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AGENT TECHNOLOGY APPLIED TO INFORMATION SYSTEMS

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To my friends Gianni and Meris

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TABLE OF CONTENTS

1. INTRODUCTION

Software agents represent the ultimate idea of artificial intelligence. For many years now computer engineers and scientists have drawn attention to define how software agents may be useful for tackling issues concerning intelligent and pervasive computer systems. Despite the soundness of the theoretical results presented in literature, software agents have not yet entered mainstream technology.

Some share the belief that there basically exists a lack of tools intended to support designers and programmers in building systems based on software agents. This inspired the present work and brought to a less theoretical and more practical approach to the topic because of the urgency of providing tools and experiences of applied agent technology.

The thesis is thus divided into three parts. In the first one, software agents are presented and critically compared to other mainstream technologies. We also discuss modeling issues. In the second part, some example systems where we applied agent technology are presented and the solution is discussed. The realistic scenarios and requirements for the systems were provided by the WINK and SEWASIE projects. The third part presents a logical framework for characterizing the interaction of software agents in virtual societies where they may act as representatives of humans.

The contribution of the thesis has been twofold. First, facing the problem of implementing systems, we started to define tools through which agent technology could be effectively applied. This has been the case for instance for Agent UML and the logical framework presented in chapter 6. Second, we adopted technologies developed by others and this served as testing activity for ongoing efforts. It is the case of JADE, the Java Agent Development Environment, developed by Telecom

Italia Lab located in Turin, that was used to implement the multi-agent systems for the WINK and SEWASIE projects.

Part I

Sofware agents and agent technology

2. SOFTWARE AGENTS

The concept of agent represents a milestone in the thinking of computer science. The genesis of such a concept can be tracked down to a number of disciplines among which a prominent contribution has been derived from artificial intelligence. Agents are basically intelligent entities. Intelligent as they show behaviors in which they make *rational* choices. Entities as they are artifact of human endeavor. We distinguish two coarse categories of agents. The first one comprises robots, intended as entities having an hardware body and executing in the real world. The second comprises software agents, the purely software counterpart of robots. The main dissimilarity between the two concerns the environment they experience, how they sense it and what actions they can undertake to change the state of the environment. On one side we have a physical world with its mechanical laws, on the other a logical one, built on top of operating systems and networks. Usually to build robots we have to solve problems like vision, motion control, live speech, physical sensing and human-like interfaces. To program software agents, we need visual interfaces, distributed computer architectures and IT security. Both have to face issues such as high-level communication, distributed planning, cooperation and negotiation, though they may find different forms of application. The commonality is that both pull towards making a system (no matter if hardware or software or hybrid) *more* intelligent, more suitable to serve human or human-like purposes. With this respect they are complementary to the goal of producing artificial intelligent artifacts: these artifacts will have two dimensions, one related to their physical presence in the world, the other related to the exploitation of the advantages an infrastructure such as computer networks offers. We will focus here on software agents.

2.1 Defining software agents

As they are the object of the present work, we will give a characterization of their properties. The need for a specification arises from the fact that, being agents and software agents one of the main objects of study of artificial intelligence, as AI has become more and more interdisciplinary, agents have been applied to a wide spectrum of fields, assuming from time to time slightly different connotations. At present, there is no commonly accepted definition of agent, although many share some points.

In [RN03], a classical reading in AI, the authors define an agent as an "entity that perceives and acts", "a function from percept histories to actions". On the same line of discourse is the definition by Hayes-Roth [HR95], "intelligent agents continuously perform three functions: perception of dynamic conditions in the environment; action to affect conditions in the environment; and reasoning to interpret perceptions, solve problems, draw interfaces, and determine actions".

The most evident feature of agents lies in that they are supposed *to activate* their capabilities (reasoning or acting for instance), i.e. *to act* without the control of external entities [Mae95, OPB00]. Upon request, they can deny execution or, even in the case no external request has arrived, they can undertake actions. Autonomy appears thus as a key feature of agents. The concept can be approached by different perspectives.

We can take for instance a knowledge perspective. In [RN03], the authors state that "[a rational agent] should learn what it can to compensate for partial or incorrect prior knowledge". This view encompasses that, when built, an agent is provided with some knowledge and the capability to evolve it, learning from its experience. The agent will then refine its knowledge and, at a certain time in its life, it may even have deeply changed its behaviour, so that we can hardly find any hint of the original behavior. If this is the case, the agent's knowledge has become "independent" from its original state. This view emphasizes *how* agents reason about things. The actions of the agent can be even decided by an external entity, but how it executes them is not directly controllable, responding to an internal, possibly intelligent thread of control. The result is that such agents can become flexible enough to face the different situations that can happen in their environment. An example is represented by an expert system which provides on-demand medical consultancy, whose knowledge grows as cases are faced and whose decision-making algorithms varies according to the patient's medical history.

Numerous contributions seem to consider autonomy under a different light, that of deliberative choice of actions. The agent, once activated and initially instructed, has its own thread of control and can decide if an action has to be undertaken by itself. The focus here is on *what* the agent does. Typically, an agent is assigned an overall goal in a declarative way and it can decompose it into a hierarchy of sub-goals and finally actions. It is the agent that has the last word in choosing which actions are supposed to conduct to the best possible result, it is the agent that knows (or reasons about) when to undertake them and if other partners (agents) have to be involved. An example of such a system is an house alarm system, which responds according to the geometry and the physical conditions of the environment, but also in response to intruders' moves.

Again, autonomy can be seen as deriving from *internal motivation. A motivation is any desire or preference that can lead to the generation and adoptions of goals and which affects the outcome of the reasoning or behavioral task intended to satisfy those goals* [Ld95, dL96]. We classify agents as having goals and autonomous agents as having goals totally or partially generated under the influence of internal motivations. As Luck and D'Inverno put it, "motivations are not-derivative and governed by internal inaccessible rules, while goals are derivative and relate directly to motivations".

Further perspectives on autonomy have been presented in [Pit04a, Pit04b]. The authors give a characterization of agents' autonomy in terms of a relational concept, how agents are interrelated or correlated with each other (it is typical of social sciences to consider agents both artificial and human entities, as in the work of Castelfranchi). They then distinguish between social autonomy (or autonomy from other agents) and non-social autonomy (or autonomy from the environment).

Collecting these ideas, we can observe that in order to build agents which are in some way autonomous, we need to design agents which show a degree of intelligence. In literature we distinguish three degrees of intelligence: *reactivity*, that is the ability to react to external inputs, *pro-activeness* that is the ability to undertake actions and finally the capability of *learning*. Learning is the highest expression of intelligence as it allows agents to evolve over time, adapting their behavior by verifying the conditions of the environment and the results of their actions.

2.2 Software agents vs. software objects

"Is it an object or an agent?" is a popular question in the agent community [FG97]. As often happens, answers much depend on the assumptions we made. The following lines are an attempt to make things less confusing.

Software objects are instances of classes. Classes represent abstract data types, with their data structures and methods that work on them. Booch writes that "An object has state, behavior and identity" [Boo94]. The state is represented by the variables defined for that class of objects, the behavior is given by the methods and the identity is unique within the local execution environment.

Software agents represent objects with enhanced capabilities, or "active objects, exhibiting both dynamic autonomy (the ability to initiate action without external invocation) and deterministic autonomy (the ability to refuse or modify an external request)" [OPB00]. They are based on the same concepts, applied to a wider range: their state is not only produced by internal computation but also by perceiving external conditions, their behavior results from more complex considerations than method execution, messages are not simple method invocations, but are true high-level messages [FFMM94, New82] with a performative, a well-defined semantics and possibly follow an interaction protocol.

The internal state of an agent is represented by the set of properties that identify its status, the snapshot at a certain time of the state of its evolution. It is usually accessible only to the agent itself and is used to reason about the facts (actions and conditions) the agent is able to consider. A purely reactive agent does not hold an internal state, as the choice of what to do next is based only on the latest percept input received. Having an internal state is the enabling factor that brings an agent from purely reactive to more sophisticated behavior. Objects resemble to purely reactive agents, where the environment is the execution environment and the only perceivable external events are method calls. Each method call than fires exactly the execution of the method with the specified name. We cannot of course claim that having a state is a fully distinctive feature of agents. Each piece of software can be conceived to hold variables that it uses to carry out its computation. Nevertheless, whilst we commonly use variables to store values that are produced internally, the internal state of an agent may derive from external inputs, from what it senses of the environment external to it.

Object systems are implicitly meant to execute on the top of an operating system and an execution environment (sometimes also a virtual machine). More and more frequently applications expose their services over a network. With software agents the presence of the environment is more explicit, as they observe it and the collected information may impact on the way agents will reason in the future. The environment becomes an active component of the system, a far more complex entity than a mere execution environment. As such it requires to be explicitly modeled in the agent knowledge. For this reason, we say agents are *situated*. They are expressively designed to operate in a specific environment. Sometimes a dramatic change of the environment will not allow an agent to execute appropriately or at all. It is the case, for instance, of a mobile robot with a camera, which is suddenly out in a dark room.

Building agents means indeed finding the best performing agent for the environment it must operate in [RN03].

The concept of software agents is thus an extension of the concept of objects, perhaps realizing in its full the potential of the object paradigm. In the same way the definition of an object is the ground for defining the object-oriented software paradigm, so does the definition of agent for the agent-oriented paradigm. What appears to be different to one approaching the field is that while the object-oriented movement has produced object-oriented languages and compilers, the agent-oriented has not. And it was never the intention of the proposal, as agents stress upon features of objects that are usually underestimated in object-oriented systems. We can say that the object-oriented way of designing producing results in using the most straightforward elements of objects, while agent-oriented proposes a paradigm where designers are forced to consider more advanced features of objects in order to build complex systems. As the authors of [RN03] put it, “the notion of agent is meant to be a tool for analyzing systems, not an absolute characterization that divides the world into agents and non-agents”. This also explains why the most widely used agent toolkits are built using object-oriented languages, this being evidently no contradiction.

Nevertheless, we still like to distinguish between objects and agents. *We will consider a software component as a software agent whenever it is characterized by a sufficiently significant internal state, a sensing activity possibly impacting on the internal state, a reasoning activity which makes the component choose the actions to undertake (or whether an action has to be undertaken at all) [WJK00] and high-level communication through speech-acts [Aus62, Sea69].* Having at disposal these features presupposes an underlying architecture that is more complex than the bare facilities provided by an operating system and an execution environment. We will discuss the software architecture needed by agent systems in Chapter 4.

2.3 Agents vs Services

Services in a service oriented-architecture may closely resemble to software agents.

A service-oriented architecture is essentially a collection of services which interact with each other. Interacting could imply either simple data passing or a coordination process involving two or more services. A service is a function that is well-defined, self-contained, and does not depend on the context or state of other services. Nowadays the technology of *web services* is the most used to realize such architectures. According to the W3C [Con], "a web service is a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically WSDL). Other systems interact with the web service in a manner prescribed by its description using SOAP messages, typically conveyed using HTTP with an XML serialization in conjunction with other web-related standards."

A first account on the difference between agents and services is given by the W3C itself: "A web service is an abstract notion that must be implemented by a concrete agent. The agent is the concrete piece of software or hardware that sends and receives messages, while the service is the resource characterized by the abstract set of functionality that is provided".

Other differences may be found. Web services are way to use a server-based system.Web services run as background processes of an application server and as such are fully controllable. They do not hold a proper autonomy.

Further, both agents and services are meant to build interoperable systems. While agent solve the matter using high-level communication with speech-acts [Aus62, Sea69], services relies on standard interfaces like WSDL to specify how remote methods invocations can be performed.

3. PERFORMING AGENT DESIGNING

The characterization given in the previous chapter covers the definition of software agents, highlighting their *qualitative* features. Qualitative features are good to give a general idea of the technology but are insufficient for a software designer who wants to include agents in a system. This can also be seen as one reason why agent-based systems have not yet entered mainstream industrial applications, despite during the last decade a high number of theories, models, agent toolkits and design methodologies have been proposed. A qualitative approach should be backed up by more tangible tools that allow the actual development of agent-based systems. We share the view proposed in [BMO00] that, in order to be more widely adopted, we have to present agents as an extension of existing knowledge and practices.

Practices in the field of software design are mainly related to object-oriented software design and development, which relies on well-established and trusted methods. One of these is the Unified Modeling Language (UML) [Boo94], a widely accepted notation for designing software systems according to the object-oriented paradigm. The view of software as the next step beyond objects has lead to explore extensions to UML to accommodate the distinctive requirements of software agents [BMO00]. In [OPB00, BMO00, Bau02, Hug02a, Hug02b, Mod03b, Mod03a] ideas were progressively refined around the specification of an Agent Unified Modeling Language (*AUML*). The quality of these efforts have brought the Foundation of Intelligent Physical Agents [fIPA] and the Object Management Group [Gro] to form an interest group to complete the AUML specification.

As the work on AUML specification is still on-going, we present here the ideas developed so far, resulting from previous work and draft specifications, together with extensions we find useful for modeling software agents [Ber].

3.1 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 first approaches are surveyed in [IGG99]. Some more recent methodologies are interesting to understand what are the main issues to worry about when approaching the design of a multi-agent system.

The Gaia methodology [WJK00] 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 [MKC01] 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 Modeling Language which is based on a meta model 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 agent hood: 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.

It follow that 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 (be) organize(d) as a community. We have four views: the agency view, which deals with agents knowledge, belief, intentions, plans and behaviors; the environmental view, which models how agents react to external changes; the interaction view, where interaction protocols are specified; the organizational view, which gives details on organizations to which an agent belongs. In order to fulfill its unification purpose, AUML should provide a sufficiently rich notation to support these views. AUML as unified modeling language should thus aim at covering both the conceptual and the implementation level of systems' design. 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 inter curring among these entities.

The first move towards the definition of Agent UML class diagrams has been done by Bauer [Bau02]. According to Bauer an agent can be divided into three parts: a communicator, carrying out the physical communication, a head, dealing with goals and states, and a body, performing the actions of the agent. Bauer's approach gives rise to a class diagram as the one depicted in Figure 3.1, where Bauer considers the following information:

- agents and roles: an agent role identifies a set of agents satisfying distinguished properties, interfaces, service descriptions or having a distinguished behavior;
- state description: it is a logical description of the state using well formed formula which can be expressed in whatever logic we choose;
- actions: agents can perform two types of actions. Pro-active actions are triggered by the agent itself. Re-active actions are triggered by another agent. An agent action is defined by its signature toghter with pre- and post-conditions, effects and invariants;

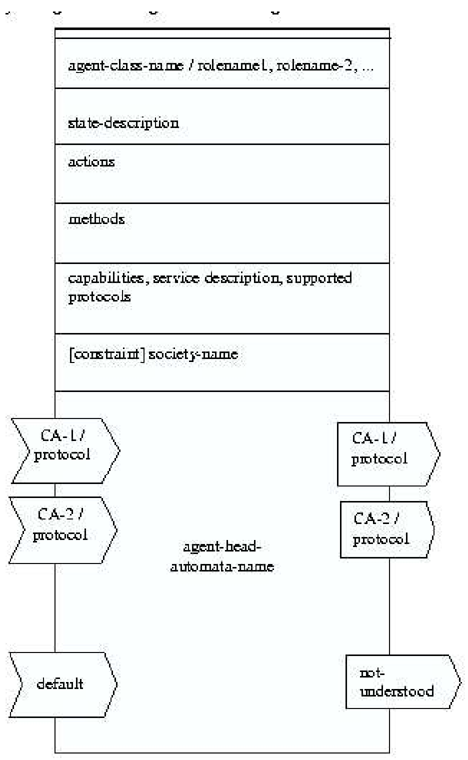


Fig. 3.1. Bauer's approach to AUML class diagrams

- methods: similar to UML methods;

- capabilities, service description and supported protocols: capabilities, services and protocols are described in an informal way. Capabilities may be alternatively rendered by object-oriented class diagrams;

- constraints and society: the constraints to enter or leave societies of agents;

- agent head automata: the behavior of the agents head has to be specified in the agent head automata. The automata defines the re-active behavior of the agent, relating the incoming messages with the internal state, actions, methods and the outgoing messages. it also defines the pro-active behavior, triggering different actions, methods and state-changes depending on the internal state of the agent.

These concepts have been critically revised and extended by Huget in [Hug02a]. Similarities between the two approaches are to be found in the way they consider actions as reactive and proactive (Huget's internal actions are Bauer's methods), capabilities and protocols (Huget adds the information on role, as an agent can play more roles given a protocol). According to Huget himself, the main difference between his approach and Bauer's lies in the use of the agent head automata. Bauer's head automata are meant to model information related to communicative acts and the impact they have on the activity of an agent. We agree with Huget in that head automata capture a part of agent dynamic behavior and should not belong to a static view of the system. We should rather use sequence or activity diagrams to model the dynamic and interactive aspects of the agent project. A second difference is how the two consider the description of the state of an agent. Bauer's state description is for the computation of beliefs, desires, intentions and goals as well-formed formulas. Huget considers instead these elements as objects linked to an agent. In this way it is easier to retrieve, merge and modify the state of an agent. Further, as they are objects, they are external to an agent and can be easily shared among a group of agents. A third difference is in the modeling of organizations. With respect to Bauer, Huget adds the notion of role and the conditions by which the agent can enter, stay in and leave a particular organization.

3.2 Class diagrams

UML class diagrams are intended to capture the static architecture of the system, a graphic view of the static structural model. They collect elements such as classes, interfaces and the relationships among them. Classes and interfaces are characterized by having an header, whose value is the name of the class, a set of variables and a set of operations as depicted in Fig. 3.2. Interfaces have a similar representation.

