

Experiencing AUML for the WINK Multi-Agent System

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Abstract—In the last few years, efforts have been done towards bridging the gap between agent technology and de facto standard technologies, aiming at introducing multi-agent systems in industrial applications. This paper presents an experience done by using one of such proposals, *Agent UML*. *Agent UML* is a graphical modelling language based on *UML*. The practical usage of this notation has brought to suggest some refinements of the *Agent UML* features.

I. INTRODUCTION

In the last decade agent technology has been a mainstream research area. Though many relevant advancements and results have been achieved in the field, multi-agent systems have not become widespread as industrial and commercial applications. Recently, some efforts have been done towards bridging the gap between agent technology and methodologies or technologies accepted for real world applications. These aim at relating multi-agent systems to practical standards in order to leverage on existing knowledge and tools. Opening agent technology to industry means proposing the new technology as "an incremental extension" [3] of proven practices.

It is the case of object-oriented software design and development, which relies on well-established and trusted methods. One of these is the Unified Modelling Language (*UML*) [6], a widely accepted notation for designing software systems according to the object-oriented paradigm. Extensions to *UML* to fit in notions related to software agents and multi-agent systems have been proposed [1], [2], [3], [11], [12]. Thanks to a cooperation between the *Foundation of Intelligent Physical Agents (FIPA)*, www.fipa.org) and the *Object Management Group (OMG)*, www.omg.org) these extensions have been coherently collected and known as *Agent UML (AUML)*, www.auml.org).

In this paper, we present our experience about applying *AUML* diagrams to design a real world application. The use case is given by the system developed in the *WINK* European project (Web-linked Integration of Network based Knowledge IST-2000-28221). For the scope of the paper, we will focus on the subsystem charged of keeping the system data up-to-date. Our experience has lead to some observations on the suitability and usefulness of the proposed extensions, together with some suggestions for further improvements.

Throughout the paper, we refer to *AUML* as the set of working drafts available on the *AUML* web-site and on the

published scientific papers on *AUML* [2], [3], [11], [12]. As the status of the specifications is not stable, these contributions show some degree of dissimilarity. Whenever required by the context, we will point out which of the aforementioned contributions we refer to. Further, while reporting on our experience, we will highlight the extensions we have found useful for our work. For the sake of plainness, all proposed extensions are also summarized in Section VI.

The paper is structured as follows. In Section II, we set the background for our work. Section III provides a basic understanding of the *WINK* system while Section IV presents the high-level requirements related to our use case subsystem. Section V reports the application of *AUML* to the conceptual and implementation design of our use case. Finally, conclusions are drawn in Section VI.

II. BACKGROUND

Research on agent-based software development has been a very important discipline for agent technology. In the last few years a number of methods have been proposed to the scientific community. The field is characterized by a variety of approaches, surveyed in [13]. Some recent methodologies are most interesting to us. The *Gaia* methodology [17] proposes to break the process in an analysis stage and a design stage. In both stages, designers are required to deal with models (roles model and interaction model for the analysis stage and agent model, services model and acquaintance model for the design stage). This way, designers and developers are progressively guided through specifying more and more details about the application and the system, being encouraged to follow a process based on organizational design. The *Tropos* methodology [10] is based on two features: the notions of agent, goal, plan and other agent related concepts are coherently used throughout the process and requirements analysis and specification are an essential part of the methodology. At the core of the methodology there is the *Tropos* Modelling Language which is based on a metamodel and is conceived as an extensible language. Commonalities between the two methodologies are:

- they distinguish a conceptual and an implementation or development phase during the overall process;
- they use different models to catch different views of the system-to-be. These views concerns the following

aspects of *agenthood*: agents, environments, interactions and organizations;

- they support not only agent-based systems, but are aware that real applications envisage a blend of object-oriented services and agent technology.

These features are also present in *AUML*, a graphical modelling language. The first moves towards *AUML* have been made by Odell et al. [14]. *UML* Class diagrams have been revisited in [2] and further extended in [11]. While Bauer et al. proposed a base form of Class Diagrams, Huget gave a precise semantics to the relationships intercurring between agents and between agents and objects. Huget further redefined the compartments of a Class Diagram taking a Vowel [7]-based approach. *UML* Sequence and State diagrams have been initially extended in [1]. This has brought to the definition of a new Class of Diagrams, called Protocol Diagrams. Bauer et al. included in Protocol Diagrams agent roles, threads of interactions, nested and interleaved protocols and protocol templates. Protocol Diagrams have been subsequently refined in [12]. To the basic set of primitives, Huget added new features such as broadcasting, synchronization, triggering actions, exception handling, time management, atomic transactions and repeated messages, leveraging on his experience in the domain of reliability, electronic commerce and supply-chain management.

