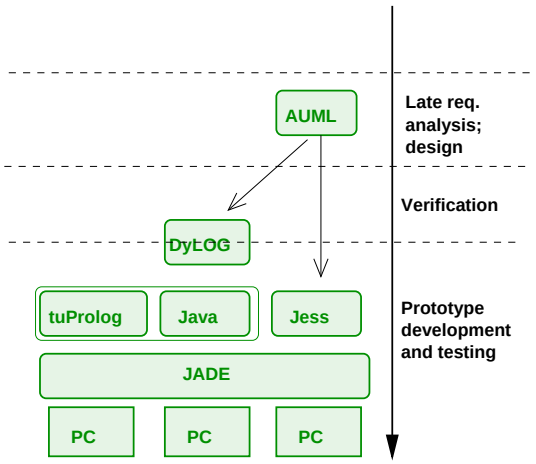


**Fig. 2.** Interating DyLOG into DCaseLP.

interaction protocols could be only translated into Jess code, which could not be formally verified but just executed. The use of DyLOG bears some advantages: on a hand it is possible to automatically verify that a DyLOG implementation is *conformant* to the AUML specification [8], moreover, it is also possible to *verify properties* of the so obtained DyLOG program. Property proof can be carried out using the existing DyLOG interpreter, implemented in Sicstus Prolog [1].

Besides the methodological integration, DyLOG can be also integrated in a *physical way*. The possibility to develop a Java interpreter for DyLOG and to take advantage of some of the mechanisms already provided by tuProlog is currently under evaluation. Once the physical integration will be completed, it will be possible to animate complete DyLOG agents into DCaseLP. This will mean that agents specified in Jess, Java, DyLOG, tuProlog will be able to interact with each other inside a single prototype whose execution will be monitored using JADE.

In the rest of this section, however, we deal with the *methodological integration*. Let us suppose, for instance, to be developing a set of interaction protocols for a restaurant and a cinema that, for promotional reasons, will cooperate in this way: a customer that makes a reservation at the restaurant will get a free ticket for a movie shown by the cinema. By restaurant and cinema we here mean two generic service providers and not a specific restaurant and a specific cinema. In this scenario the same customer will interact with both providers. The devel-

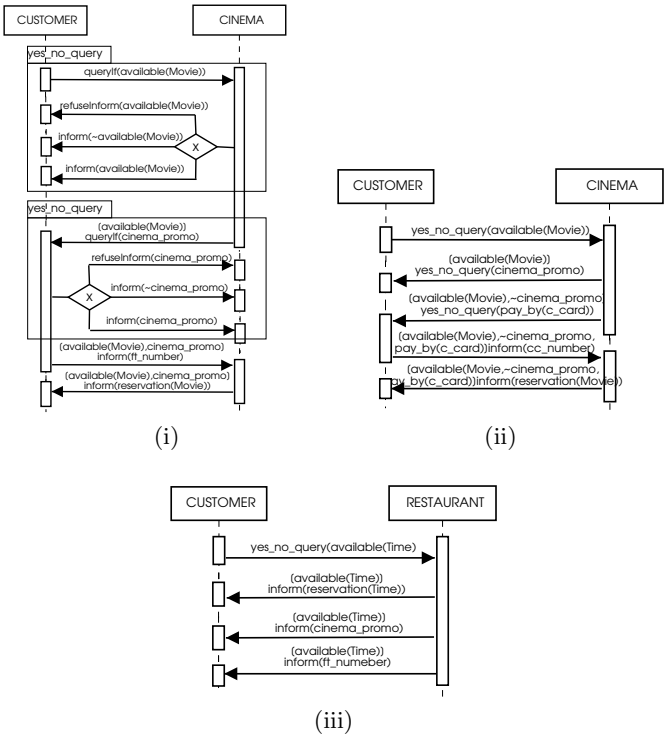


**Fig. 3.** AUML sequence diagrams representing the interactions between customer and provider: (i) and (ii) are followed by the cinema service, (iii) is followed by the restaurant. Formulas in square brackets represent preconditions to speech act execution.

oper must be sure that the customer, by interacting with the composition (by sequentialization) of the two protocols, will obtain what desired. Figure 3 shows an example of AUML protocols, for the two services; (i) and (ii) are followed by the cinema, (iii) by the restaurant. This level of representation does not allow any proof of properties because is lacking of a formal semantics. Supposing that the designed diagrams are correct, the protocols are to be implemented. It is desirable that the correctness of the implementation w.r.t. the AUML specification can be verified. If the protocols are implemented in DyLOG, this can actually be done. In fact, if one restricts to the AUML operators message, alternative, loop, and sub-protocol, described in the new proposal [6], it is possible to produce in an automatic way a *skeleton* of a DyLOG implementation, by translating the sequence diagram in a *grammar*, whose terminal symbols correspond to the set of labels of the message operators in the diagram, and whose *production rules* sketch the *interaction protocol*. Actually, for each protocol we obtain as many procedures as agent roles because of the subjective view, that is characteristic of DyLOG agents. All the conversations that are instances of the skeleton pro-

gram are legal w.r.t. the sequence diagram. Notice that the translation does not produce a full implementation because the sequence diagrams do not define the semantics of the speech acts, which is to be added, as well as an implementation of the tests described by words in the diagram. Nevertheless, the necessary addings will only reduce the number of possible conversations, avoiding to introduce illegal speech act sequences.