The relationships between two static elements classes can be of four types (Figure 3.3):

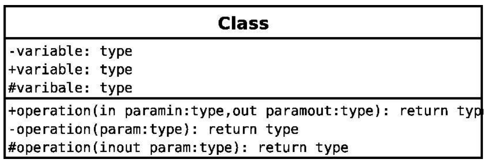

Class
-variable: type
+variable: type
#varibale: type
+operation(in paramin:type,out paramout:type): return typ
-operation(param:type): return type
#operation(inout param:type): return type

Fig. 3.2. The notation for a class in UML

- association: there is an association whenever two classes are generically connected. It is the case of the class *Dog* and the class *Owner*. Multiplicity can be specified at both ends. Possible values are n, (n, m) and $(n, *)$ with $n < m$, $n, m \in \aleph$. To help readability we may add an arrow to assign a direction to the association;

- generalization: there is generalization when a general class (called parent) abstracts the features of more specific classes (called children). If more classes are abstracted, then the general class models their common features, i.e. children inherit all of the properties of the father. It is otherwise named "is-a" relationship. An example is given by classes *Car*, *Spider* and *Coupé*. Constraints may specify whether an instance of the general class can be mapped to only one or to more specialized classes (overlapping versus disjoint) or whether an instance may belong to a non-listed child (complete vs. incomplete). It is represented by a solid line with a triangle where it meets the more general element;

- aggregation: there is aggregation whenever a class is formed as a collection of other classes. It is a "whole/part" relationship. It is the case of class *RoomFurniture* and class *Table*. Aggregation is represented by a solid line with a diamond near the aggregate class. A variation is the composition relationship that indicates that one instance of a part element belongs only to one instance of the formed element. It can be the case of the class *Bicycle* and the classes *Wheel*, *Brake* and *Frame*. For composition, the arrowhead is filled;

- dependency: a dependency represents a semantic relationship between two elements. It indicates a situation in which a change to the target element may imply a change to the source element and not vice-versa. It is the case of class *Agenda* and the class *Meeting*. It is represented as a dashed arrow between the two elements with the arrowhead meeting the target element.

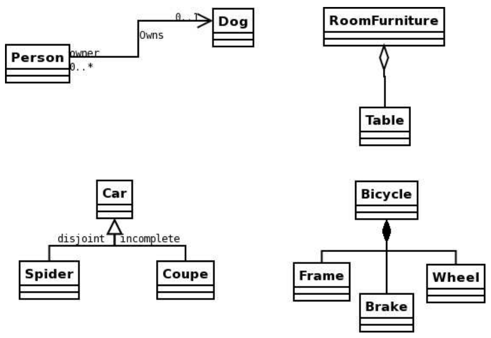


Fig. 3.3. The possible relationships between two classes in UML

Agent UML [1] aims at extending the existing UML definition and notation introducing the concept of agent. The extended notation should be usable to model agents' features. The first trivial step is of course to introduce the stereotype $\ll$ *agent* $\gg$. To place this stereotype with respect to the stereotype $\ll$ *classes* $\gg$, [Hug02a] defines the UML relationships association, generalization, aggregation and dependency for agent/agent relationships, giving them a semantics under the light of agent properties:

- association: the connected agents are acquainted and can exchange messages. This relationship prevents that the two agents are in a context of cooperation or coordination;

- generalization: as for classes, the definition of an agent can be derived from other agents;

- aggregation: aggregation among agents is possible only in the case of recursive agent architectures [FO00];

- dependency: in multi-agent systems a dependency can be unilateral, as for classes, or mutual. The latter case happens when agent A relies on agent B for some task execution and B needs therefore information from A in order to deliver the service;

- order: this is a hierarchical relationship representing organizational order between agents.

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

[1]UML Class diagrams have been revisited in [Bau02] and further extended in [Hug02a]. While Bauer et al. proposed a base form of class diagrams, Huget gave a precise semantics to the relationships inter curring between agents and between agents and objects. Hughet further redefined the compartments of a class diagram taking a Vowel-based approach [Dem95].

- association: it is a unidirectional relationship, from an agent to the classes it exploits for their execution. These may include classes to handle tasks, to build plans or to reason about goals;
- generalization: we cannot derive an agent from a class and vice-versa;
- aggregation: the agent is defined as an aggregation of several classes. It is the case of agent architectures which may comprise a reasoning part, a planning part and so on;
- dependency: the agent needs the class either in its code or during its execution.

To graphically identify these associations we use the same notation used for the corresponding UML relationships (Figure 3.3).

To give a finer semantics, we consider the following. Taking an agent perspective, every execution that can be performed is a behavior. An agent may have for instance a behavior which allows it to rationally participate to an auction. With the same perspective in mind, even an object whose method *printOnScreen()* is called is performing a behavior. Thus, we indicate classes representing agent execution with the stereotype $\ll$ *behavior* $\gg$. Behavior classes are directly connected to agents. We further distinguish behaviors into internal behaviors and external behaviors (expressed as attributes). Internal behaviors are those which are known and immediately executable by an agent. External behaviors are those that are needed by the agent and it does not know how to execute. It must either rely on some other entity to perform it or it has to know a way to learn it. A third type of class that can be directly bound to an agent are those that represent the data structure storing its state. The state of an agent can be of whatever complexity and in general it is required to define particular data types to hold the agent status. These classes will be identified by the stereotype $\ll$ *state* $\gg$. We have also classes that are not directly bound to agents and we call them services (stereotype $\ll$ *service* $\gg$). Services are objects that expose some functionality and have to be modeled in the system because useful to the agents' activity. A typical example of service might be a web service.

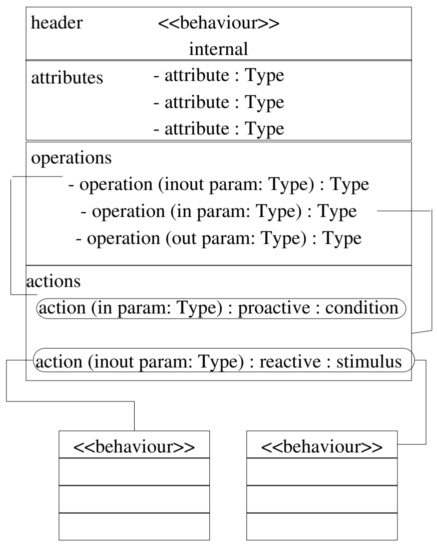

header
<<behaviour>>
internal
attributes
- attribute : Type
- attribute : Type
- attribute : Type
operations
- operation (inout param: Type) : Type
- operation (in param: Type) : Type
- operation (out param: Type) : Type
actions
action (in param: Type) : proactive : condition
action (inout param: Type) : reactive : stimulus
<<behaviour>>
<<behaviour>>

Fig. 3.4. The behavior representation in AUML

Considering the relationships between agents and classes, we should update their meaning. The association relationship connects an agent to a state class. It means that the agent needs the data type for representing information related to its status. Aggregation happens between an agent and a behavior class. It implies that the agent aggregates the (internal or external) behavior. 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 executing some behavior class (for reasoning, interacting, perceiving). Dependency happens between an agent and a service class. It means that one agent exploits the service execution. A dependency between agents and behavior classes is also possible, but it would have the same semantics as aggregation.

3.3 Behaviors

Internal behaviors have a representation similar to classes (Figure 3.4).

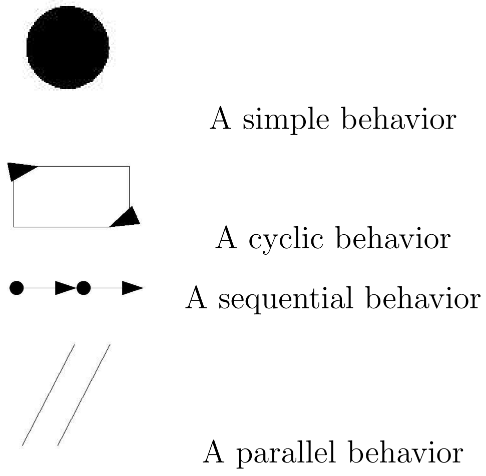


Fig. 3.5. The icons associated to threaded behaviors

The *Header* compartment contains the stereotype modifier (internal or external), the name of the behavior and a symbol specifying the threaded nature of the behavior. Possible values are simple (behavior executed only once), cyclic (behaviors whose execution is reset and restarted after each completion), sequential (an order execution of sub behaviors), parallel (a parallel execution of sub behaviors) and a final state machine-like execution sequence. The icons associated with this values are shown in Figure 3.5.

The *Attributes* and *Operations* compartments must contain only non-public members. Members of a behavior may not be public as no other entity must access to the behavior's internal. The agent itself has the permission to start, suspend, reactivate and stop the behavior. The behavior's execution may have an impact on the status of the agent. State classes may be connected with these two compartments to indicate the data structure used during computation. Additionally, we foresee a compartment named *Actions* which contains the information related to the flow of execution of the behavior. It is a list of actions. An action line in the flow compartment comprises the action name with its input parameters, an action modifier and a condition separated by a semi column. The first part is similar to the way we define operations in the operation compartment. Action modifiers are reactive, proactive and internal. Reactive means the execution of the action is fired after an external stimulus (the content of the condition part). Proactive means the action is internally fired after a condition is met.

Complex actions rely on the execution of methods or sub behaviors or both. These elements are connected to the action by means of a solid line and the action is wrapped by a circle (see Figure 3.4).

A behavior has thus an *Operations* compartment where the internal operations are captured and an *Actions* compartment where that action corresponding to reactive and proactive actions are detailed. The difference between the two lies in that actions represent higher-level actions that can map in more operations or even in a set of sub behaviors, while operations are punctual and play the role of usual methods. Actions have an associated modifier and condition, operations have not. Actions can be connected to behaviors, operations to state which represent the data structure they use. Actions represent what behaviors offer to agents, operations how actions can be carried out. A behavior can posses the action "Find the best deal" related to a commercial item. The outcome of this action depends on how the operation "Quote a deal" operates, i.e it is price-oriented or it considers also other features (warranty, quality, experience and so on).

3.4 Behavioral matching

An external behavior specifies all data necessary to find out matching behaviors, that is behaviors of other agents that could possibly fulfill the expected functions of the external behavior. Behaviors are publicly advertised detailing the actions they provide and how they can be accessed (protocols). This corresponds exactly to the public part of the behavior in our AUML class diagram. We essentially need the *Actions* compartment and the *Protocol* compartment. The former contains the actions that the behavior is expected to perform. Actions once again have their parameters, pre- and post-conditions and conditions that have to be verified during execution of the action itself. The *Protocol* compartment specifies the protocols the behavior supports to call for other agents' behaviors. While actions are placeholders for matching other behaviors, protocols are needed to ensure the behavior can correctly interact with matching behaviors. Matching actions and protocols ultimately provides a mechanism for binding agents together, thus creating coordination. The process can be so simple as querying a behavior registry or as complex as negotiating service availability and conditions.

If the behavior is a learning one, then we suggest to approach the design as done in [BTS$^+$04]. Note that as behaviors are learned, we may want to update their design, modeling the created behaviors. This is possible for instance for neural networks, for which we could write the weight configuration.

3.5 Interactional view

One important aspect of multi-agent systems is how agents come to interact. With class diagrams we have seen how the system can be statically designed. The mechanism of behavioral matching clearly shows that communication between agents is needed to enable cooperation or collaboration. It is the purpose of the interactional view to clarify how this interaction may happen and according to which rules. The interactional view encompasses sequence diagrams, interaction overview diagrams, communication diagrams and timing diagrams. We focus here on sequence diagrams as they propose the richest insight of the interaction. Other diagrams either express similar information in different ways (communication diagrams) or simpler information (interaction overview diagram and timing diagram). Through sequence diagrams we ultimately design how coordination can be produced among agents thanks to communication patterns.

3.5.1 Background

The modeling of communication protocols is not a new topic in computer science [Hol91, SW00].

Techniques mutuated from other computer science areas and adapted to multi-agent system interaction design include finite state machines, Petri networks [Arg79, Pet81], the Z notation [Spi89], the Specification and Description Language (SDL) and temporal logic [FW94].

Final state machines represent an intuitive tool for depicting the flow of action and communication. They are useful for a first approach to conversation modeling and sufficient for modeling sequential interactions. As conversations grow in size and complexity, concurrent patterns emerge, final state machines suffer some limitations in capturing the dynamics of protocols. Petri networks are more suited to model concurrent processes. Petri networks or place transition networks are directed, connected, bipartite graphs in which each node is either a place or a transition. Tokens occupy places. When there is at least one token in every place connected to a transition, we say that the transition is enabled. Any enabled transition may fire, removing one token from every input place, and depositing one token in each output place. Applying high-level Petri networks to the specification of multi-agent systems can be found in a number of works [Hol95, HK98, MW97, PC96]. In particular [CCF+99, CCF+00] proposes to use a variation of Petri networks called colored petri networks (see [Jen92, Jen94, Jen97]) to model agent interaction.

The Z notation is a formal specification notation based on set theory and first order predicate logic and generically intends to describe computer systems and their behaviors. In [dL96], the authors provide an example on how to use this notation to formalize the contract net protocol [Smi80] in terms of nodes, agents, tasks, goals and actions. Such an approach leads to very precise conceptions of a system, resulting in non-modular and sometimes difficult-to-read design.

SDL is an object-oriented formal language for the specification of complex, real-time applications. It is a graphical language that is both formal and object-oriented. The language is able to describe the structure, behavior, and data of real-time and distributed communicating systems with mathematical rigor. It has been used in the Mas-Common Kads methodology [IGCGV98] for the coordination model of agents.

The most significant approach born in the area of multi-agent system is AgentTalk [KIO95]. AgentTalk is a programming language capable of implementing protocols and agents that behave according to them. AgentTalk does not support a specific agent model. The main features of AgentTalk are:

- explicit state representation: an extended finite state machine is used as a basis to describe coordination protocols;
- incremental protocol definition: as in an object-oriented language, a protocol can be incrementally defined by inheriting a definition of an existing script (a script in AgentTalk represents the state transition of an agent in a protocol);
- protocol customization: when calling a protocol execution, agents can provide their specific delegate functions to be executed on state transitions;
- conflict resolution between coordination processes: as protocols may be simultaneously executed, we need a mechanism to get these protocols communicate in order to solve conflicts.

Our aim is to find a notation with which designers can capture the essential traits of an interaction among agents, both at a high-level of abstraction (what we usually call conceptual level) and at a detailed level (what we usually call implementation level). The notation should be neutral with respect to any methodology designers may adopt to design the system. The presented approaches fail to address these requirements for various reasons. The AgentTalk language misses a proper notation. Petri nets and the Z notation require a detailed view of the system, that may produce difficult-to-read projects or over verbose views in the early design stages. They fail in incrementally representing the system. SDL is bounded to a methodology.

3.5.2 Agent UML

AUML does not compete with any of above efforts. It rather aims at extending and applying a widely accepted modeling and representational formalism (UML) in a way that harnesses their insights and makes it useful in communicating across a wide range of research groups and development methodologies. AUML proposes an intuitive way to design system, hopefully with enough expressive power to catch the peculiarities of agent interaction. Most probably, once we have designed the system, other approaches may be used to give insights on particular parts. For instance, Petri networks seem to suit a precise and fine-grained view of interaction processes.

AUML sequence diagrams are informed by these requirements. The preliminary move towards sequence diagrams [2] for multi-agent systems was done in [BMO00]. They represent an extension to UML 1.5 state and sequence diagrams. Extensions included:

- agent roles: an agent role abstracts the properties, interfaces, service descriptions and behaviors shared by a set of agents;
- multi threaded lifelines: an agent lifeline in sequence diagrams defines the time period during which an agent exists. It is possible to specify parallel or concurrent message flows by means of *AND, OR* and *XOR* connectors;
- extended message semantics: messages can be synchronous or asynchronous and have cardinalities;
- nested and interleaved protocols: protocols are designed in a modularized way so as to allow their composation and their interleaving.

Many of these concepts are encountered in later work, refined and expressed by means of a notation which takes into consideration the evolution of UML [3].

[2]What is now called sequence diagrams was named by Bauer as protocol diagrams to highlight the distinction with UML. The same name has been used by succesive work by Huget. In order to avoid overlapping concepts, we call them sequence diagrams as the authors do in the FIPA draft proposal to comply with UML 2.0.

[3]In the meanwhile, UML has evolved from version 1.5 to version 2.0

The subsequent step towards AUML sequence diagram specification has been done by Huget in [Hug02b]. Huget added new features such as message broadcasting, messages triggered by conditions, interaction synchronization, a form of exception handling, time management with deadlines and delays between messages and atomic transactions.

In the following we present these concepts conforming to the latest FIPA specification [Mod03a]. We remind that specifications about AUML have not a definitive form and are subject to changes. We finally propose possible extensions to the model.

3.6 Sequence diagrams

The notions encompassed in AUML protocol diagrams are the followings:

- frame: frames encapsulate all the elements used in the interaction protocol as a unit. It is depicted as a solid-line rectangle with a *sd* header on the upper-left corner. *sd* stays for sequence diagram and is followed by the name of the protocol;

- protocol templates: they are determinate by the stereotype $\ll$ *template* $\gg$ (see Figure 3.6a). A template defines a pattern for a protocol. Information in a protocol pattern can be prefixed by the stereotype $\ll$ *unbound* $\gg$ making it a parameter to be specified when creating instances of the template protocol. A frame representing an instance of the protocol template will have attached the list of parameters that correspond to that particular instantiation (see Figure 3.6b). Mandatory parameters for each protocol instance corresponds to the keywords *ontology*, *ACL* (agent communication language) and *CL* (content language);

- agents and their roles: agents have an identity, i.e. they are an instance 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;

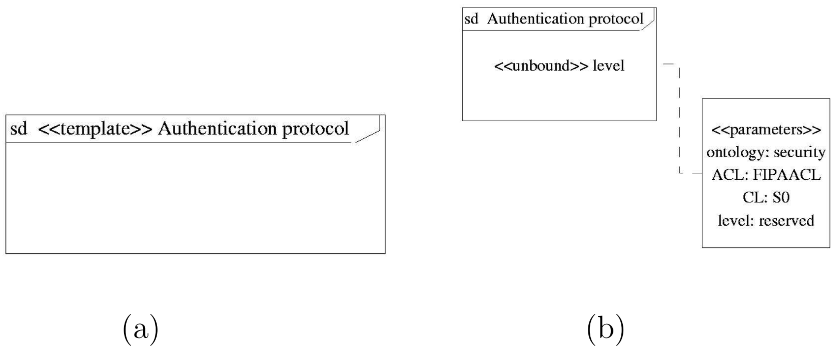


Fig. 3.6. The (a) template protocol and (b) its instantiation with parameters.