III. WINK OVERVIEW

The *WINK* project [4] aims at supporting large-scale multi-supplier and multi-site projects, usually known as one-of-a-kind production. The *WINK* system implements a so-called integration network process model that helps managers plan and monitor all aspects related to project management such as personnel, resources, planning, exception handling and budgeting. The main features of the *WINK* system are:

- advanced planning and budgeting functionalities, which lead to better forecasting, reducing re-planning overheads during the execution of the projects;
- alert-based activity monitoring, which reduces cost and risk assessment;
- management of contingent factors, including pro-active analysis of deterministic and casual risk factors, re-planning to face deviations, impact verification and solution comparison, re-alignment of plans and budgets for the involved project units, change-tracking mechanisms for revision evaluations;
- full exploitation of the network potential, by describing its resources, competencies and operating processes, and speeding up and automating information processes during the entire project life cycle, spanning companies and organizational unit boundaries.

From an architectural viewpoint, the *WINK* project aims at combining two existing systems, the Gruppo Formula's *WHALES* and the *MIKS* [5] from University of Modena and Reggio Emilia. The goal is to compose an architecture that leverages the strength of both systems. Figure 1 depicts the

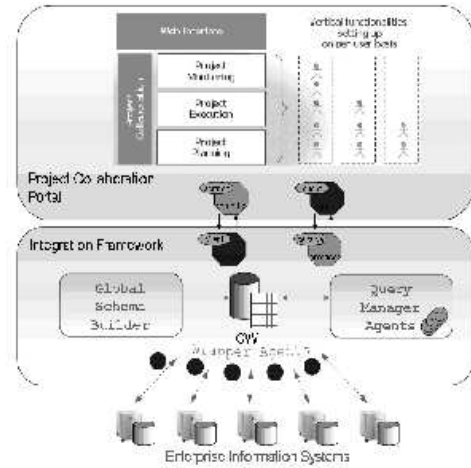


Fig. 1. The overall *WINK* system architecture

resulting three-tier model: The *WINK* architecture (Figure 1) is based on a three-tier model where the client tier makes available a Virtual Integrated Cockpit on which information is collected and presented as a customized web interface, the data tier manages the interactions with the data provided by the Enterprise Information Systems, and the business logic tier combines the capabilities of two separated modules: the *Project Collaboration Portal* and the *Integration Framework*. In particular, the first module supports the definition of business logic for the monitoring, the execution and the planning of a project. The *Integration Framework* provides a global virtual view representing all the sources and an engine, based on agent technology, to query distributed data sources. We observe that all the *WINK* tiers may be distributed on the net and have to communicate with each other.

IV. SYSTEM REQUIREMENTS

The multi-agent subsystem we consider in this paper is charged of supporting the execution of tasks that involve functionalities of both the *WHALES* and the *MIKS* systems. We can also see the subsystem as an application integration module as it enhances the interoperability between the two existing systems. From an operative perspective the subsystem should function as follows. The *WINK* users interact with a web interface. Whenever new data have to be retrieved, users are presented an *Interface Module* (that can be rendered for instance by means of a dynamic web page by the *Project Collaboration Portal*) where they can compose the query to be submitted. Once the query is ready and submitted, the *Interface Module* invokes an appropriate web service, which acts upon the *WINK Agency* in order to activate the agents that will be charged of the query execution and result delivery. The query to be executed is handed on to a *Service Agent* together with the notification the query has to be executed on a regular basis. The *Service Agent* exploits the *GVP* to know which data sources are involved by the posed query. According to this mapping and to the contingent system workload, the *Service Agent* will contact a number of *Query Agents*. At this stage,