Let us describe one possible implementation of the two protocols in a DyLOG program. Each implemented protocol will have two complementary views (customer and provider) but for the sake of brevity, we report only the view of the customer. It is easy to see how the structure of the procedure clauses corresponds to the sequence of AUML operators in the sequence diagrams. The subscripts next to the protocol names are a writing convention for representing the role that the agent plays; so, for instance, $Q$ stands for *querier*, and $C$ for *customer*. The customer view of the restaurant protocol is the following:

(a) $\langle \mathsf{reserv\_rest}_C(Self, Service, Time)\rangle\varphi \subset$
$\langle \mathsf{yes\_no\_query}_Q(Self, Service, available(Time))$ ;
$\mathcal{B}^{Self} available(Time)?$ ;
$\mathsf{get\_info}(Self, Service, reservation(Time))$ ;
$\mathsf{get\_info}(Self, Service, cinema\_promo)$ ;
$\mathsf{get\_info}(Self, Service, ft\_number)\rangle\varphi$

(b) $[\mathsf{get\_info}(Self, Service, Fluent)]\varphi \subset [\mathsf{inform}(Service, Self, Fluent)]\varphi$

Procedure (a) is the protocol procedure: the customer asks if a table is available at a certain time, if so, the restaurant informs it that a reservation has been taken and that it gained a promotional free ticket for a cinema ($cinema\_promo$), whose code number ($ft\_number$) is returned. Clause (b) shows how get_info can be implemented as an inform act executed by the service and having as recipient the customer. The question mark amounts to check the value of a fluent in the current state; the semicolon is the sequencing operator of two actions. The cinema protocol, instead, is:

(c) $\langle \mathsf{reserv\_cinema}_C(Self, Service, Movie)\rangle\varphi \subset$
$\langle \mathsf{yes\_no\_query}_Q(Self, Service, available(Movie))$ ;
$\mathcal{B}^{Self} available(Movie)?$ ;
$\mathsf{yes\_no\_query}_I(Self, Service, cinema\_promo)$ ;
$\neg\mathcal{B}^{Self} cinema\_promo?$ ;
$\mathsf{yes\_no\_query}_I(Self, Service, pay\_by(c\_card))$ ;
$\mathcal{B}^{Self} pay\_by(c\_card)?$ ;
$\mathsf{inform}(Self, Service, cc\_number)$ ;
$\mathsf{get\_info}(Self, Service, reservation(Movie))\rangle\varphi$

(d) $\langle \mathsf{reserv\_cinema}_C(Self, Service, Movie)\rangle\varphi \subset$
$\langle \mathsf{yes\_no\_query}_Q(Self, Service, available(Movie))$ ;
$\mathcal{B}^{Self} available(Movie)?$ ;
$\mathsf{yes\_no\_query}_I(Self, Service, cinema\_promo)$ ;
$\mathcal{B}^{Self} cinema\_promo?$ ;
$\mathsf{inform}(Self, Service, ft\_number)$ ;
$\mathsf{get\_info}(Self, Service, reservation(Movie))\rangle\varphi$

Supposing that the desired movie is available, the cinema alternatively accepts credit card payments (c) or promotional tickets (d). *We can verify if the two implementations can be composed with the desired effect*, by using the reasoning mechanisms embedded in the language and answering to the query:

$\langle \mathsf{reserv\_rest}_C(customer, restaurant, dinner)$ ;
$\mathsf{reserv\_cinema}_C(customer, cinema, movie)\rangle$
$(\mathcal{B}^{customer} cinema\_promo \wedge \mathcal{B}^{customer} reservation(dinner) \wedge$
$\mathcal{B}^{customer} reservation(movie) \wedge \mathcal{B}^{customer} \mathcal{B}^{cinema} ft\_number)$