- agent lifelines: in Agent UML lifelines can be associated not only to particular instances of agents (like in UML 2.0 happens for objects) but can also be associated to roles and groups, or to agent instances playing specific roles in certain groups. A role is a class that defines a normative behavioral repertoire of an agent. A group is a set of agents that are related via their roles, where these relationships must form a connected graph within this group [Ode02]. A lifeline represents the time frame an agent instance playing a role in a group is active during interaction. It is depicted as a vertical dashed line headed by a label box, containing an agent identifier and/or a role and possibly a group and the cardinality of the agents playing that role (see Figure 3.7). Time flows going from top to bottom. Multiple classification, i.e. an agent playing more than one role within the same interaction, is obtained by using labels with equal values of the agent instance. Dynamic classification, i.e. agents changing roles during interaction, is rendered as a directed line from the current role to the new role. The directed line is adorned with the stereotype $\ll$ *change role* $\gg$. If new roles are added during interaction, then we use a directed line adorned with the stereotype $\ll$ *add role* $\gg$ (see Figure 3.7);

- messages: information about messages is spread in the diagram. The sender is the agent or role the directed line starts from. The receiver is the agent or role pointed by the directed line. The ontology, the language and the content language are parameters attached to the diagram. The communicative act and its content are adorned on the directed line. The notation for a message is a line from the lifeline of the sender directed to the lifeline of the receiver. Asynchronous messages have an open arrowhead, while synchronous messages have a filled arrowhead. In the case the lifeline of the sender and receiver are the same, we may precise that the sender agent will not receive the message by barring the beginning of the directed line;

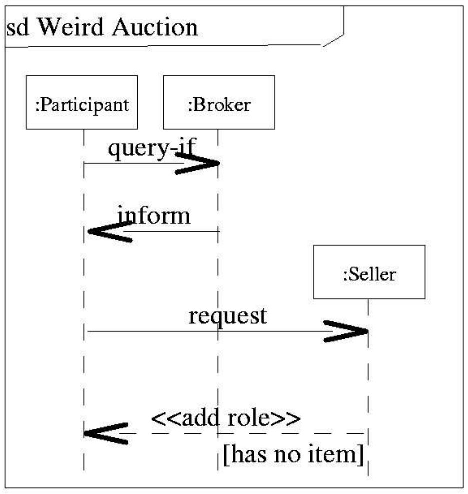


Fig. 3.7. An example of sequence diagram with activation lifelines and multiple roles

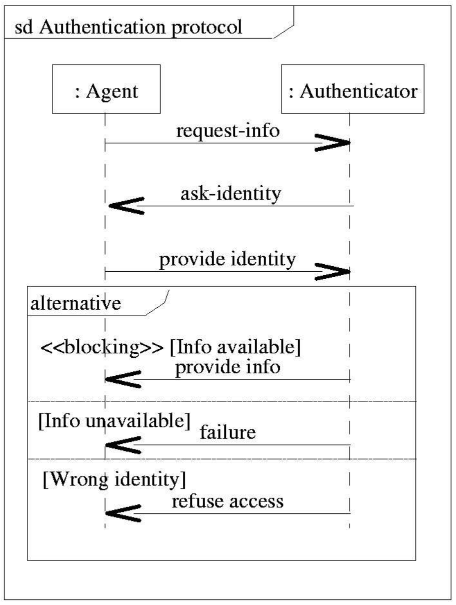


Fig. 3.8. An example of sequence diagram with constraints on messages and interaction paths

- constraints: It is also possible to specify constraints on messages and on interaction paths. Constraints on a message imply that the message is inhibited if the constraints are not satisfied. General constraints on messages are written near the sending lifeline within square brackets. Constraints on interaction paths guide the choice of which alternative path is to be followed. Both type of constraints can be blocking or non-blocking (constraints are blocking only for the role they apply to, leaving all other roles an agent posses unaffected). Figure 3.8 depicts an example of using constraints;

- timing constraints: timing constraints allow to verify the delays between two messages. The constraint is rendered as a quote between the two messages and the interval between curly brackets;

- path constraints: in general interaction protocols have more than one path. Adhering to UML 2.0, AUML represents alternatives execution using `CombinedFragment`. The splitting operators that give a semantics to the `CombinedFragment` are

Alternative, Option, Break, Parallel, Weak and Strict Sequencing, Negative, CriticalRegion, Ignore, Consider, Assertion and Loop. In order to identify splitting paths we use a solid-outline rectangle with the operator written in a top-left "snipped corner" pentagon. Each optional path is separated by a dashed line. The merging operator is called Continuation. Continuation is rendered as a rounded rectangle with a name. A Continuation can be outgoing (a filled triangle is depicted after the name) or incoming (a filled triangle is depicted before the name);

- protocol combination: we may have interleaved protocols. This happens when the execution of a protocol foresees at a certain stage the execution of another protocol. The execution of the principal protocol continues after the interleaved protocol execution finishes. Graphically, this is rendered by a solid-outlined rectangle. Designers must pay attention to coherently match role when passing from one protocol to the interleaved one;

- protocol interaction: two protocols may come to interact in that the first sends a message to the second passing information and the second, after finishing some execution, sends information back to the calling protocol. As interaction happens through messages we can have blocking or non-blocking relationships. We represent protocol interactions using the usual message notation.

3.7 Experiencing AUML sequence diagrams

In this section we consider some uses of AUML sequence diagrams. This has the purpose to show the expressiveness of AUML and to propose extensions. The following observations have been inspired by our experience in using AUML on fielded systems (see chapter 5 and 6).

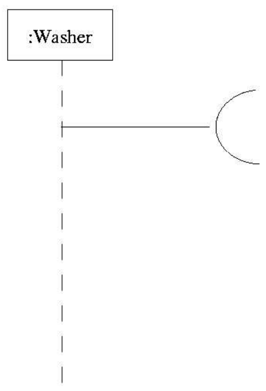


Fig. 3.9. A broadcast message

3.7.1 Sending messages to more than one agent

In protocols it often happens that one agent has to send a message to a group of agents. The group can be the totality of the agents present in the environment and in this case we have a *broadcast* or to a subset of them and we call this *multicast.*

Broadcast messages are sent to an undetermined set of agents. Broadcast messages do not address any particular group, role or agent instance. They are represented with a message line closed by an arc (Figure 3.9). The line must not meet any lifeline. As normal messages, broadcast messages can be synchronous or asynchronous. We may precise whether the sender itself receives the message or not. In the latter case, we bar the beginning of the directed line.

Multicast messages can be rendered in AUML at three different levels, corresponding to groups, roles and agent instances. At group and role level, the simplest form of multicast is when a message is sent to all agents belonging to that group or playing that role (see Figure 3.10(a)). For roles, the number of agent addressed depends on the role cardinality. A second form of multicast happens when we want to identify, among all agents belonging to a group or playing a role, a distinct subset. This might be the case of a single agent or group of agents winning an auction: only winners have to be notified of their success. We call this messages *selective* multicast messages. Our suggestion is to adorn the message with a number expressing how many agents should be addressed (possibly a range) and a condition which filters out the agents which hold a distinctive property (see Figure 3.10 (b)). Only the number or range is optional. At the level of agent instances, a multicast message must be represented with a line which forks to direct to the different agents lifelines (see Figure 3.10 (c)). No number or ranges nor condition specific to multicast must adorn the message line.

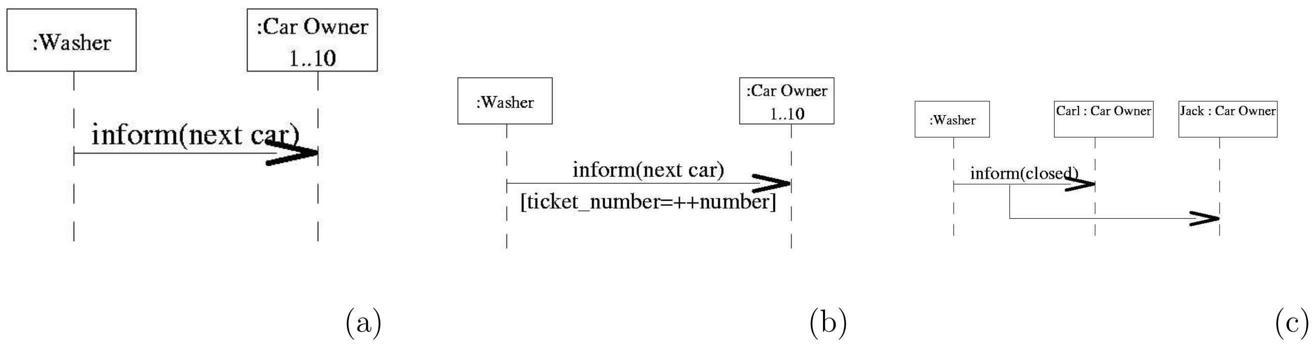
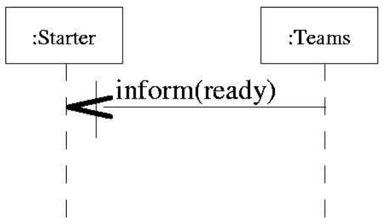
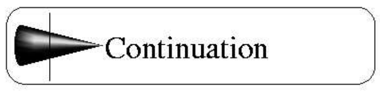


Fig. 3.10. Multicast messages: (a) simple, (b) selective and (c) to agent instances.

As more agents can be involved in an interaction, there might be the need for creating a synchronization at some stage. A synchronization is a point where all agents are expected to get and until all required agents are not arrived at that point of the protocol execution, the protocol cannot further execute.

Synchronization points can be of two types. Simple synchronization points are related to synchronization on messages. Suppose an agent asks to all agents of a given role if they are up and running and the asking agent will undertake further actions only when all answers have been received. In this case, the message arrowhead is crossed out by a vertical line. Synchronization can also be applied to merging paths. Execution must not go on until all paths have reached the merging point. To model synchronizing merging points we bar the arrow of an `incoming Continuation` box (see Figure 3.11).





(a) (b)

Fig. 3.11. Synchronization for (a) messages and (b) merging paths.

3.7.2 Trigger management

Triggers are actions to be undertaken under particular conditions. We identify two types of triggers. Those that fire after an exception and those that fire when specific conditions are met.

The notions of exception and exception handling are important in programming any computer system. An exception fires when a behavior does not complete successfully. Handling exceptions means getting catching it and adopting responsive actions. In AUML exceptions can be inserted using the `Break` operator, one of the splitting path operators we have listed above. The `Break` operator starts a breaking scenario that stops the current execution of the sequence diagram, executes the scenario and does not resume the main sequence flow.

We suggest to use a similar mechanism to model triggering actions. Triggering actions take place when particular conditions are met. Triggering actions are like exceptions, but their execution does not break the interaction. After a triggered action we always resume the main sequence flow. We use once again the break operator with a `resume` keyword in the label as in Figure 3.12.

3.7.3 Atomic transactions

Atomic transaction is a concept developed for database systems. An atomic transaction collects a set of actions to be executed after some sequence. The execution is to be deemed successful only if all actions terminate successfully. If at least one action does not, all the results produced by the execution of the successful actions must be rolled back. This is to say that we have either the combined result of all actions or none. In AUML we could think to model this aspect using `CriticalRegion`, a splitting operator. A `CriticalRegion` tells us that a sequence of actions has to be executed atomically with no interleaved message sequences. We claim atomic transactions are different from critical regions. Atomic transactions are not only atomic but imply that in case of failure to complete that sequence, the

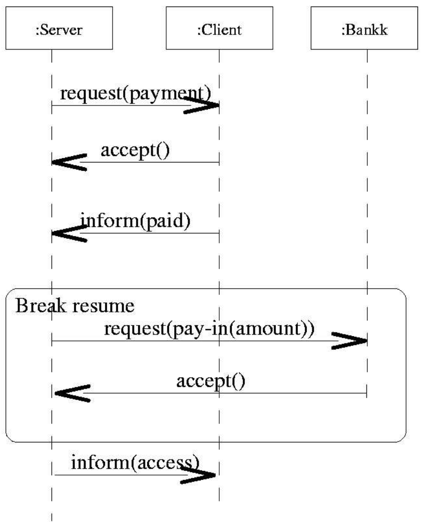


Fig. 3.12. Representing triggered actions with the resuming `Break` operator

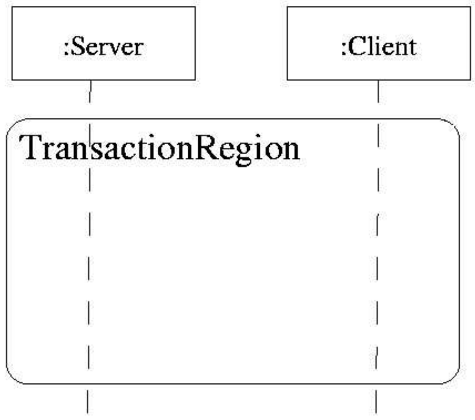


Fig. 3.13. An atomic transaction is represented by the tt TransactionRegion operator

state is brought back to the value it had before the atomic transaction started. We add therefore a new splitting operator called `TransactionRegion` (Figure 3.13).

3.8 Comparison with previous AUML proposals

In this section we will point out the main differences between our extensions and what has been proposed in previous work on AUML.

As for AUML class diagrams, we referred the work by Bauer [Bau02] and Huget [Hug02a]. As Bauer we distinguish between methods, which are internal, and actions, which are the visible behavior of an agent. With respect to both approaches, we enrich the diagram by distinguishing classes into behaviors (internal and external) and services. This gives us the possibility to describe in a modular way the behaviors associated with an agent. We can connect actions to the operations that they imply or to those sub behaviors that realize parts of its functioning. This also helps identify coordination link among agents.

As Huget we represent the state of an agent with objects, because objects are handier to manage than simple variables stating conditions like *tire(2000km, in-*

flated). The state of an agent changes when an agent operation or one of its behavior acts on it invoking the available methods.

Huget includes in class diagrams a *Capability* compartment. Capabilities describe what agent are able to do in a free-format text. Capabilities are derived as services to agents. These services are rendered as lollipops linked to the agent. We use a different approach. We have behaviors, which can be internal or external. A generic behavior may be associated with an action. An action has a condition which tells why it fires. External behaviors have to be matched against the services available in the environment. In this way, we try to capture as much as possible the structure of the system, reducing the free-format text and precising the relationships among the diverse elements along with their nature.

As for AUML sequence diagram, we have been mainly inspired by the current working draft on interaction protocols by FIPA [Mod03a]. In proposing our extensions fundamental has been a work by Huget [Hug02b]. With respect to the latter, we have proposed extensions which suit the current AUML interaction protocol draft which refers to UML 2.0. Differences mainly concern the use of the notation and how we discern concepts like multicast messages, triggered actions, exception handling, atomic transactions and critical regions.

3.9 Conclusions

In this chapter we reviewed the definition of software agents. First, we have discussed their qualitative features and showed how perspectives belonging to different disciplines concur in defining the character of agent technology. Despite different views in the literature, commonalities can be found. Autonomy plays a central role with its many facets. Intelligence is another key feature to which we assign different degrees (reactivity, pro activeness and learning). Secondly, we showed how we can practically design systems holding such features. Our analysis has been inspired by the recent moves towards extending UML for multi-agent systems. Reviewing the current proposal, we have proposed some extensions aiming at facilitating the design of a system which contains software agents. Our observations are not meant to be stable and reliable, but are intended to put forward themes that we consider essential to capture the nature of multi-agent system from a design perspectives. Insights on experiencing AUML are given in [BGGV03a, BGGV03b].

4. ARCHITECTING AGENT SYSTEMS

Discussing the design of information systems with software agents we pointed out how the environment plays an active role in multi-agent systems. Basically, the properties of the environment determine the “nature” surrounding the agent, what actions can be done and which resources are available. The environment may also influence how agents are built, providing the means by which agents can execute, communicate, move and use resources. This chapter is dedicated to present how the environment of software agents is modelled and implemented in multi-agent system toolkits.

With respect to physical agents which may live in the same environment humans experience, software agents seem to have a more limited living space. They execute in computer systems, usually connected through computer networks. This *physically* bounded space is *virtually* huge. Physical distances are hidden by a uniform logical addressing space. Basically we find three reasons for which this environment is difficult to model. First, dealing with distribution in computer systems requires to build software layers capable of supporting the system activities we find on local systems such as identification, messaging, data transfer and resource localization. This has to be done in a transparent way so as to lessen applications from the burden of managing distribution. Secondly, as for physical agents, software agents should include a representation of the external world in terms of software (agents, objects and services) and hardware (disks, printing facilities, networks, and in general physical devices) resources. Thirdly, virtual environments may be enriched as to resemble to physical environments (sometimes they even amplify physical nature). This is the case of simulation systems in which virtual environments implement physical laws such as the effects of magnetic fields or social dynamics. An example of an agent-based simulation environment is KidSim [SCS94].

Tackling these issues means creating a software layer that has richer functionalities than those available from an operating system. Most commonly, the solution is building a software layer which abstracts the execution environment on the top of the operating system. We call this layer an infrastructure. The study of multi-agent system infrastructures is a relatively young field. While fairly sophisticated theories and technologies have been developed in fields like coordination, interaction, languages and dynamic organizations for agents, we have little experience about the practical deployment of multi-agent systems. This may also be viewed as a reason why agent-based systems have not yet become a widespread technology in commercial applications. Experiences in other areas have showned that until a critical mass of fielded systems is in place, pulling towards stable, reliable, accessible infrastructures offering compelling services, the potential of agent technology will not be converted into kinetics. In this chapter, we will discuss which are the mandatory features of a virtual environment for software agents on top of which we can build more sophisticated dynamics. The ultimate vision is that of Russel and Norvig [RN03] "the Internet is an environment whose complexity rivals that of the physical world and whose inhabitants include many software agents".