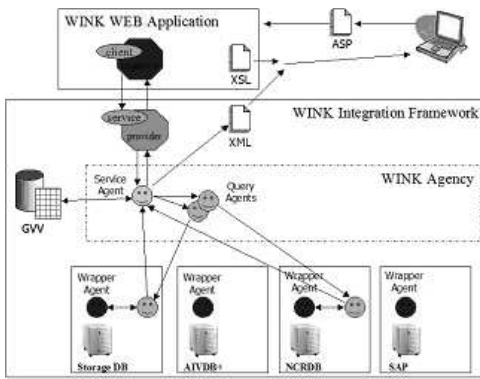


Fig. 2. Our reference subsystem

a *Query Agent* will move to the data source(s)/container(s) the query refers to, will interact with *Wrapper Agents* in order to execute the local query(ies) and finally will report the answer to the calling *Service Agent*. In order to deliver results so as to update the correct information, *Service Agents* have been implemented in order to report query answers in the desired format (in our case, an *XML* format). The calling *Interface Module* will then apply the desired *XSL* stylesheet to present data on the *WINK* web interface. Figure 2 depicts this scenario, where the *Interface Module* is relieved by an *ASP* page:

V. APPLICATION OF AGENT UML DIAGRAMS

In this section we report our experience in using *AUML* Class and Protocol Diagrams. We first present the conceptual level of abstraction and then the implementation view.

A. Class Diagrams: Conceptual Level

The conceptual level of design is intended to provide an overview of the system, representing the different agents and classes that compose it and the relationships intercurring among these entities. The fact that both agents and classes can be described and interrelated using a uniform notation is a step towards the understanding of complex systems as composed by a blend of object-oriented and *MAS* technology. We find this is a very realistic approach to industrial and commercial applications.

AUML notation extends the *UML* notation. Besides classes, we distinguish of course agents, identified by the stereotype `<<agent>>`. Besides the *UML* relationships association, generalization, aggregation and dependency defined between classes, the same set of relationships has been proposed in [12] for agent-agent and agent-class relationships, giving them a semantics under the light of agent properties. According to Huget, the meaning of the relationships that can be applied between agents can be summarized as follows:

- association: the linked agent are acquainted and can exchange messages;
- generalization: the definition of an agent can be derived from other agents;

- aggregation: an agent is aggregate of another if it has a recursive architecture;
- dependency: it is a mutual dependency between the linked agents.

Huget states also the meaning of the relationships that can be applied between an agent and a class:

- association: the agent uses the connected classes for their execution;
- generalization: not possible;
- aggregation: the agent is defined as an aggregation of several classes;
- dependency: the agent needs the class either in its code or during its execution.

For the graphical notation associated to these relationships see [11].

Although we find this semantics well-defined, there is room for some observations. Let us consider the association relationship between agents. Looking at Figure 2 above, it could be the case of the *Query Agent* and the *Wrapper Agent* that are to be considered acquainted and can exchange messages. We find this view is not properly correct. We should note that the *Query Agent* relies upon the *Wrapper Agent* in order to deliver the result to the *Service Agent*. The relationship is not only of acquaintance (the *Query Agent* knows which *Wrapper Agent* to contact and consequently, the *Wrapper Agent* knows the *Query Agent* which started the conversation), but there is a sort of cooperation between the two. How to capture this aspect using *AUML* class diagram is not yet clear to us. For the time being, the only way we have found is to consider the relationship as a dependency. We claim this is not generally suitable, as cooperation and coordination are different from dependency.

Consider now the possible relationships between an agent and a class. We claim using classes has to be considered as a general case. In order to give a finer semantics, we suggest to extend the definition proposed in [Hug02a] by distinguishing classes into *service classes* (or simply services) and *behavior classes* (or simply behaviors). Following our proposal, the meaning of the diverse type of relationships has to be anew stated as follows (we paraphrase Huget's definition to underline the change in meaning):

- association: the association relationship connects an agent to the service classes it exploits. It means that this agent uses the connected service classes for their execution;
- aggregation: the aggregation between agents and behavior classes implies that agents are defined as an aggregation of several behaviors, i.e. an agent can show the set of connected behaviors (no matter whether they are statically or dynamically acquired). Agents usually comprise several parts such as a reasoning side, an interaction side and a perception side: they can all be seen as an agent acquiring some behavior class (for reasoning, interacting, perceiving);
- dependency: the dependency between agents and service classes is possible and means that one agent needs the