This query amounts to determine if it is possible to compose the interaction so to reserve a table for dinner ($\mathcal{B}^{customer} reservation(dinner)$) and to book a ticket for the movie *movie* ($\mathcal{B}^{customer} reservation(movie)$), exploiting a promotion ($\mathcal{B}^{customer} cinema\_promo$). The obtained free ticket is to be spent ($\mathcal{B}^{customer}$ $\mathcal{B}^{cinema}$ $ft\_number$), i.e. *customer* believes that after the conversation the chosen cinema will know the number of the ticket given by the selected restaurant. If the customer has neither a reservation for dinner nor one for the cinema or a free ticket, the query succeeds, returning the following linear plan:

$\mathsf{queryIf}(customer, restaurant, available(dinner))$ ;
$\boxed{\mathsf{inform}(restaurant, customer, available(dinner))\ ;}$
$\mathsf{inform}(restaurant, customer, reservation(dinner))$ ;
$\mathsf{inform}(restaurant, customer, cinema\_promo)$ ;
$\mathsf{inform}(restaurant, customer, ft\_number)$ ;
$\mathsf{queryIf}(customer, cinema, available(movie))$ ;
$\boxed{\mathsf{inform}(cinema, customer, available(movie))\ ;}$
$\mathsf{queryIf}(cinema, customer, cinema\_promo)$ ;
$\mathsf{inform}(customer, cinema, cinema\_promo)$ ;
$\mathsf{inform}(customer, cinema, ft\_number)$ ;
$\mathsf{inform}(cinema, customer, reservation(movie))$

This means that there is first a conversation between *customer* and *restaurant* and, then, a conversation between *customer* and *cinema*, that are instances of the respective conversation protocols, after which the desired condition holds. The linear plan, will, actually lead to the desired goal given that some *assumptions* about the provider's answers hold. In the above plan, assumptions have been outlined with a box. For instance, an assumption for reserving a seat at a cinema is that there is a free seat, a fact that can be known only at execution time. Assumptions occur when the interlocutor can respond in different ways depending on its internal state. It is not possible to know in this phase which the answer will be, but since the set of the possible answers is given by the protocol, it is possible to identify the subset that leads to the goal. In the example they are answers foreseen by a yes_no_query protocol (see Figure 3 (i) and [7]). Returning such assumptions to the designer is also very important to understand the correctness of the implementation also with respect to the chosen speech act ontology.

Using DyLOG as an implementation language is useful also for other purposes. For instance, if a library of protocol implementations is available, a designer might will to search for one that fits the requirements of some new project.

Let us suppose, for instance, that the developer must design a protocol for a restaurant where a reservation can be made, not necessarily using a credit card. The developer will, then, search the library of available protocol implementations, looking for one that satisfies this request. Given that *search_service* is a procedure for searching in a library for a given category of protocol, a protocol fits the request if there is at least one conversation generated by it after which $\neg\mathcal{B}^{service} cc\_number$; such a conversation can be found by answering to the existential query:

$$\langle search\_service(restaurant, Protocol)\ ;\ Protocol(customer, service, time)\rangle \\ (\mathcal{B}^{customer}\neg\mathcal{B}^{service} cc\_number \wedge \mathcal{B}^{customer} reservation(time))$$

which means: find a protocol with at least one execution after which the customer is sure that the provider does not know his/her credit card number and a reservation has been taken.

## 6 Conclusions and future work

In this paper we have discussed the methodological and physical integration of DyLOG into DCaseLP in order to reason about communication protocols. A methodology for semi-automatically generating a DyLOG implementation from a AUML sequence diagram is described in a similar way as it has been done for the AUML → Jess translation [4]. Such an integration allows to support the MAS developer in many ways. In fact, by means of this integration we add to DCaseLP the ability of reasoning about the properties of the interactions that occur among agents before they actually occur, during the design phase of the MAS; this feature is not offered by DCaseLP (without DyLOG) since protocols can only be translated into Jess code and executed. The ability of reasoning about possible interactions is very useful in many practical tasks. In this paper we have shown a couple of examples of use: selection of already developed protocols from a library and verification of compositional properties. It would be also interesting to use formal methods for proving other kind of properties of the interaction protocols. We mean to study the application of other techniques derived from the area of logic-based protocol verification [17] where the problem of proving universal properties of interaction protocols (i.e. properties that hold after every possible execution of the protocol) is faced. Such techniques could be exploited to perform the *validation stage* [21] in order to check the coherence of the AUML description with the specifications derived from the analysis. This is usually done by defining a model of the protocol (AUML) and expressing the specification by a temporal logic formula; thus model checking techniques test if the model satisfyies the temporal logic formula.

The physical integration is in progress; in particular, we are implementing a new DyLOG interpreter in Java (inspired by tuProlog) that will be used in DCaseLP also as an implementation language for the definition of agents, in the same way as Jess and (recently) tuProlog are currently used.

**Acknowledgement**

This research is partially supported by MIUR Cofin 2003 "Logic-based development and verification of multi-agent systems" national project.

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