4.1 An abstract infrastructure model

A technical infrastructure is meant to provide solutions to basic, essential, commonly problems experienced when tackling a particular category of systems. Exploiting an infrastructure means taking advantage of its features in order to focus on application-specific issues, avoiding costly and repetitive activities. The quality of an infrastructure resides in how well it satisfies global needs that are useful for building specific applications. Using general purpose infrastructure for solving a range of specific problems allows shared knoweldge and use of common criteria in the community. Following Star and Ruhleder, in general infrastructures hold the following properties [SR96]:

- they are built on top of other structures. Technically, the most common example of infrastructrue is middleware [Mye02, Bri01];
- they are transparent to users as they offer services that can be used with a high-level interface and manifest from a design standpoint;
- they are based on standard specifications and learned community practices.

The infrastructure of a multi-agent system includes the set of services and knowledge to support the agent's social activities such as coordination, communication and mobility. Figure 4.1[1] depicts one of the most popular models which has been presented in [SPVG01] for the RETSINA toolkit. The layered placement suggests that each level exploits the services of the underlying levels.

A MAS infrastructure is built upon an *operating environment*. An operating enviroment is composed by computers, operating systems, networks and how they are interconnected. While relying on the services provided by this layer, a MAS infrastructure should make agents unaware of the underlying operating environment. In this way, software agents may work across heterogeneous settings. The lower level of a MAS infrastructure is represented by the *communication infrastructure*. The communication infrastructure is responsible for message transfer. Message transfer can happen both among agents and between an agent and the infrastructure components (these latter may or may not be agents themselves). Communicating with infrastructure components assumes the components can be easily addressed by means of a discovery service. No matter what the modality of the communication channel is (wired, wireless, infrared ,...), agents should be able to exchange messages. The communication service should also be independent from the actual transport layer and

[1]The original figure has two columns, the undepicted one representing the individual agent infrastructure. We are not concerned here with the individual agent architecture because it is implied by the infrastructure, i.e. if the infrastructure offers services, agents executing in such infrastructure are given the capabilites to effectively exploit them.

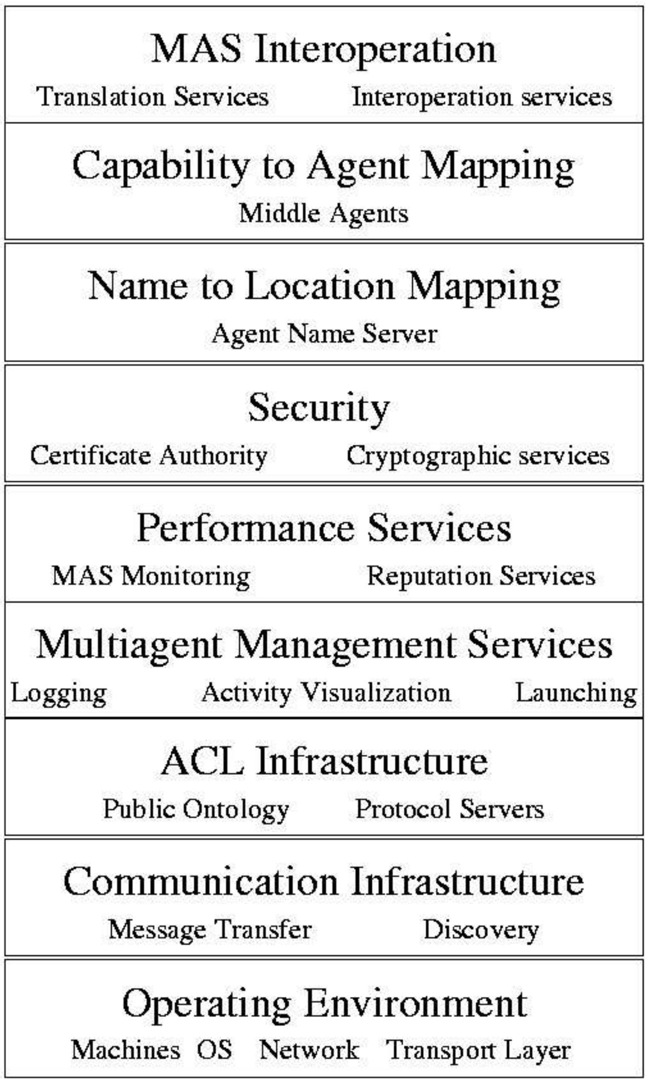


Fig. 4.1. The abstract agent infrastructure derived form the RETSINA system

from the particular *Agent Communication Language* (ACL) used in messages [SS00]. The specification of an ACL rules both the syntactic form of the language and the semantics associated with its primitives, called *speech acts*. The interpretation of messages by an agent is done according to some specified ontology. Further to messages, we may specify which conversational policies [GHB00] are enforced and which protocols [SCB$^+$98] can be used to carry out conversations.

A MAS infrastructure supplies other high-level services. The *multi-agent management services* comprise the set of services needed to control the system (logging, management tools, installation and launching services). Performance measurement may also be in place for monitoring the performance of software agents and evaluate their features (as for instance their reliability or reputation [ZMM99]). As multi-agent systems are open systems, where agents dynamically appear and disappear, programmed by different people, we need to secure the system against misuse of its resources and misbehaviours towards agents. The security layer responds to this requirement.

A MAS infrastructure provides also a location abstraction, supporting software agents that move in the environment. This is achieved by activating what is named an *Agent Name Server* (ANS) which registers the name of each agent together with its current positions. Messages sent to the agent are routed according to the information stored in this table. The ANS keeps the table up-to-date in a real-time fashion. Supporting mobile agents brings into play the issue on how agents can meet and find each other capabilities while changing location over time. The *Capability to Agent Mapping* layer makes provision of the service through *middle agents* [DSW97]. Middle agents hold registries which store entries related to agents and the descriptions they advertise about their features. This service may be rendered in a number of ways as investigated in [WS00]. The upper layer of the infrastructure is dedicated to make the MAS interoperable with others MASs, which will be in general designed and implemented independently and responding to different architectures. Making diverse MASs interoperate (for instance knowing the agents that enter the system and make them reachable by messages) is a very important task and a very difficult one. In order to promote interoperability and discussion on MAS infrastructures the *Foundation for Intelligent Physical Agents* (FIPA) has been constituted with the aim of pursuig agent standards. In the next section, we present the FIPA standard model for MASs.

4.2 FIPA: a standard model for MAS infrastructures

The model presented above was developed by abstracting the architecture of RETSINA, one of the first complete agent environment implemented and has been useful to introduce the basic layers a multi-agent system should comprise. We will not comment on the quality or coherence of the model. What is important is that what observed was a premise for further efforts, and in particular to the initiative of FIPA aimed at creating a standard specification for multi-agent system infrastructures.

The FIPA agent management reference model [fIPA04] and the abstract architecture [fIPA02a] define the framework within which FIPA agents exist and operate. They detail the logical reference model for the creation, registration, location, communication, migration and retirement of agents. According to the FIPA specifications, the infrastructure is composed by (see Figure 4.2):

- *agents* as computational processes with an identity (unique identifier called Agent Identifier), an owner (a human or an organization), a service description which describes their capabilites. Agents communicate using an ACL. A single agent may be contacted at a number of logical addresses;

- a *directory facilitator* (DF) provides yellow pages services to other agents that can be used by agents to register, unregister their services and query in order to know other agents. While a DF is optional in the system [2], it is possible to have more federated DFs exchanging data about agents. If a DF has federated

[2]If present, the DF has a reserved AID of the form *(agent-identifier :name df@platform :addresses (sequence platform transport address))*

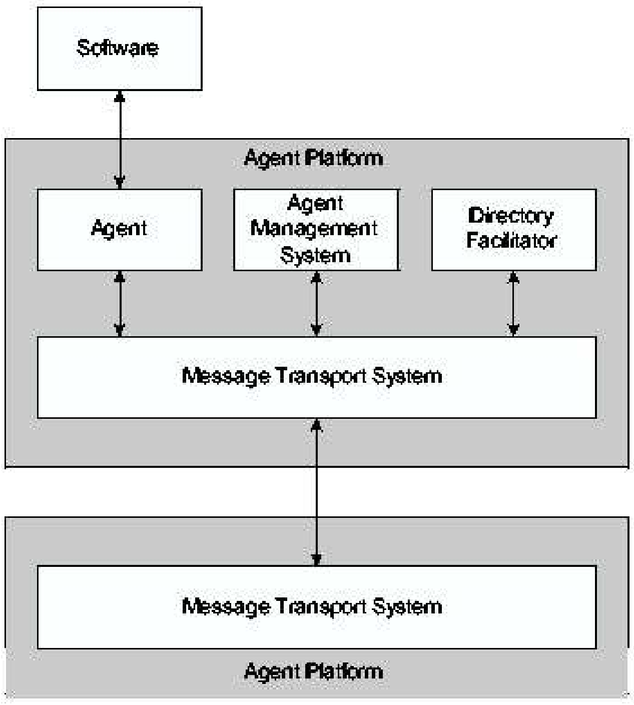


Fig. 4.2. The FIPA reference model

companions, then executing a search means first looking at its own table and then extending the search to other DFs;

- an *agent management system* (AMS) is responsible for controlling the access and the use of the agent system. It offers a white pages service. Each agent must register with the AMS. The AMS stores all the information about agents required to excert its control over the platform. An AMS is mandatory and unique in the platform [3];

- a *message transport service* (MTS) is the default communication method between agents on different platforms.

All the actions related to management activites within the platform (such as registrations, changing states, moving form one place to another) have a correspond-

[3]The AMS on an AP has a reserved AID of: *(agent-identifier :name ams@platform :addresses (sequence platform transport address))*

ing standard message type with standardized parameters. This ultimately defines a *management ontology* which is shared and known to all agents in the platform.

It must be noted that no mandatory requirements concerning how a platform is actually designed are imposed by FIPA. To be compliant with the FIPA specifications it is only requested that all defined services are in place.

4.2.1 The directory facilitator

The DF basically provides yellow pages services. As a service provider it is supposed to be reliable and securely open. Reliable as it must keep a view of the system up-to-date in a real-time fashion. If an agent has advertised a service description, the directory facilitator must, from that time on, answer to queries with the updated data. Securely open as it must be available to all regularly authorised agents in the platform. All the management functions can be requested by agents using the `fipa-request` interactional protocol [fIPA02b]. The DF may restrict access to information in its directory and verify all access permissions for agents which attempt to inform it of agent state changes.

The DF is a passive component: every agent can register its own services, but it is not guaranteed that the agent actually provides such services or is willing to do so upon request. No restrictions are placed on the data that are supplied for registration. If an agent deregisters its services the DF is no longer committed to broker information relating to that agent.

Searches submitted to DFs are carried out locally by the receiving DF. If requested and a federation of DFs is active, the DF will ask companion DFs to perform the same search. In order to create federations, directory facilitators must register their service with each other.

Additionally to single queries, a DF may support also persisted queries. This is realised through a subscription mechanism[4]. Agents submit the query to be persisted

[4]The mechanism is implemented by means of the `fipa-subscribe` interaction protocol [FIP02]

and the DF will inform them when changes to the result of the subscribed query happen.

4.2.2 The agent management system

An agent platform is mandatorily managed by one AMS. The AMS holds a description of the agent platform itself and of all agents in the system. While the DF holds data about agents' services, the AMS description of an agent contains the logical addresses of the agent. Each agent to get to execute must register with the AMS of the platform it was born in. Upon registration an agent receives a unique agent identifier. Deregistration is possible only when the agent deceides or is forced to terminate.

As an agent platform is a logical abstraction that may span over multiple physical machines, the AMS represents the authority across all machines.

4.2.3 The message transport service

The MTS is the most complex service within an agent platform. The MTS is charged of delivering messages between agents within a platform. If other platforms are attached, it must also make possible messaging to agents that are resident on other platforms. Each agent must have access to at least one MTS in order to be able to communicate. An MTS is intended only for messages sent to agents. On a particular platform, an MTS is instatiated by a so-called *Agent Communication Channel* (ACC).

The reference model for an agent message transport comprises three levels as shown in Figure 4.3:

The object to be delivered is a message. A message comprises two parts: a message envelop holding transport information and a message payload with the ACL message the agent wishes to communicate. A receiving agent is mainly interested in interpreting the ACL message for which FIPA defines the semantics. The information

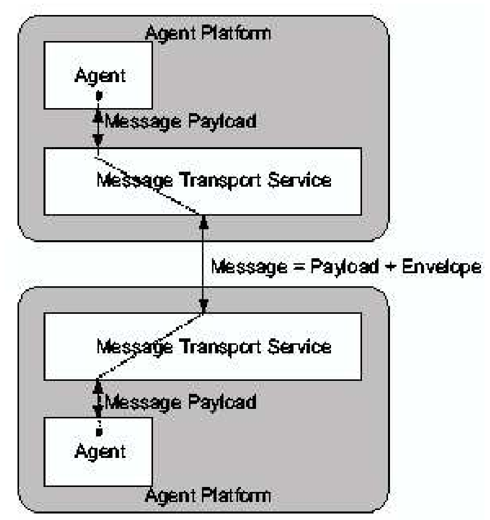

Agent Platform
Agent
Message Payload
Message Transport Service
Message = Payload + Envelope
Message Transport Service
Message Payload
Agent
Agent Platform

Fig. 4.3. The reference model for the agent message transport

in the envelop is for transportation support only. FIPA does not specify whether and how this information may be processed by receiving agents. A message envelop contains a list of parameters in the form of name/value pairs. A message transport protocol may use different internal representaion of a message envelop but must express them in a standardized way. Mandatory parameters concern the receiver of the message (parameter `to`), the sender (parameter `from`), the time the message is sent (parameter `date`) and the representation of the ACL message (parameter `acl-repesentation`). Each ACC handling a message may add new information to the message envelope, but it may never overwrite existing information. An ACC must transfer the messages it receives according to the transport instructions contained in the message envelope. An ACC is only required to read the message envelope; it is not required to parse the message payload. In performing message transfer tasks, the ACC may be required to obtain information from the AMS or DF.

Message routing is performed as follows. If the ACC receives a message with the `intended-receiver` slot, then it forwards the message to the agent specified in that slot. If multiple receivers are specified then the most recent one is taken. If the `intended-receiver` slot is empty, then the ACC fills it in with the names comparing in the `to` slot. In delivering a message to a receiver agent, an ACC looks up the addresses specified for that AID. If the agent posses more addresses, the the ACC first try to reach the agent using the first in the list. If the operation is unsuccesful it iterates through the list of addresses. If still unsuccesfull, the ACC may try to resolve the AID by contacting alternative resolvers (usually those listed in the `resolvers` parameter of the agent identifier, as specified in [fIPA04]). If still unsuccesful, a failure message is sent to the sender.

In the setting of more agent platforms, an agent desiring to communicate with an agent on another platform has two possibilities. The first is to send the message to its local ACC. The ACC then takes care of sending the message to the correct remote ACC using a suitable MTP. The remote ACC will eventually deliver the message. The second is to send the message directly to the ACC on the remote agent platform on which the receiver agent resides. This remote ACC then delivers the message to B.

4.3 JADE

Since the early stages of FIPA activity, researchers have not only contributed to delineating the standard but also to test the feasibility of a FIPA-compliant toolkit. The first FIPA standards were published in 1997. The first FIPA-compliant product was released in 1999 by Nortel Networks and was called FIPA-OS. It was soon followed by other examples both as licensed products and open source projects. Commercial products are the Agent Development Kit by Tryllian BV, Cybele by Intelligent Automation Incorporated and JACK by AOS. Open source projects are FIPA-OS by Emorphia (spin-off company by people of the former agent group in Nortel Networks), the Java Agent DEvelopment JADE by TILab, the April Agent Platform (AAP) by Fujitsu and ZEUS by BT.

Open source projects have demonstrated to be very appealing for the research community due to free usage and source code availabilty. This gives the chance to researchers to build toolkits ahead of commercial products as the research advance. As a matter of fact, many open source projects were born thanks to researchers' effort.

Another issue concerns programming languages and more specifically Java $^{\text{TM}}$. With its multi-platform and network programming support, Java$^{\text{TM}}$represents the ideal choice in developing multi-agent systems and environments. With respect to these points, the most succesful projects have been FIPA-OS and JADE. JADE in particular has been having a big momentum and current releases merge the state-of-the-art techniques in agent environments.

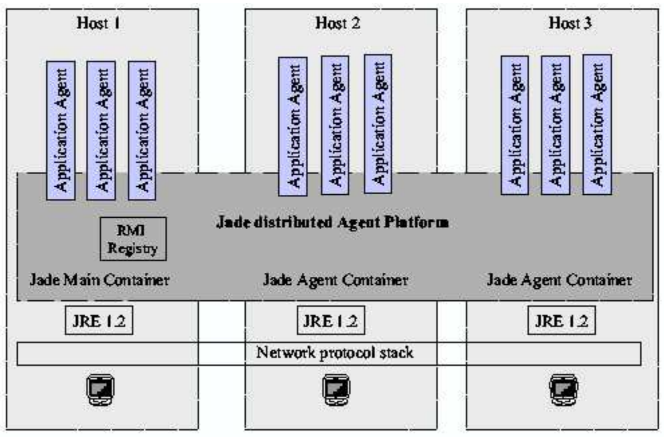


Fig. 4.4. A JADE platform

4.3.1 The JADE agent platform

JADE is a toolkit for implementing and deploying multi-agent systems [5].

JADE complies with the FIPA specification and as such provides an agent management system, a directory facilitator, the FIPA Management Ontology to contact their services, and a message transport system.

A JADE platform is a logical space that can be distributed over diverse physical hosts (Figure 4.4). Each host participating to the platform has its own Java Virtual Machine running. Each JVM is an agent container, i.e. a runtime environment that allows agents to concurrently execute. In order to boot the platform, a *Main-Container* has to be created. The Main-Container hosts the AMS and the DF. It also contains the RMI registry that JADE uses to allow containers and agents to reside on multiple hosts. Other virtual places can be added to the platform by creating containers. Containers may or may not reside on the same host where the Main-Container runs. No matter where containers are located, the agent platform is seen as a uniform logical space, where all containers can be reached simply knowing their name.