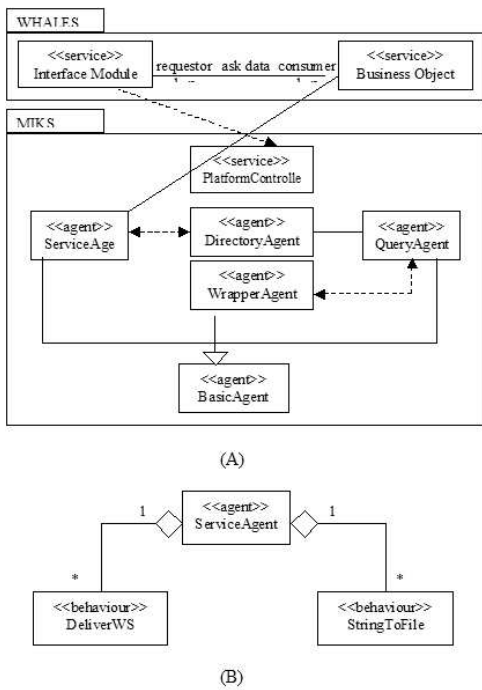


Fig. 3. Conceptual level of our scenario

services during its execution since the agent would possibly exploit the service execution. A dependency between agents and behavior classes is also possible, but it would have the same semantics as aggregation.

It follows that, at least for the classes that are connected to some agent, we should specify their type. For this purpose, we have introduced the stereotypes `<<service>>` and `<<behaviour>>`. Figure 3 depicts the Class Diagram for our use case scenario. It concerns the conceptual level of our design since no details about attributes or operations are given. We have used packages to organize objects into groups as defined in *UML* [6].

In part (A) we can recognize the following:

- class-class associations: in the *WHALES* package we can navigate between the *Interface Module* service and the *Business Object* service as there is a relationship concerning the data that have to be used and asked for;
- class-class dependency: it is a unilateral dependency. A change in the specification of the *Platform Controller* service may affect methods that are used by the *Interface Module* service;
- agent-class association: the *Service Agent* uses the connected *Business Object* service for manipulating the data on the *WHALES* server, not otherwise accessible;
- agent-agent dependency: the pairs *Service Agent* - *Directory Agent* and *Query Agent* - *Wrapper Agent* are formed by agents that are somehow dependent on each other. The *Service Agent* asks for available agents which match some properties to the *Directory Agent*. The *Query Agent* exploits the *Wrapper Agent* for managing connection

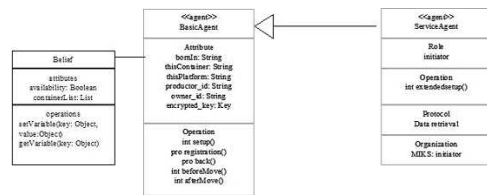


Fig. 4. Implementation level of our scenario

- details to data sources, passing the query to be executed;
- agent-agent association: the *Directory Agent* and the *Query Agent* can exchange messages as a *Query Agent* must register to the *Directory Agent* when it is started;
- agent-agent generalization: the *Basic Agent* collects all common features an agent in the *MIKS* system must have.

Part (A) gives a first overview of the subsystem. The conceptual level design can be further refined, starting from the relationships established in part (A) and focusing on smaller parts of the subsystem. For instance, a *Service Agent* should be capable of calling external services and communicating with other agents. We can thus draw a Class Diagram which models these features, still remaining at a conceptual level of abstraction (no details on operations and variables are given). Part (B) gives a first insight on the *Service Agent*. It is an aggregate of a set of behaviors (for communicating with external services, for storing data, for communicating). Part (A) and (B) can be obviously combined in one single diagram.

B. Class diagrams: Implementation level

This level of abstraction develops the implementation phase. Details have to be fully specified. In general, in order to provide a comprehensive view of a system involving agents, we have to specify facts about the architecture of agents and their features, the interactions that can happen among them, the environment that supports their execution and how they can organize or be organized as a community. This concepts or a subset of them can be found in a number of proposed methodologies [Woo00, Giu02]. These methodologies help designers focussing on the following aspects of *agenthood*:

- the agency view, which deals with agent's knowledge, belief, intentions, plans and behaviors;
- the environmental view, which models how agents react to external changes;
- the interactional view, where interaction protocols are specified;
- the organizational view, which gives details on organizations to which an agent belongs.