[5]At the time of writing JADE 3.2 is the latest release

JADE provides compliant implementation also for the agent communication language with its speech-acts, content language support, and the FIPA interaction protocols.

4.3.2 The JADE agent model

The JADE agent model defines agents as running thread. The JADE *Agent* class implements indeed the *Runnable* Java interface, meaning that agent instances are executed by a thread. Developers can therefoer program their own agent inheriting from the JADE *Agent* class. When instatiated, an agent is assigned a Java thread which takes hold of its execution. The template *Agent* class defines features to accomplish basic interactions with the JADE agent platform such as start-up registration, service registration, service querying, roaming and sending messages.

As an entity of a MAS, each agent is identified by an *Agent Identifier* (AID) (see FIPA Abstract Architecture Specification [fIPA02a]). An AID labels an agent so that it may be distinguished unambiguously within the platform. The Jade AID is an abstract data type which includes a number of fields, the most important of which are `name` and `addresses`. The `name` field contains the globally unique identifier (GUID) assigned to the agent. A GUID is constructed by concatenating the nickname assigned by the launching user to the name of the platform the agent was born in, separated by the '@' character. GUID are used to identify receivers of sent ACL messages. The `addresses` field, instead, contains a number of transport addresses at which an agent can be contacted. The syntax of these addresses is just a sequence of *Uniform Resource Identifiers* (URIs). When using the default IIOP MTP, the URI for all the local addresses is the *Interoperable Object Reference* of the local agent platform.

As a running thread, instead, an agent has a life-cycle, i.e. can be in different states. Following the FIPA Platform Lifecycle Specification [fIPA] an agent can be in one of the following states at a given time (see Figure 4.5):

- initiated: the agent is instatiated as object but does not hold the agent features such as a valid AID and a registration entry by the AMS. In this state the agent cannot communicate with other agents;
- active: the agent was instatiated and now has all the required agent features. It can communicate with other agents and execte behaviours;
- suspended: the internal thread of the agent is stopped and all behaviours are blocked;
- waiting: the agent thread is sleeping on a Java monitor and can be woke up by some event (typically an incoming message);
- deleted: the agent stops living, its thread termintes and the agent is no longer registered by the AMS;
- transit: this state allows to know when an agent is moving. While the agent is moving cannot receive messages. The messages sent to the agent must be buffered by the platform services and delivered when the agent leaves this state to the new location;
- copy: this state is internally used by JADE for agent being cloned;
- gone: this state is internally used by JADE when a mobile agent has migrated to a new location and has a stable state.

The Agent class provides methods to command state transitions.

When in the active state, agents can execute its operations. More precisely, in JADE agents' actions are called *behaviours*. Behaviours can be simple as the execution of one single action or a set of actions to be executed only once, or complex such as the execution of actions in strict sequence or in a parallel fashion. Agents may execute more than one behaviour at a time. A JADE agent has thus a multitask computational model which allows the execution of whatever combination of simple and complex behaviours. This is achieved by implementing an internal scheduler

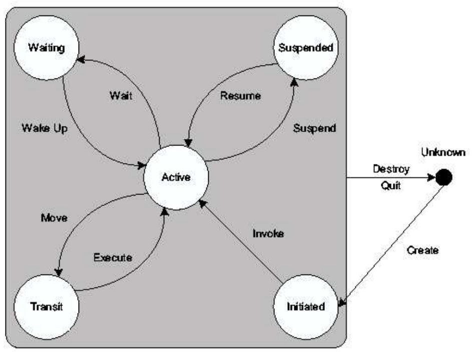


Fig. 4.5. The possible states for an agent

which *interleaves* the execution of the agents' behaviours. The result is that tasks are executed concurrently, assigning each a slice of time in a non-preemptive way. The scheduler is hidden to the programmer and automatically schedule agents' tasks. Control by an agent over the behaviour execution can be done at two levels. A finer level of control is reached by using the *block()* method on a behaviour. This will block only the activities related to that behaviour. A coarse grain control can be obtained by acting on the state of the agent. If the agent transits in the wait state then all its activities are blocked.

4.3.3 The JADE kernel

The JADE kernel is made up of multiple services. Some services map functionalities foreseen by the FIPA specification. Additional services have been implemented for deployment purposes such as replication, security and persistent communication. The additional features make JADE a comprehensive solution for deploying multi-agent systems in real world scenarios. Each service can be separetely activated.

The kernel services are:

- messaging: the messaging service supports ACL message exchange and MTP management. JADE comprises a framework which supports multiple MTPs. JADE itself provides some implemented MTPs (the IIOP MTP and the HTTP MTP) and new ones can be written by developers. In general, MTPs can be dynamically loaded at runtime and more MTPs can be active on a given container. This helps administrators create the topology that best suit their needs. JADE performs message routing for both incoming and outgoing messages, using a singlehop routing table that requires direct visibility among containers. When a new MTP is activated on a container, the JADE platform gains a new address that is added to the list in the platform profile. Moreover, the new address is added to all the agent descriptions contained within the AMS knowledge base;

- agent management: this service launches the AMS and the DF. The AMS supports the agent life cycle, i.e. activation, execution, suspension, reactivation and destruction of agents. The AMS regulates also the shutdown of a platform or a container. The DF can be configured according to the following parameters:

  – autocleanup: when set to true indicates that the DF will automatically clean up registrations as soon as agents terminate;

  – leasetime: indicates the maximum lease time (in millisecond) that the DF will grant for agent description registrations (defaults to infinite);

  – number of result: indicates the maximum number of items found in a search operation that the DF will return to the requester (defaults to 100);

  – database URL, driver, username and password: the first parameter indicates the JDBC URL of the database the DF will store its catalogue into. If this parameter is not specified the DF will keep its catalogue in memory. The other parameters indicate respectively the JDBC driver, the username and the password to be used to access the DF database. These three parameters are ignored if the databse URL is not set.

  The full FIPA management ontology (see subsection 4.2) is implemented;

- agent mobility: the mobility service allows agents to move from one container to another. JADE supports strong mobility [FPV98], i.e. mobility of both code and data. The nice feature is that an agent can migrate to a remote container running on a host which does not actually store the agent Java classes on filesystem;

- persistent delivery: this service defines a buffering, storage and retry strategy for undelivered ACL messages. This is useful when we want to manage situations where the agent is not found and which require a special handling beyond the standard failure notification to the sender. Instead of adopting the standard FIPA behaviour, the persistent delivery service buffers the message. Which message types to buffer is chosen according to a user defined filter. Filters are defined on a per-container basis. As a message fails to be delivered, the service goes through the chain of filters to check whether a filter claims the message. Unclaimed messages produce an immediate failure notification to the sender. If some filter claims the message, it is buffered and a delivery attempt is made after the delay specified by the filter. If the message still results undelivered a failure message is sent back to the sender. The buffering of the message is done by default by storing the message in main-memory. Alternatively, one can specify a directory in the file system;

- main container replication and address-notification: the basic logical organization of an agent platform comprises one *main container* to which agent containers are linked. The main container holds information vital to keep the platform up and running. The main container is the only which knows the set of all nodes making up the platform, the set of all agents in the platform and the set of all activated MTPs. Further, the AMS and DF are hosted by the main container. Having one main container inevitably produces a single-point of failure. The main container replication service is inteded to overcome this limitation by replicating the main container. The basic idea is to allow the creation of backup containers. The first activated main container plays the role of master and the others are simply backups. The master and backup main containers form the group of main contianers. Main containers are always organized in a logical ring: if one of them falls, the others can detect the event. An agent container may be linked to any of the main containers available in the platform. If an agent container detects the main container it is attached to is not running any longer, it attaches to another one. This mechanism implies that the list of all main containers is known to each agent container. This action can be done statically or dynamically. Statically binding is obtained by passing the list of all main containers when launching a new agent container. Dynamic binding is obtained by activating the *address notification service* on all main containers and agent containers so as to propagate updates on the logical organization of the ring whenever the list is modified.

4.3.4 Persistence

An agent platform is a highly dynamic environment. Whilst agent are deemed to be intelligent enough to execute in such environment, system failures may endenger agents' lives as they operate. The fact that an agent can suddenly die is a dangerous event in an agent platform. Think about a learning agent that has matured a certain experience on how to deal with some situations. If the agent dies, replacing it may not be a straightforward task as this implies the loss of the agent's memory. Thus, unanticipated system failures must be accounted for and a proper solution put in place.

A common way to solve this problem is to activate a persistence mechanism that stores on non-volatile memory the data required to restore the system prior to the failure. In terms of MAS, this translates in recoverying both the system topology (the agent containers) and the agents with their capabilities and memory. To this purpose JADE offers a persistence add-on. The JADE persistence add-on provides a runtime system that can save and retrieve the topology of the MAS and the state of the agents on a persistent storage system. A persistent storage system can be either a filesystem or a DBMS. We call this a repository.

The service allows the following operations:

- save container: saves the name, the executing agents and the activated MTPs of the given container in the repository;

- reload an agent container from the repository. All agent and MTPS are reloaded from the repository;

- delete container: deletes a container data from the repository;
- save agent: stores the agent state on the repository. The action is actually executed at the next scheduling checkpoint, i.e. when the control returns back to the JADE scheduler after behaviours execution. The agent itself must be declared serializable in order to allow this operation;
- load agent: creates a new agent and initializes it according to the state read from the repository;
- reload agent: the agent's state is replaced by the state read form the repository;
- remove agent: removes the agent's state from the repository;
- freeze agent: stores the agent state on the repository. The agent execution is then stopped and its identity preserved. This means the agents is addressable and messages can be sent to it. Any ACL message sent to the frozen agent will be persisted following the persistence service of the kernel;
- thaw agent: activates a frozen agent, loading its state from the repository and delivering to it the messages buffered while it was frozen.

4.3.5 JESS

A JADE agent is an object which has its own thread of control, has a message queue and may interleave the execution of one or more behaviours. In addition, JADE agents can do automated reasoning. An agent with automated reasoning capabilities basically handles external or internal events applying some kind of algorithm. A way to build such algorithms is to use sets of rules. Rules are used to represent heuristics which specify a set of actions to be performed for a given situation. A rule is composed of an *if* portion and a *then* portion. The *if* portion of a rule is a series of patterns which specify the facts (or data) which cause the rule to be applicable (pattern matching). Pattern matching always occurs whenever changes are made to facts. An inference engine automatically matches facts against patterns and determines which rules are applicable. The *then* portion of a rule is the set of actions to be executed when the rule is applicable. As the actions are executed, the list of applicable rules may be affected by adding or removing facts. The inference engine then selects another rule and executes its actions. This process continues until no applicable rules remain.

The rule engine used by JADE is the popular Java Expert System Shell (JESS). JESS is a scripting environment written entirely in Java^{TM}. JESS processes knowledge in the form of declarative rules and its language has been inspired by CLIPS [NAS84]. Like CLIPS, Jess uses the Rete algorithm [For82] to process rules, a very efficient mechanism for solving the difficult many-to-many matching problem. Besides providing an inference engine which extends CLIPS including backwards chaining and working memory queries, JESS binds with the Java environment, being able to manipulate and reason about Java objects.

4.3.6 JADE-S: security for multi-agent systems

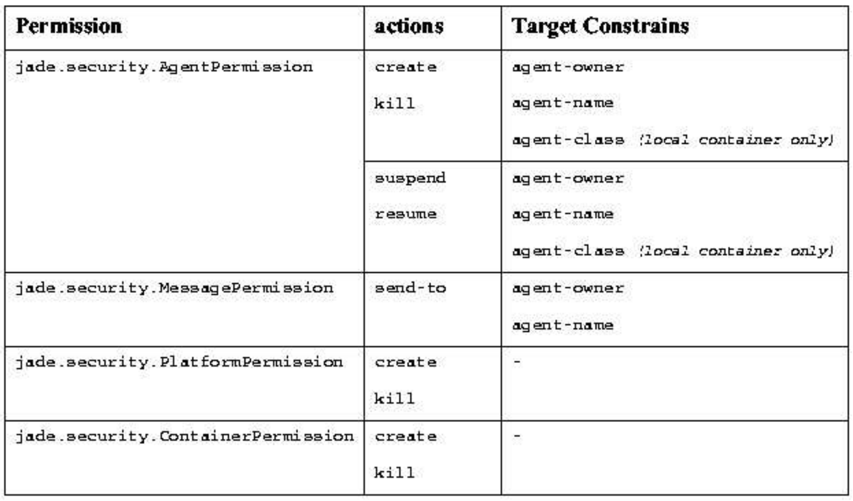
As for all today's IT products, security is an essential feature for deploying multi-agent systems. Without proper security measures we cannot bring a system to market. Security concerns are in some way amplified for multi-agent system as they configure as distributed systems, allow strong mobility (both the code and the data can be moved) and make intensive use of high-level communication. Dangers include securing an agent's execution (it must not be destroyed by other unless they are otherwise allowed), protecting against message sniffing, guaranteeing the identity of agents and securing their profile (for instance the actions they are permitted to perform).

JADE addresses the security issues by extending the Java security model. The three pillars of Jade's solutions are user authentication, agent actions authorization against agent permissions, and message signature and encryption.

Authentication provides a way to know which users are logged on in a JADE platform. A user is known by its name and an associated password. The JADE authentication service is based on the Java Authentication and Authorization Service (JASS)and is called *security service.* It has a callback mechanism that allows users to provide their identity's data and a login module which verifies the supplied data. The available callback mechanisms are based on command-line parameters (eventually in a plain text configuration file) or on interactive (textual or graphical) dialogs prompted upon the creation of a container. As login modules the security service supports both modules for authenticating operating system users (Unix and Windows NT) and a module for authenticating system-independent users (Kerberos). In this way, each container or agent in the platform is owned by an authenticated user.

Permissions concern which actions an agent is allowed to perform in a platform. Agents are granted access to platform services and resources according to a set of rules. Sets of rules are stored in *policy* files. JADE policy files may include all standard permissions defined by Java/JAAS plus specific permissions pertaining the domain of software agents and containers (see Figure 4.6). JADE policy files can have two scopes. Policy files assoicated with the MainContainer specifies rules valid for the whole platform. Policy files associated with peripheral containers enforce rules which are valid only in the same peripheral container. The JADE service charged of checking that agents are actually authorized to perform the actions they request is called *permission service.*

Finally, JADE provides two services called *signature service* and *encryption service* which are meant to guarantee the integrity and the confidentiality of messages.



Permission	actions	Target Constrains
jade.security.AgentPermission	create kill	agent-owner agent-name agent-class *(local container only)*
	suspend resume	agent-owner agent-name agent-class *(local container only)*
jade.security.MessagePermission	send-to	agent-owner agent-name
jade.security.PlatformPermission	create kill	-
jade.security.ContainerPermission	create kill	-

Fig. 4.6. The possible permissions as reported by the Jade-S administration guide [Boa04]

Part II

Applying agent technology to information systems

5. WINK: WEB-LINKED INTEGRATION OF NETWORK-BASED KNOWLEDGE

The Wink is a collaborative project management system. The Wink was the result of a project funded by the European Commission and executed by the University of Modena, Gruppo Formula SPA and Alenia Spazio (Turin site), one of the worldwide leading space industry. This latter offered the testbed for the system deployment. In particular, the Wink system was used for the management of projects related to the design and manufacturing of satellites or International Space Station modules.

5.1 Project motivation

The increasing of globalization and flexibility required to the companies has generated, in the last decade, new issues, related to the managing of large scale projects within geographically distributed network and to the cooperation of enterprises. ICT support systems are required to allow enterprises to share information, guarantee data-consistency and to establish synchronized and collaborative processes. In particular, the management issues related to the aerospace industry, with specific regard to the production of scientific satellites and in-orbit infrastructures, are very specific even if compared to the traditional one-of-a-kind production models. Many critical factors are combined together: absolute reliability of materials, components, equipments and final assembled outputs; unique production processes and products for unique aims; huge investments and high risks related to the return on investment factor and strict time constraints. As regards to the reliability and uniqueness, they have led to the development of sophisticated and accurate procedures for requirements analysis, verification and testing. All of them are particularly detailed and require the accurate management of an enormous quantity of technical documentation. The high quality of final products can only be assured by acquiring components from highly specialized companies; therefore, it is very rare that the entire space project (called space program) is carried out within the scope of a single organization, but more often the prime contractor (typically a large company with adequate know-how) outsources specific components or activities to smaller firms through various forms of subcontracting. In these scenarios, the relations between main contractors and subcontractors are strategic and must be supported by adequate collaboration practices. Finally the strict time constraints and the huge investments require that all the activities of the entire product life-cycle (design, manufacturing, verification and testing, launch) must be planned and monitored precisely, by adopting project management tools capable of taking into account several factors like resource and product availability, budget and time constraints, personnel skills and availability, and so forth. Traditionally, all these issues have been dealt with information systems capable of managing one feature at a time, nevertheless requiring integration among them that was hard to automatically obtain. Nowadays, the integration of the diverse management tools and information sources is necessary for several reasons. Firstly, due to the fast technology evolution that has shortened the overall product life-cycle: quite often, during a space program, the time elapsed between the design and the launch phases is so long that some of the involved technologies become obsolete. Secondly, new collaboration paradigms such as Collaborative Project Management, Supply Chain Management and Knowledge Management are definitely mature to support the overall process and must be accompanied by adequate information systems [EM03, WZ99]. Finally, the availability on the market of new technologies (XML for the data exchange between different systems, SOAP for the interoperability between different software platforms, mobile agents for accessing remote systems resources) allows a more powerful and potentially easier interoperability than in the past. In response to these needs the WINK system offers a collaborative project management system that integrates information coming from a real world scenario in aerospace industries, offered by Alenia Spazio, the Italian leader of aerospace industry. The WINK provides users with a set of tools which increase the capability of managing large projects by supporting operations such as alert firing, activity scheduling, and project planning structures, providing a customized and integrated web interface. The business logic is realized by a multi-agent query management component and web services [Con], which ensure the whole interoperability of the software components.

5.2 Case study

The life cycle of an Alenia space program (i.e. the plan related to the design, manufacturing, assembling and launch of a scientific satellite or an International Space Station module) can last up to ten years. Among the scheduled processes, the Assembly, Integration and Verification (for short AIV) phases are very critical in an aerospace context due to the fact that numerous components and relative manufacturing and testing procedures are unique as well as the fact that high levels of quality must be guaranteed. At Alenia Spazio S.p.A., the AIV department is responsible for the supervision of the whole project life cycle. At the beginning of the project, requirements lead to a products tree that is split among external enterprises that play a role of contractors or subcontractors on the basis of budget amount and responsibility. The AIV department analyzes the project requirements and organizes them in a hierarchical tree where the lower levels typically list the needed equipment, the intermediate levels represent the assembled components and the root level is the system perspective. In this way, the best verification procedures matching the requirements are defined. These activities are supported by different information systems (of different enterprises) and involve many complex and distributed processes:

- project scheduling systems for Gantt definition;

- project accounting systems for the definition of project costs, budget and final balance;

- resource planning systems for personnel allocation combining the right skills with the right activities according to timing and cost constraints;

- requirement management systems: requirements are managed by dedicated databases due to the complexity of the product and the high value of the materials;

- document management system to manage Non Conformity Reports (NCRs). As for the product requirements, the non-conformity reports are managed by a specific database.

5.3 Architecture

The WINK architecture, shown in Figure 5.1, is based on a three-tier model where the client tier makes available an *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 (resource management, non conformities, alert, document organization and so on). The Integration Framework collects the data required by the implemented business processes in a very dynamic way, integrating information coming from heterogeneous and possibly distributed data.

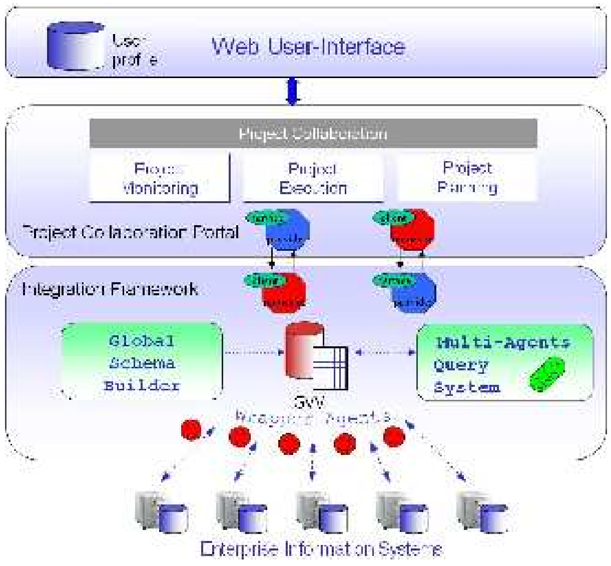


Fig. 5.1. The WINK architecture

5.4 Overview of the Project Collaboration Portal

The Project Collaboration Portal (PCP for short) addresses the issues related to the decentralization of the project and production activities with the related concentration on the core business in the specific industrial sector of the one-of-a-kind production (e.g.: industrial equipment, ship building, aerospace). These activities assure both final high quality and low overall logistics and production costs of the final products. In these distributed contexts, where the product life-cycle is characterized by activities that are not repeated, the only way to guarantee high levels of quality of service within distributed manufacturing processes is to adopt a strategy of *collaboration* extending the concurrent engineering techniques to the entire network of partners (main contractor, subcontractors and suppliers). This model implies not only a series of formal agreements among different partners, but from a technological perspective, it also implies the existence of a collective shared information system integrated with the different local legacy application to create a truly shared and collaborative workspace.

The PCP is composed of four modules: *project collaboration*, *monitoring*, *execution* and *planning* (see Figure 5.1) The PCP allows visibility of data presentations in aggregate and detailed views, searching, filtering, printable reports and links between different data for each node or actor according to visibility rights. A document based system has been developed that permits a large number of documents related to each data object (products, bills of material, projects and so on) to be managed at a distributed level. Moreover a smart configurable workflow automation system has been developed to allow interactions between users in order to negotiate specific aspects (orders, activity or phase duration and so on) in all the project life-cycle phases (planning, execution, monitoring). Project planning permits defining the transversal project structures called respectively *work breakdown structure* (WBS), *extended project organizational structure* (EPOS) and *activity plan* (AP). The WBS is a deliverable oriented structure mainly utilized for accounting purpose, the EPOS describes the temporary, multi-site and multi-company hierarchical organization created to carry out a particular project, and the AP describes the project in terms of operational phases and activities. The *project execution* allows tracking the project progress in terms of consumed resources, exception management, and performance (time and costs) to identify variances from the plan, generating alerts if the consumption overcomes the budget, according to the rules defined for the WINK *alert system.* Finally the *project monitoring* allows reporting all the relevant data information by means of OLAP functionalities and printable reports.

5.5 The integration framework

While the PCP provides a user-friendly presentation layer, the Integration Framework represents the data engine of the WINK system. It plays two main functions: integrating knowledge and query processing. These two functions are related in that the latter presupposes the mappings among data and data sources produced during the former. The Integration Framework is thus naturally separated in two modules. The first is a mediator system, which describes data sources according to an adopted common language (ODL_{i^3}) and builds mappings among data according to the affinity of their semantical meaning (the meaning is assigned annotating concepts with WordNet). The mediator system used in the WINK system is MOMIS [BCBV01]. The second module is a multi-agent system, composed by agents capable of carrying out a user query.

5.5.1 Information integration

The MOMIS is a mediator system which adopts a semantic approach: affinity among classes coming from diverse sources is measured on the classes annotations. Annotations are produced by a designer and are based on the WordNet [Fel98]. Details of the logic and algorithm governing the MOMIS integration process are reported in [BSBV97, BBGV01, BCBV01].

We here report about the integration done in our case study as exemplifying the mediation process.

Space Program Integration

The activities of the AIV manager require the AIV manager is constantly kept up-to-date on diverse aspects of the projects s/he is managing from personnel to materials and components, from costs to non-conformities. Starting from the requirements we have identified through interviewing AIV managers in collaboration with the IT department of Alenia, we selected a set of sources that are necessary data to support AIV managers throughout their job. Due to the internal organization of Alenia, the interesting data sources have been created and managed by different units. Each unit has been managing data following different styles and criteria, resulting in an heterogeneous collection of information sources. The set of sources to be integrated includes:

- Storage DB: serves the logistic management of the AIV department. It stores information about material and equipment and the requests submitted to the storage unit and the subcontractors. It has been implemented using MS Access;

- AIV DB: stores data related to product trees, project requirements and project activities. This source is under the direct control of the AIV manager and has been implemented using Oracle 8i;

- SAP DB: this is a classical SAP system. The portion of data belonging to this source that is interesting in our application scenario are mainly related to the project organization (cost centers, resources, workpackages) and supply management (order, billing, etc);

- NCR DB: collects data related to non-conformities and their impact on the project schedules. It has been implemented using Lotus Notes;

- WHALES: is the data source managed by the PCP module. Its structure is mainly application independent, with a few tuning parameters. It is a data source we decided to create to materialize on the WINK system related to specific project management functionalities not present within Alenia systems. It has been implemented using MS SqlServer.

The integration process has been carried out over 70 relations distributed in 5 data sources.

Schema-derived relationships

First, the schema-derived relationships holding at intra-schema level are automatically extracted by analyzing each ODL_{i^3} schema separately. These relationships are determined using the information on foreign keys holding between the relations of a schema. As an example, we report a few relationships extracted from the AIVB schema. A relation of the AIVB schema is PRODUCT_TREE. It contains the data related to the product tree of a project. A product tree is identified by the field PT_ID. In the same schema there are other relations declaring a foreign key to the identifier of a product tree. Just to cite a few, relations that have this constraint are for instance CI_PRODUCT that stores the information on each item of the product tree and CI_PHASE_DEFINITION that stores the phases to be accomplished in order to realize the tree. We obtain thus the following RT relations:

1. AIVB.CI_PRODUCT_TREE RT AIVB.CI_PRODUCT
2. AIVB.CI_PRODUCT_TREE RT AIVB.CI_PHASE_DEFINITION

In the case we have the additional property of the attribute being the primary key of both relations we have an ISA relationship identified with a BT/NT link. A BT relationship is extracted for the relations REQUIREMENT - that stores the requirement of each activity to be executed and IMAGE_LINK that stores the links to a technical document for each requirement (such as drawings):

3. AIVB.REQUIREMENT BT AIVB.IMAGE_LINK

Lexical-derived inter-schema relationships

In this step, terminological and extensional relationships holding at intra-schema level are extracted by analyzing ODL_{i^3} schemata together. The extraction of these relationships is based upon the lexical relations holding between classes and attribute names. This is a kind of knowledge which is not based on the rules of a data definition language but derives from the names assigned by the integration designer. This is achieved during the annotation phase where the designer assigns a meaningful word and meaning to each relation and attribute name. This phase is crucial in the integration process as much attention has to be drawn towards the selection of the meaning to be assigned to a name; this presupposes a correct and complete knowledge about the content of all schemata. In our case, we have annotated approximately 1400 terms and obtained 900 relationships. A few examples are:

4. WHALES.PHASE SYN AIVB.CI_PHASE_DEFINITION

5. StorageDB.request SYN WHALES.MyPR

6. NCR.NCR.item SYN AIVB.CI_PRODUCT.CI_ID

7. StorageDB.request.Program SYN SAP.ODA.PROGRAM

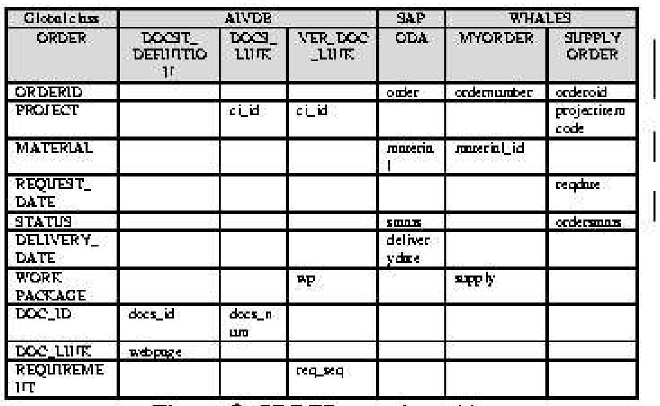
In 5) both the antecedent and subsequent elements are relations. The relationship explicits that requests of equipments stored in the request relation of the StorageDB schema are synonym of the requests stored in the MyPR relation of the WHALES schema. In the following two relationships, both the antecedent and the subsequent elements are attributes. Thus, an item in a non-conformity stored in the NCR schema is synonym of an item of the product tree of the AIVB schema. The same goes for the attribute Program which identifies the program a request in the StorageDB schema and an order in the SAP schema refer to. All relations have been built starting from the annotated schema and exploiting the inference engine of ODB-Tools.

Clustering and global mapping

Once the relationships among the classes of the schemata have been inferred, the integration process goes on with the clustering phase. During this phase, we identify classes that describe the semantically related information, grouping them in the same cluster. The level of semantic matching is measured by means of the affinity function [CAdV01]. In our test case, the Integration Framework automatically recognized twelve clusters. A cluster comprises from two to four classes, being the average three. Significantly, there have been built clusters for personnel, resources, material orders, equipment requests, non-conformities, product tree, requirements, procedures and project documents. Let us take as an example the cluster where all information concerning orders has been grouped. The cluster (named ORDER) comprises six relations that cover diverse aspects related to order management within the AIV department. First, we find the relation ODA from the SAP schema, which stores very general information about an order (buyer, program, item, description). Then, we have two relations taken form the WHALES schema that store additional information such as request and delivery dates, quantity, and supplier. As order is here intended to be an item of the product tree, the cluster includes also three relations from the AIVB source that report the description of the requirements related to the particular item. All these data provide a comprehensive view of the concept of order as meant within the AIV department. Given its semantic relevance, the cluster was chosen to form a global class during the last stage of the integration process. Mappings are defined by means of a table whose columns represent the set of the local classes which belong to the cluster and whose rows represent the global attributes (see Figure 5.2).

5.5.2 Query processing

The typical usage scenario of the WINK system foresees the AIV Manager and other users operating the WINK web interface to view and manage project infor-



Global class	AIVDB			SAP	WHALES	
ORDER	DOCST_ DEFINITIO N	DOCS_ LINK	VER_DOC _LINK	ODA	MYORDER	SUPPLY ORDER
ORDERID				order	ordernumber	orderoid
PROJECT		ci_id	ci_id			projectitem code
MATERIAL				materia l	material_id	
REQUEST_ DATE						reqdate
STATUS				status		orderstatus
DELIVERY_ DATE				deliver ydate		
WORK PACKAGE			wp		supply	
DOC_ID	docs_id	docs_n um				
DOC_LINK	webpage					
REQUIREME NT			req_seq			

Fig. 5.2. The ORDER mapping table

mation. The first operation is the logon where the user specifies the node (that represents the user point of view for accessing and interacting with other nodes), the role (which is the organizational position he/she wants to impersonate for the current session), user name and password. After having stated the logon credentials the WINK system enables the use of the proper functionalities and presents the personalized home page. For example the WINK Personal Home Page for an AIV manager includes current alerts coming from relevant project events, currently ongoing workflow activities, a list of relevant links for easy access of the users projects and frequently used functions. In order to propose the entry point for any collaboration process in WINK, the main areas in the WINK Personal Home Page are the following:

- My alerts: contains the notification of relevant events occurred in the project to the actor of the system, regarding the project and position s/he chooses to select. The actor can have a look to the data that caused the alert, and can finally decide to get rid of it, by ignoring it;

- Open NCR: contains the list of currently open non-conformities that have to be solved. The actor can navigate the list and access documents that accompany the non-conformity generation;

- My Orders: contains the list of all order that have been submitted but no yet closed. The actor can thus monitor the execution of the orders he submitted or the orders for which an authorization is required;

- My Requests: contains the list of internal equipment requests, reporting the status and tracking any change in the data related to them. The actor can thus know whether a requested instrument can be available on time and subsequently decide alternative actions or requests;

- My Activities: contains the list of open negotiation that the logged on actor must consider, since he is requested for authorization or negotiation. The actor must follow the linked workflow interaction in order to comply with the negotiation activities he is involved in;

- My Projects: contains the list of the organizational positions that the logged on actor has in the moment of logging on. The actor can choose among the different projects and organizational positions he is in charge of. Whenever he selects another position, the home page reloads in order to present the above mentioned collaboration alerts and activities for the specific project and position;
- Whats new: contains a series of static information that are common to the project network the user choose to log on.
- My Link: contains the preferred links (typically to external web sites or application) for the actor, regarding the chosen position.
- My Frequent Tasks: contains the most frequently used WINK function of the logged in organizational position, along with the workflow activities it is in charge to activate.

Many of these operations require the execution of queries in order to retrieve up-to-date data, to be subsequently processed. The analysis of the WINK system requirements brought to classify query types according to two orthogonal dimensions. The first captures the design perspective, i.e. whether the query responds to explicit and well-known application requirements or is introduced by users for contingent needs. The second dimension concerns an operative perspective, i.e. the times a specific query is issued. In addition, queries can be submitted either in response to explicit users requests or as scheduled operations required to keep data up-to-date in an automatic fashion. Combining the two dimensions, we have four kinds of queries:

- designed and user-submitted queries: these are defined at design time to meet explicit application requirements and are executed only when the user explicitly calls an operation that relies on the query execution;

- designed and scheduled: these are defined at design time to meet user requirements and consist in the automatic execution of queries on a regular basis (to materialize distributed data at scheduled time);
- user defined and user submitted: while operating the system, new queries can be composed and executed under explicit user requests;
- user defined and scheduled: while operating the system, new requirements may emerge and determine the introduction of new queries to be scheduled on a regular basis. This type of query is important for designers when new application requirements are unfolded.

All these kinds of queries are executed by the WINK system by exploiting the multi-agent query system included within the Integration Framework.

The main contribution of agent technology in the WINK project concerns what we call *query agents*. Query agents support the execution of all identified query types.

Two are the technological peculiarities of query agents.

The first is the way they carry out the query process. The basic principle is that a query agent always executes a query locally to the data source. A WINK query assigned to an agent always retrieve data from a single source. Wink query agents are mobile agents.

The second is interoperability. In the Wink system query agents glue together functionalities pertaining to different layers, namely the Project Collaboration Portal and the Integration Framework. As these layers are realized using different technologies, software agents must be able to deal with both 'worlds'. Interoperability comes into play in two situations. Query agents are assigned tasks from within the web interface, which from the viewpoint of an agent platform is an external application. The matter is how to make an application running outside the Java virtual machine of the agent platform communicate with the services it provides and the agents which run within it. To this purpose JADE makes available a wrapper class, which allows to retrieve an instance of a Java runtime environment and perform a few administrative task in a programmatic way. More precisely, an application acting as a wrapper of a Jade platform can create containers and set up agents. Although limited in functionalities, this interface is enough to access a running agent platform. Our contribution was to develop a web service for the wrapper class. This move allowed to give access to the agent platform not only to external Java-based applications but also to external non-Java applications through the web.

Interoperability comes also into play when the execution of a service involves agent and non-agent software component. The easiest example is when a query is submitted through the user interface: the query is actually solved and the result will appear as a new web page. A query agent must have a way to communicate results back to the calling component. In order to guarantee the best possible level of interoperability the communication from agents to non agent components has been realized by means of web services. Query agents are include indeed a web service client which can perform remote procedure calls to remote services on the web.

The web service version of the Jade wrapper class together with the integration of a web service client into an agent enable the communication between agent and generic non agent components.