Taking into consideration the use case of the *Service Agent* and the *Basic Agent*, we obtain the following Class Diagram (Figure 4):

From the conceptual level we know the *Service Agent* and the *Basic Agent* are linked with a generalization relationship. As the *Basic Agent* is a sort of template for all other agents

we use, only the needed compartments are present, specifying the attributes and operations (internal, pro-active and reactive) shared by all agents in the subsystem. We have followed Huget's proposal of storing beliefs, desires, intentions and goals as objects. We have chosen to model this *BDI* information using one class for each type of information. All classes share a common architecture. Variables are stored in tables (just like Sun's Java *HashTable* objects) over which at least four operations must be present: two for adding or deleting variables and two for setting or getting the value of a specified variable. We can possibly add operations that impact on the value of the attributes, producing intelligent beliefs (pro-active and reactive according to the type of operations). This approach allows an agent to store variables of standard data types (integers, strings, and so forth) and also variables that synthesize in complex objects (such as for our example a list of visited containers).

For the *Service Agent* we have done the same, considering it inherits from the *Basic Agent*. Note that we have specified the *Service Agent* takes part to an interaction protocol named *Data Retrieval*. Coherently, we have reported the role the *Service Agent* plays in this interaction protocol (initiator). The protocol is started whenever the initiator wants to retrieve updated data. This role is played by the *Service Agent* while it participates to the *MIKS* agent society (or organization). The *Data Retrieval* protocol is to be defined outside of the Class Diagram in what has been called Protocol Diagrams [3]. This allows for a modular design.

One remark concerns the *capabilities* compartment and the *service lollipops* proposed in [11] for the organizational view. The *capabilities* compartment should contain a free-format textual description of what agents are able to do. "These capabilities are derived as services to agents" as Huget writes. We have not used this compartment and external services as we have already reported in the diagrams the behavior classes exploited by our agents. We understand behavior classes as specifying the capabilities of the agents as operations (or sub-behaviors). Thus, considering we have introduced the notion of behavior classes, our suggestion is to omit the *capabilities* compartment and *service lollipops*, producing a more compact notation.

1) *Interactional View*: In this subsection we present how the agents interact relying on the expressive power of *AUML* protocol diagrams. Agent interaction protocols precise communication patterns. The basics of *AUML* protocol diagrams can be found in [Bau01b]. The notions encompassed in *AUML* protocol diagrams are the followings:

- agents and their roles: agents have (a) an identity, i.e. they are instances of some entity and play one or more roles. We have a box for each instance and for each role this instance plays in the protocol;
- agent lifelines: these are graphical elements that state an agent/role is active within a protocol;
- connectors: alternatives and choices in the protocol are expressed through three logical connectors that correspond to AND, OR and XOR options;

- conditions: these are conditions on sending messages;
- cardinality: expresses multicast messages;
- type of message: messages can be sent asynchronously or synchronously;
- repetition: tells how many times a message should be sent;
- nested protocols: as protocols can be reused, we can nest protocols within other ones;
- interleaved protocols: as protocols can be reused, we can break the execution of a protocol executing another one and then getting back to executing the first.

We also consider the extensions proposed in [Hug02b]. These are:

- broadcast: messages can be sent to all agents in the environment;
- synchronization: allows to define a meeting point during the interaction;
- triggering actions: actions that take place when particular conditions are met;
- exception management: allows to get rid of abnormal situation or environmental problems;
- time management: we can express deadlines on the overall interaction or specify delays between messages in the protocol;
- atomic transaction: all messages in the protocol must be sent respecting all specified constraints (deadlines, delays, conditions and so forth) as one single failure implies the other messages must be cancelled and partial results rolled back;
- sending messages until delivery: a message of this type has to be sent until acknowledged by the receiver.

In order to obtain the system functionalities as explained in Section IV, we have to further refine our requirements. First, we note that the process of data retrieving and updating should be configured as one atomic transaction. Then, we specify that the transaction consists in a sequence of operations and message exchanges. The *Service Agent* charged of starting the interaction contacts the *Directory Agent* to know the identity of the *Query Agents* that can possibly help it. The strategy is to use the *FIPA Recruiting Interaction Protocol* [8] as a matchmaking service [16]. Once, they have been identified, they are involved in the interaction and asked to execute a query. A *Query Agent* depends on *Wrapper Agents* for querying the required data sources. Figure 5 depicts the Protocol Diagram. Through the *proxy* performative, the *Service Agent* makes the *Directory Agent* contact only those agents that satisfy the given properties. When the *Directory Agent* sends its multicast message, the resulting semantics of this multicast is not the same as the one of a normal multicast, since the message is sent to agents selected for holding certain given properties. We find this has to be possible independently from the particular interaction protocol to be executed. Huget's definition of multicast does not allow to express this situation. There is a need for further extending Protocol Diagrams. We propose to introduce *selective*