Example execution

An example execution is the processing of a *designed and user submitted query* (Figure 5.3). First, the WINK users compose the query by means of a parametric dynamic web page. Then, once the query is ready and submitted, the ASP page invokes an appropriate web service. For example when the AIV manager wants to know the list of closed orders including the requested item number, the date it was requested, the date it was delivered, the workpackage and the requirement it was associated to, the composed query over the GVV could look like the following: `Select Item,`

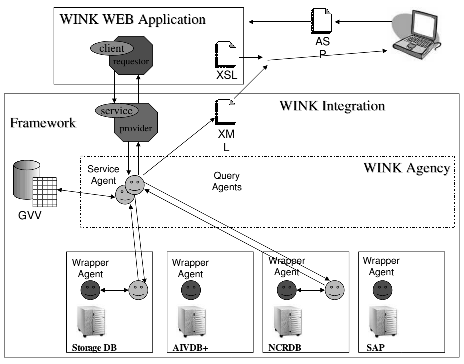


Fig. 5.3. The execution of a designed and user submitted query

`RequestDate, DeliveryDate, WorkPackage, RequirementID from Order where Status-=closed`

The ASP page calls a web service that acts upon the WINK Agency in order to spawn the agents that will be charged of the query execution and result delivery. The queries to be executed are handed on to query agents. In the example we obtain the following queries which are executable directly at data source level: `SAP source: Q1 Select Material, Wp from SAP. ODA where State=closed WHALES source: Q2 Select ProjectItem, Date from WHALES.MyOrder where Status-=closed WHALES source: Q3 Select ProjectitemCode, DeliveryDate from WHALES.SupplyOrder where DeliveryDate is not null and OrderStatus =closed AIVB source: Q4 Select CI_ID, REQ_SEQ from AIVB.VER_DOC_LINK` These queries are assigned to a same number of Query agents. Each Query Agent will move to the data source the query refers to, will interact with the Wrapper Agent in order to execute the local query and finally will report the answer. In order to deliver results so as to update the correct information, Query Agents reports query answers in the desired format (in our case, an xml format). The calling ASP page will then apply the desired XSL stylesheet to present data on the WINK web interface. Note that no query fusion is perform in order to present one global result from the answers to executable queries. This improvement has been presented in the Sewasie system (see Chapter 6).

6. THE SEWASIE MULTI-AGENT SYSTEM: MANAGING A NETWORK OF MEDIATORS

The **SE**mantic **W**ebs and **A**gent**S** in **I**ntegrated **E**conomies (for short SEWASIE) project aims at creating a prototype information system for the integration of business information. The high-level goal is to support information exchange among enterprises which seek collaboration to improve their market position. In particular, the reference scenario taken into consideration is that of small and medium enterprises (SMEs) which activate partnerships and group together facing the market with a common strategy and products (we will call such an aggregate of companies a *consortium*). In order to allow the emergence of such *integrated* economies two are the key enabling factors: (a) *information integration* in order to build shared knowledge which partners can reliably refer to during their production and business activities and (b) *information exchange* in order to deliver products and services to external companies.

The SEWASIE system represents the natural evolution of mediator systems [Wie92], i.e. systems which are intended to provide an integrated, uniform view of an heterogeneous and distributed set of data sources. Each node, i.e. each company or consortium belonging to the SEWASIE network, exposes what is called a *Global Virtual View* (for short GVV) of the underlying data. A GVV is a structured representation of the information a node exposes. This representation contains all concepts and relationships among them. A GVV can be navigated and queries can be produced over its content.

Each node needs thus to *produce* this GVV starting from the collection of data stored in its data sources, which in general spans over different types from free format files to web pages to databases. This activity is carried out by a mediator system.

When isolated nodes come together to form a consortium then the SEWASIE system provides services to further integrated the GVVs of the involved nodes to build a higher level GVV corresponding to the knowledge produced and shared within the consortium. This brings the possibility to perform a number of operations from the search of consortium with particular features (like belonging to a specific market segment or providing a certain service), to the negotiation of contracts and to the processing of queries over the integrated schemata (GVVs).

From a technical viewpoint, the vision of the SEWASIE system is to manage a network of information systems, distributed and heterogeneous in its nature. The approach adopted to face the challenge of heterogeneity is the one proposed by mediator systems [Wie92]. Mediator systems allow to wrap data sources so as to express their schema according to a chosen model. This unifies the schema representations and allows the application of reasoning techniques which disambiguate the schema semantics and help build mappings among them. The result is what can be called a *Global Virtual View* which gives one single integrated view of the underlying schemata and one single point to access the underlying data sources.

In the SEWASIE system we can identify two levels at which integration is required. At local level, each company must solve its own semantic heterogeneity in order to expose a unified view of its data. At network level, the system must maintain coherent information on the GVVs exposed and how they related which each other. This is not an absolute classification but corresponds to a modular approach which can be recursively applied in a system composed of n integration levels. The scenario addressed by the SEWASIE project becomes an environment populated by mediator systems.

In the following we give more details of the SEWASIE approach and describe the issues related to the implemented solution.

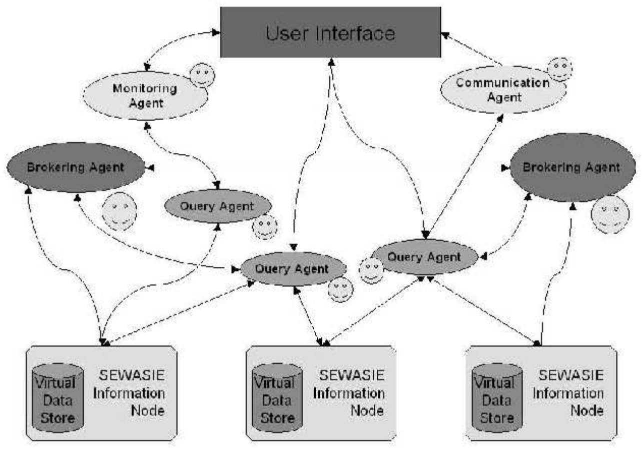


Fig. 6.1. The high-level architecture of the SEWASIE multi-agent system

6.1 The SEWASIE system architecture

The SEWASIE system high level architecture is depicted in Figure 6.1.

SINodes are mediator-based systems [Wie92], each including a *Virtual Data Store*, an *Ontology Builder*, and a *Query Manager*. A Virtual Data Store represents a virtual view of the overall information managed within an SINode and consists of the managed information sources, wrappers, and a metadata repository. The managed information sources are heterogeneous collections of structured, semi-structured, or unstructured data, e.g. relational databases, XML/HTML or text documents and are accessible by means of wrappers which are intended to translate to and from local access languages. There is one wrapper linked to each information source. According to the metadata provided by the wrappers, the Ontology Builder performs semantic enrichment processes in order to create and maintain the current ontology which is made up of the GVV, of the managed sources and the mapping description between the GVV itself and the integrated sources. Ontologies are built on a logical layer based on existing W3C standard. The *Metadata Repository* holds the ontology (GVV) and the knowledge required to establish semantic inter-relationships between the SINode itself and the neighboring ones.

In order to support the set of SINodes in offering an integrated view over their ontologies, a set of agents has been defined. These agents cover functionalities required to keep knowledge of the topology of the system as well as the semantical mappings that can be established among the GVVs of the SINodes. The topology of the system is used to know which SINodes participate to the SEWASIE network, whether they are available in a certain moment to solve queries posed to the system or request to update the ontology. The semantical mappings are exploited in the query processing phase, where a query may involve more SINodes. More precisely, SEWASIE agents have four basic types: *Brokering Agents*, *Query Agents*, *Monitoring Agents* and *Communication Agents*.

Brokering Agents are the peers responsible for maintaining a view of the knowledge handled by the network. This view is maintained in *ontology mappings*, that are composed by the information on the specific content of the SINodes which are registered by the brokering agent, and also by the information on the content of other brokering agents. Thus, brokering agents must provide means to publish the locally held information within the network.

Query Agents are the carriers of the user query from the user interface to the SINodes, and have the task of solving a query by interacting with the brokering agent network. Once a brokering agent is contacted, it informs the query agent which SINodes under its control contain relevant information for the query. Then, the query agent asks the involved SINodes for collecting partial results. Also, it decides whether to continue the search with other brokering agents. Once this process is over, all partial results are fused into a final answer to be delivered to the user. A Query Tool Agent is part of the SEWASIE user interface. It includes a query tool that guides the user in composing queries. A query tool agent is responsible for contacting brokering agents in order to get ontologies and is also responsible to manage the set of query agents required to solve users' queries.

Monitoring Agents and Communication Agents provide user-oriented services. Monitoring agents are responsible for monitoring information sources according to user interests which are defined in *monitoring profiles.* Each monitoring agent is assigned a specific topic of interest chosen by one user. Each monitoring agent contains an internal ontology, i.e. a *domain model*, which is linked to brokering agents ontologies. Agents of this type regularly set up query agents to query the SEWASIE network, filter the results, and fill *monitoring repositories* with observed documents.

A communication agent supports negotiation between one user and other parties present in the SEWASIE network (usually parties that have exposed an SINode). Any query including contact information sets the context to launch the communication. Several types of communication agents can be created for one communication each helping find and contact potential business partner, asking for initial offers, and ranking them. The human negotiator can then decide and choose the best offer to begin negotiating, with support from the communication tool. This latter maintains four types of agents, that can act in the different phases of the negotiation [Con04]. The Initiation Agent tries to establish contacts with potential partners according to the a user's preferences. The Filtering and Ranking Agent maintains the overview of the negotiation process (containing several parallel negotiations) and provides support for decision making by calculating the scores of received offers and ranking them. The main task of the Resource Management Agent is to notify the user when resources lack. The Negotiation Agent can act when the negotiation achieves a well structured and defined state. In this case the Negotiation Agent tries to provide some offers depending on user defined preferences and negotiation strategy.

6.2 The SEWASIE multi-agent platform

The SEWASIE system is distributed and as such has been designed using a multi-agent system. To build a robust solution we have to tackle at least two issues:

- coordination: as more entities operate in a distributed application suitable coordination between the actions of one module and among the actions of different modules is required in order to preserve the system in a coherent state.

- fault tolerance: distribution makes difficult the road to reliability and fault tolerance. Nevertheless appropriate mechanisms are required to avoid and/or to recover from system failures. In particular, failures in the execution of one component should not compromise the functioning of the system;

6.2.1 Coordinating agents: protocols and final state machine behaviors

In order to easy the design of the SEWASIE multi-agent system and keep track of the system state we have used two techniques. The first is to design agent communication following standard protocols so as to have conversations that obey to a predefined set of rules. This help keep track of the state of a conversation. The second technique is to assign agents behaviors as final state machines to have control over the activities and the transition from one activity to the other. This help keep track of the internal state of an agent. For this, we distinguish agents as characterized by two state flows.

One flow is a threaded one with states which correspond to those we find for threads in operating systems. At each time an agent has a state which tells about the activity of the agent itself. For instance, the agent can be in the active or suspended mode.

The second state flow is an application flow. The agent holds a state which tells essentially what the agent is doing, which operation it is busy at. This state can be kept private or can be verifiable by other agents. The application state determines whether the agent is available or not for some operations. The result of the current operation brings to new states according to a set of specified transition rules.

The threaded flow and the application flow might be related at some stage.

While all agents are threaded, not all agents possess an application flow. An application flow is desirable whenever an agent engages in complex, possibly lasting activities and when the number of activities is considerable. Defining an application flow helps the agent have a finer control over its activities and internal state.

An application flow is composed by states and transitions among states. For each state, one or more activities are defined. These activities may be simple behaviors or complex ones. Each activity or group of activities must imply a final result. On the basis of the final result, a transition happens according to the applying transition rule.

In SEWASIE agents have all an application flow which times their activities. This is necessary as some operations may require time or because the result of an operation changes how the agent will respond to service requests. With respect to this, the application flows allows to isolate activities or group of activities which disconnect the agent services to the outside world as ongoing changes will impact how these services are provided.

6.2.2 Fault tolerance

Of course, fault tolerance is a desirable feature and a complex issue in distributed systems. Fault-tolerance solutions usually span over a number of areas, considering data replication, code exception handling, network reconfiguration and other countermeasures. Our scope is not at system level and focus on agent's state. We do not consider system-wide fault-tolerance solutions and restrict our attention to being capable of reloading an agent in the case it dies for unpredicted events. For doing this we use a persistence layer.

Persisting run-time objects means being capable of saving on a persistent storage the state of an object and later retrieve this state from the persistent storage to re-instantiate the object with the same features. Persistence is useful for instance when we need a random access file that stores objects or seek an inexpensive, easy-to-use OODB library for Java.

While this appears a natural way for handling objects in fail-safe applications, the solution is not as straightforward. Persisting an object does not boil down to serialize and deserialize it. A number of issues are present, first of all how to recall the object identity.

Most importantly, we have to take into consideration what is called the *object/relational mismatch* (also referred to as the *impedance mismatch*). This is due to the fact that most persistence layers use relational database management systems to manage the underlying persistent storage, leveraging their capability of organizing data files and the power of their query engines. This forces to design some sort of mechanism to map objects into relations. In fact, while objects are defined by means of data and behaviors, relational technologies store data in tables and allow manipulation internally within the database via stored procedures and externally via SQL calls. The mismatch is clear if we consider how we can access data. We traverse objects via their relationships whereas we join the data rows of tables in the relational case. If we want to store object states relying on a DBMS, some logic is required to translate between the object model and the relational model. A persistence layer thus transparently folds database activity into applications, allowing programmers to concentrate on solving the applicative issues.

We may distinguish three approaches. The first foresees the design of classes which contain how they map to some table in the relational database. That is to say a class directly contain the SQL code to produce its relational representation. This approach is in general suitable for applications with a small demand in terms of persistence and which are supposed to be simple enough to stay stable for a long time. A change of the database schema implies a redefinition of the class itself. The second approach is to decouple the SQL mapping from the class definition. In this way, if changes to the relational storage happen, there is still the need to recompile the classes which manage the mappings but not the original objects. Again, this is not suitable for applications which evolve over time. The third and more suitable approach foresees the mapping is done by an appropriate persistence layer which handles the details and complexity of storing and retrieving objects from a database. Application programmers do not need to know the objects of the classes they implement will be some day persisted, relational database do not know that data are distilled from objects. This is the approach adopted by current state-of-the-art persistence framework as Hibernate [fIJ] and Solarmetric's KDO [Sol].

Distinctive features of these products are:

- transparent persistence: no required interfaces or base classes for persistent classes;

- flexible object/relational mapping: mapping strategies can be of different types like table-per-class-hierarchy, table-per-subclass, table-per-concrete-class or table-per-field;

- object-oriented query language: query are expressed on objects. The language may be the ODMG standard OQL or SQL-like. The language usually supports polymorphic queries;

On the same basis, agents can also be persisted in the same way objects are.

Agent persistence reflects the fact that agents are different from objects. First, an object is self-contained. In general, saving an agent may be a more limited operation, as an agent does not hold pointers to other agents. It may contain their universal identifiers but no explicit pointer to them. This surely facilitates the persistence management. On the other hand, persisting an agent can be more sophisticated than persisting objects. While agent identifiers and state much resemble what we do for objects, for agents gets relevant saving also the queue of messages. As messages are indeed objects in an agent platform they deserve the status of first class citizen and may undergo persistence.

This implies also that we can have different persistence actions in the case of agents:

- save: this action stores the agent state on database and eliminates the agent from the list of executing ones. The agent is no longer reachable within the platform;

- freeze: the agent is stored on database and it is suspended. The agent cannot act any longer but is reachable and other agents can send messages to it. The message queue is stored and made available when the agent is thaw;

- save message queue: the agent can execute but is not reachable. The messages are persisted and not delivered until the message queue is reloaded and made visible to the agent.

JADE implements these persistence modalities by means of two services.

The first is included as a standard JADE service and allows the persistence of the message queue.

The second is an add-on service and allows to save or freeze agents relying on the Hibernate persistence framework.

Our contribution for the JADE Persistence add-on focused on testing the support for multiple databases and solving issues related to the usage of the persistence service with one of the most popular DBMS, i.e. MySql [MyS]. Originally, the JADE Persistence add-on was configured to work with the Hypersonic, an all-java database management system which can be used both in the server mode and in the embedded mode. While the framework was implemented to support a generic database for which a JDBC driver exists, it was not possible to use it with MySql due to problems related to agent deserialization. Our solution to the problem was to redefine the data types of the tables in order to properly support the serialization/deserialization of agents.

6.3 The SEWASIE agents

With reference to the management of a network of mediators we identified the following issues:

- connection problem: there must be a way to build the network of mediators. This can be done in two ways. This network can be physical where mediators are configured to get links to other mediators by means of a computer network. In this case each mediator is accessible by others. Although this solution is straightforward, it is not always viable and desirable. First, opening a mediator may not be possible for security or confidentiality reasons. Second, building such a physical network does not bring any additional knowledge. The result is simply the sum of the separate parts. A second way to obtain the network is to build mappings among the knowledge of different mediators and propose a single unified view to access them. This solution is more complex because mappings have to be produced. We take the second option and call the approach *semantic brokering*;
- information access: the mediators' GVVs must not only be visible but queries can be posed over them. A mechanism to solve queries must be put in place.

The next two sections are dedicated to describe the agents designed to solve these issues.

6.4 Semantic brokering: the brokering agent

Brokering agents are a crucial component of the SEWASIE system as they solve the so-called *connection problem* [DS88]. The connection problem concerns the finding of information and capabilities in an automatic fashion in a networked environment where many computational entities and resources are present. The SEWASIE instance of this problem concerns semantical resources. The main challenge is how GVVs can be collected, integrated and queried. The role played by brokering agents

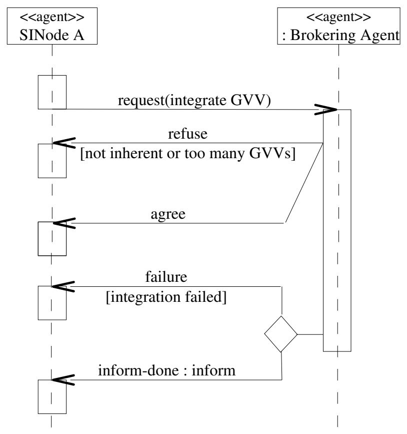


Fig. 6.2. The protocol ruling the interaction among an SINode and brokering agents

is indeed that of *middle agents* [WS00] as they assist in locating and connecting SINodes with the agent seeking them.