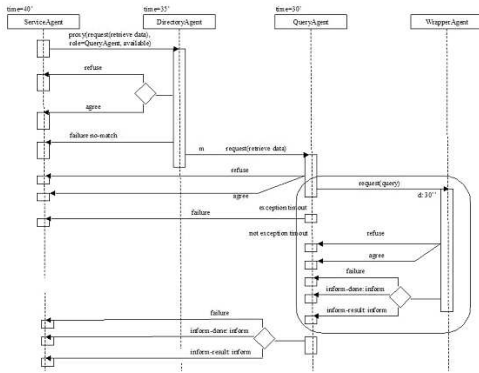


Fig. 5. The *Data Retrieval* protocol diagram. The frame underlines this is an atomic transaction

multicast messages. A selective multicast message is to be directed to a subset of agents that share some specific properties (that have been advertised or communicated upon request). The shared properties are given inside curly brackets (just like conditions are).

Once we have a set of *Query Agents*, the sub-protocol required by the proxy performative is started. In our case, it is a *FIPA Request interaction protocol* [9]. The sub-protocol execution is interleaved with another *FIPA Request Interaction protocol* that involves a *Query Agent* and a *Wrapper Agent*.

Our application requirements implicitly foresee time constraints. If Alenia's managers want to have a usable tool at hand, the whole system has to hold consistent and updated data. Starting from Huget's time management concepts, we have refined the semantics of deadlines and delays. We have assigned deadlines on interactions and named such deadlines *interaction deadlines*. We intend an interaction deadline as the minimal expected performance given the usage and the operative requirements of the system. A finer grained control over time is given by *time constraints*, that are specified as delays inside parentheses. Our experience has showed us that it is rather dangerous (and apparently meaningless) setting time constraints and not catching the corresponding timeout exceptions, as this could lead to undetermined sequences or deadlock situations. It is the case of the first request message sent by a *Query Agent* to a *Wrapper Agent*.

VI. CONCLUSION

We have shown a small and realistic example of a multi-agent system designed using *AUML*, starting from high-level requirements and specifying step by step the details till drawing an implementation view. The drawn *AUML* Diagrams will be included in the deliverables of the *WINK* project.

The choice of *AUML* has revealed a valuable help in shaping concepts related to agent technology and in expressing them in a graphical notation with a defined semantics. We have found it a clear improvement towards understanding the nature of multi-agent systems and how they combine with other

(eventually pre-existing) technologies. Following the *AUML* notation, we have been forced to reason in terms of agents and their properties, rather than narrowing our understanding of the system to traditional objects as we used to. Having a systematic approach to the agent paradigm has allowed us to analyze more in depth the overall system properties.

Nevertheless, there is room for improvements and refinements. Our experience has brought to the following suggestions for extending *AUML*:

- the concept of classes should be refined distinguishing between service classes and behavior classes. Service classes represent services that agents use for their execution. Behavior classes can be aggregated to shape agent's capabilities;
- as a consequence we could drop off the capability compartment and the service lollipops from Class Diagrams, as agent's capabilities are specified by using behavior classes;
- *AUML* should include, besides multicast and broadcast messages, the feature of selective multicast message where a message is sent to a group of agents sharing some given property;
- time management should be split into interaction deadlines, whose scope is a whole interaction (or a sub-interaction), and time constraints, which have a finer-grained scope concerning delays between messages;
- finally, some work should be done for clarifying the concepts of dependency versus cooperation and dependency versus coordination.

What really lacks when working with *AUML* are development tools that support the graphical representation and the translation into code. Future work could possibly be spent for writing plug-in modules to add *AUML* notation to existing *IDE* such as the open source *NetBeans* project promoted by Sun or the *Eclipse* platform promoted by IBM.

In our exercise, we have not tackled the design of the system topology. A proposal for Configuration and Deployment Diagrams has been done in [15]. In further work, we will consider these aspects, trying to test the expressiveness of the proposal. In future work, we will investigate Class and Protocol Diagrams, extending our experience to the overall *WINK* system. The purpose is to contribute to the definition of a reliable and fine semantics for *AUML*.

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