Brokering agents intervene in the phases of SINode registration and query decomposition.

6.4.1 Gluing SINodes

The integration of the GVV of an SINode comprises two steps. First, the SINode has to propose to the executing brokering agents to integrate its GVV. Then, each accepting brokering agents must carry out the real integration process, starting from its GVV (if any) and the GVV sent by the SINode.

We have designed the SINode request step as a FIPA Request Interaction protocol [fIPA02]. Figure 6.2 depicts the instance of the protocol.

The FIPA Request Interaction Protocol (IP) instance we use allows an SINode agent to request to brokering agents whether they can integrate its GVV. Each addressed brokering agent will evaluate if it can integrate the GVV and must send either a refuse message or an agree message. Agreeing means the brokering agent commit itself to execute the action content of the request and must report on its final status (successful or not). Note that with respect to the general FIPA request protocol this instance makes (i) the agree message mandatory as the action of integrating the ontology may not be trivial and requires time to be completed and (ii) the final message can be only a failure or an inform done (no inform result is possible as no further data must be sent back to the SINode).

6.4.2 Query decomposition

We have seen how the network of peers in SEWASIE is composed by SINodes. The main components of an SINode are the global schema, the source schemata and the mapping between them. Each SINode is integrated into the SEWASIE system after registering with a brokering agents. Brokering agents are responsible for building mappings among the ontologies they receive from the managed SINodes. This is to say that, from a user perspective, each brokering agent offers a unified ontology of the subscribed SINodes. Users thus can pose queries on these integrated schemata, addressing in general data managed by a number of SINodes. How to solve these queries is demanded to the multi-agent system supporting the peer network. In particular, we refer to the query agent and the brokering agent which together build up the module named *Query Manager*. With the notion of Query Manager we understand the set of coordinated functionalities which take an incoming query, define a decomposition of the query on the view offered by a brokering agent, demand the execution of the queries to SINodes, fuse the partial answers performing any residual filtering and propose the final answer.

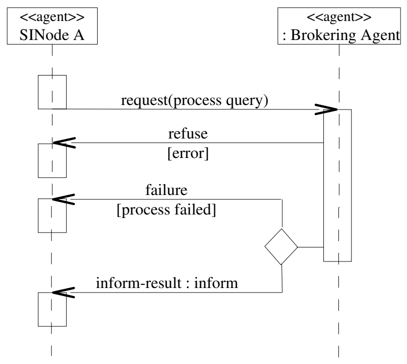


Fig. 6.3. The protocol ruling the interaction between a query agent and a brokering agent

The typical scenario of usage of the SEWASIE system foresees users navigating the global schemata which can be retrieved from brokering agents. While navigating, a user may decide to launch a query. The query composition phase is supported by the query tool agent interface. Upon the launch of a query, the query tool agent hands in the query to a query agent and the proper query management phase starts. Before being in condition to ask SINodes the execution of queries, the query agent must come to know *which* SINodes are addressed by the posed query. This activity is demanded to the brokering agent as it holds the ontology. We have designed this step as a FIPA Request Interaction protocol [fIPA02]. Figure 6.3 depicts the instance of the protocol.

The FIPA Request Interaction Protocol (IP) instance we use allows a query agent to request to a brokering agent to obtain the SINodes involved by the query. The brokering agent may refuse to execute because too busy. If it can execute, then it will directly answer with the final result of its computation. Note that with respect to the general FIPA request protocol this instance does not require an agree message and (ii) the final answer can be only a failure or an inform result containing the list of SINodes to be contacted to solve the query.

In order to get this information, the brokering agent must decompose the original query until queries are executable by the involved SINodes. This has to be asked to the brokering agent whose GVV has been queried. This query management phase must satisfy requirements related to the correctness and completeness of the answer. In the context of the integrated schemata, correctness translates into assuring that the constraints enforced on the brokering agent schema are respected when decomposing the query, while completeness translates into assuring that both the required (full-outer) join operations to fuse the final answer are performed and the necessary filtering conditions are appropriately applied for each executed query. This phase comprises thus two steps: (a) query expansion, which is the process which expand the query taking into consideration the integrity constraints of the global schema, and (b) query unfolding which decomposes a query into queries executable by local sources so as they can be coherently fused to give the final answer.

6.4.3 Query expansion

Query expansion amounts to rewriting a query posed over a global schema into a new query, in such a way that all the knowledge about the constraints in the global schema is preserved in the new query. The algorithm rewrites a query expressed over the global schema of an SINode into a new query in such a way that the result of the expanded query over the same global schema with no integrity constraints is the same as the result of the original query over the original global schema.

The algorithm essentially takes into consideration foreign key constraints. For this reason we call this algorithm *FKrewrite*. Technically, the algorithm performs two steps. First, given a query Q, for each couple of atoms g_1 and g_2 which unify[1], the algorithm adds to Q a conjunctive query called $reduce(Q, g_1, g_2)$ obtained as follows. Starting from Q itself, we eliminate g_2 from the query body; then the most general unifier of g_1 and g_2 is applied to the whole query.

After this phase, for each atom in the original query Q to which a foreign key constraint (which we indicate with I) applies we add to the query obtained in the previous step a query called $atom - rewrite(Q, g, I)$ which is the atom rewritten using as rewriting rule the foreign key constraint.

In [Con03] more details about the algorithm and an example are reported. The final output is one expanded query, the one obtained from the first step, and a set of atom queries, the ones resulting from step two. The expanded query is indeed a query that puts together the results of each single atom execution. Each atom is a query posed over one SINode schema managed by the brokering agent. As such, each atom must be trasformed into a set of queries executable at the level of local data sources where data are actually stored.

6.4.4 Query unfolding

Each obtained atom addresses only one class of the SINode schema. The further decomposition steps required to get the set of queries actually executable boils down to rewrite this single class query over the SINode schema.

We assume a global query expression over the global schema G (whose schema is $S(G)$) having the form `select AL from G where Q` where $AL \subseteq S(G)$ is an attribute list and Q is a query condition specified as a boolean expression of positive atomic predicates having the form (A $< operator >$ $value$) or (A $< operator >$ A'), with $A, A' \in S(G)$.

[1]Given an atom $g_1 = r(X_1, .., X_n)$ and an atom $g_2 = r(Y_1, ..Y_n)$, we say that g_1 and g_2 unify if there exists a variable substitution σ such that $\sigma(g_1)$=$\sigma(g_2)$. Each such a σ is called unifier. Moreover, if g_1 and g_2 unify, we denote as $U(g_1, g_2)$ the most general unifier of g_1 g_2, i.e. for every other unifier σ' of g_1 and g_2 there exists a substitution γ such that $\sigma' = \gamma\sigma$.

Indicating with g the global relation, we define the answer to a query expression having the above form as $\pi_{AL}(\sigma_Q(g))$. Since g can be viewed as the global full disjunction (GFD) applied to all local sources l_i, we can write $\pi_{AL}(\sigma_Q(GFD(l_1, ..l_n)))$. The query rewriting problem consists into rewriting this expression into an equivalent form $\pi_{AL}(\sigma_{Q_r}(GFD(lq_1, ..lq_n)))$ where lq_i is the answer to the local query for the local class L_i ($\pi_{AL_i}(\sigma_{LQ_i}(l_i))$) and Q_r is the residual condition. Since an SINode is not the owner of the data, the local queries are sent and executed on local sources. Then, in order to reduce the size of the the local query answer lq_i, it is important: (1) to maximize the selectivity of the local query condition LQ_i and (2) to minimize the cardinality of the local query select-list AL_i. For the query rewriting method shown in the following, both these properties hold. The steps to compute LQ_i, $1 < i < n$, and Q_r are the following:

1. **query normalization**: The first step is to convert Q into a *Disjunctive Normal Form* (DNF) query Q^d where the predicates are atomic. The DNF query will be of the form $Q^d = C_1 \vee C_2 ... \vee C_m$, where each conjunction term C_i has the form $P_1 \wedge P2 ... \wedge P_n$, i.e. is a conjunction of atomic predicates P_i;

2. **local query condition writing**: in this step, each atomic predicate P in Q^d is rewritten into one that can be supported by the considered local class L_i. An atomic predicate P is searchable in the local class L_i if the global attributes used in P are present in the local class L_i, i.e. the global attributes are mapped into L_i with a non null mapping. We make the hypothesis that each atomic predicate P searchable in L_i is fully expressible/supported in L_i;

3. **residual condition writing**: the computation of Q_r is performed by the following three steps:

   (a) transform Q into a *Conjunctive Normal Form* (CNF) query Q^c, the logical *and* of clauses C which are the logical *or* of atomic predicates P;

   (b) any clause C of Q^c containing not searchable (in one or more local classes) atomic predicates is a residual clause;

   (c) the residual condition Q_r is equal to the logical *and* of residual clauses.

4. **select list writing**: the select list of the query LQ_i for the local class L_i, denoted with LAL_i, is obtained by considering the union of the following sets of attributes:

   (a) attributes of the global select list;

   (b) *join attribute set* for the local class L_i[2];

   (c) attributes in the residual condition Q_r.

   and by transforming these attributes on the basis of the Mapping Table.

6.4.5 Brokering agents as final state machines

Brokering agents implements the following functionalities:

- create ontology: this type of messages comes from an SINode when it wants to advertise its ontology. If the proposal is accepted, then the GVV of the SINode must be integrated into the brokering agent's GVV;
- update ontology: this message is sent by an SINode when it wants to notify its ontology has changed and is now available to be re-integrated in the brokering agent's GVV;
- broadcast ontology: this message is sent by other brokering agents when they want to advertise their own GVVs to the receiving brokering agent;
- process query: this message is sent by query agents to ask which SINodes are involved by a given user query;

[2]The set of join conditions for all pairs of local classes of the global class G, called *Join Map*, is denoted with JM; a join condition between L_i, $L_j \in L$ will be denoted with $JM(L_i, L_j)$. Given a local class L_i, the set of attributes in $SG(L_i)$ used to express the join conditions for L_i is called *join attribute set* and it is denoted with $JA(L_i)$.

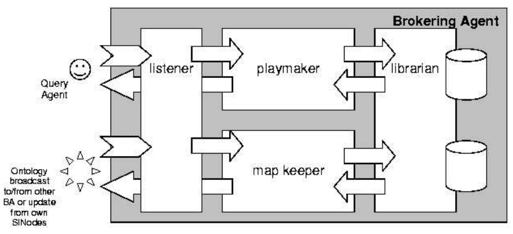

Brokering Agent
Query Agent
listener
playmaker
librarian
map keeper
Ontology broadcast to/from other BA or update from own SINodes

Fig. 6.4. The architecture of the brokering agent

- export ontology: this message is sent by brokering agents explicitly requiring the receiving brokering agent to send its GVV.

We divided these functionalities over a modularized architecture:

The *Listener* represents the interface brokering agents expose to the outside world. The listener module defines how other entities may communicate with a brokering agent and constraints the possible protocols that are supported during conversations. The *MapKeeper* is responsible for managing the incoming GVVs sent by SINodes. Managing such information means having the capability of both integrating the GVVs sent by SINodes in a new one which contains the mapping

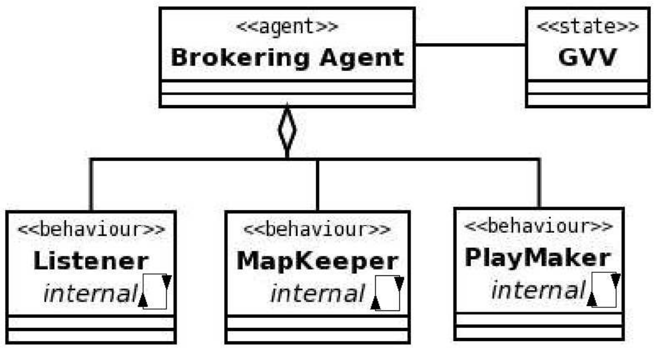


Fig. 6.5. The basic AUML diagram of the brokering agent

among the original ones, and updating such knowledge whenever changes to the GVVs of the SINode occur. The *PlayMaker* intervenes during query processing: given a query, the PlayMaker is able to return the SINodes involved by the query together with a set of queries addressing such SINodes. This is possible thanks to the mappings produced by the MapKeeper module. The *Librarian* is the repository where all information managed by a brokering agent is stored. Data are stored or read by the MapKeeper and PlayMaker modules. Although the repository may be local or remote with respect to its location, we logically view the Librarian as part of the brokering agent. From the design viewpoint, this abstract architecture is realised as depicted in Figure 6.5.

In order to facilitate the design and verification of the brokering agent behavior we adopted an approach based on final state machines. The behavior is shown in Figure 6.6. Each state includes the agent sub behaviors that are active in that state. At each state only a subset of sub behaviors is executed. Internal behaviors are as usual (see chapter 1) behaviors not visible by other agents. External behaviors correspond to functionalities available to other agents. For instance, the `CreateOntology` message starts a FIPA PROPOSAL interaction protocol and the `ProcessQuery` message activates a FIPA REQUEST interaction protocol. A transition is fired upon

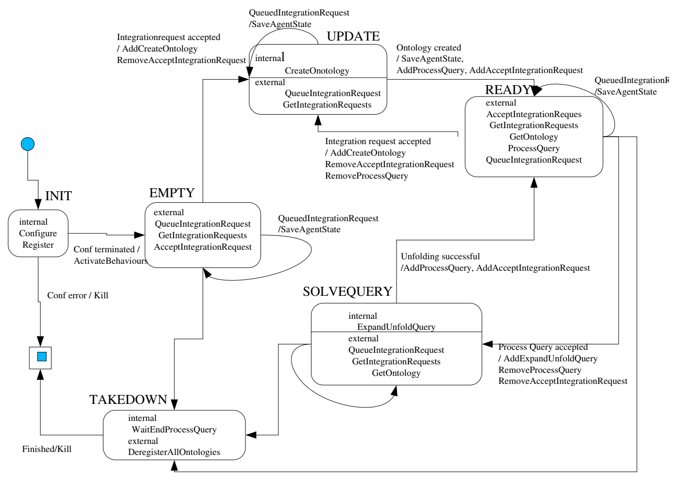


Fig. 6.6. The behavior of the brokering agent as a final state machine

the verification of an event and may imply the execution of an action (specified after the '/' symbol).

6.5 Query Agent

Query agents supervise the overall query processing phase. Given a user query, the query processing phase is composed by two sub phases. The first is the identification of the SINode involved by the query. This job is done by contacting the brokering agent whose ontology is queried. The second is the execution of local queries and their fusion to get the final result. This phase is organized by the query agent which commands SINodes to execute the respective queries and collects the partial results. When all queries are answered, the query agent applies the join algorithm to fuse them and proposes the result to the user interface.

6.6 SINode Agents

SINode agents are interface agents. They wrap a mediator system so as to expose it as an agent in the SEWASIE platform, adding a graphical user interface to manage the capability to require the mediator ontology be integrated by brokering agents. An SINode has pure monitoring capabilities and similarly to brokering agents their behavior is designed as a final state machine [Con03].

The main issue is related to the GUI of an SINode agent. The GUI reports the state of the agent and gives the chance to control part of its behavior. At the same time, the GUI is understood as remote, since it must be retrieved on the user hosts wherever the SINode agent is executing. The key problem is that activating the GUI on the user host must keep the agent executing where it is.

6.6.1 The Java GUI model and JADE GUIs

When a Java Virtual Machine is activated, two objects are instantiated: a *system event queue* (instance of *java.awt.EventQueue* class) which collects all the events which happens in the system and an *event dispatcher thread*, whose task is to continuously pick event objects from the system event queue. The event dispatcher thread offers a subscription service: a Java object may register to be alerted by the thread whenever a particular kind of event enter the system event queue. The subscribed objects are called *listeners.* When the event is produced, the event dispatcher thread, among other things, calls the various listeners registered with the event source. This implies that all event listeners are executed within a single event dispatcher thread. This is the reason it is strongly suggested that the execution time of an event listener should be short (less than 0.1 s) to ensure Java GUIs responsiveness. A very important Swing feature is the *Model/View* system to manage GUI updates. When a Swing control has some state, this state is kept in a *model object.* The model object provides commands to modify the state and the Swing built-in notification mechanism updates the visual appearance of the GUI to reflect the state change. One thing worth noting is that the Swing framework is not thread-safe, so any code that updates the GUI elements must be executed within the event dispatcher thread.

This short description of the Java GUI model arises the following issue for agents with interfaces. An agent has its own thread of control and all its behaviors are executed within this thread (and scheduled by the agent internal scheduler). A Java GUI has its own thread of control and as such cannot be bundled with an agent. We need a mechanism to handle GUIs as separate threads within the JADE agent model. Because it is quite common having agents with a GUI, JADE includes the class *GuiAgent* for this specific purpose. This class extends the *Agent* class. At start-up a *GuiAgent* instantiates a special behavior responsible for managing a queue of event objects (here instance of *jade.gui.GuiEvent*) that can be received by other threads. A thread as the GUI associated with the agent can notify an event to the agent by calling the behavior's public method *postGuiEvent()* and passing the occurred *GuiEvent* object. A *GuiEvent* object includes the source of the event, the type of the event and an optional list of parameters that can be added to the event object itself. As a consequence, an agent wishing to receive events from its GUI, should define the types of events it intends to receive. The code to be executed upon the notification of some event is programmed in the agent's *onGuiEvent()* method.

6.6.2 SEWASIE shadow agents

The solution provided within the JADE framework allows to build agents with an interface but does not meet the requirements of the SEWASIE system, where we need *to activate local interfaces on agents executing on remote hosts.* For doing this, we would need to have an agent with a detachable part capable of executing on demand on a different host but always linked to its agent.

We have thus defined a mechanism to realize this. We see an agent has having a double impersonation. The first is the agent itself and the second is its *shadow*, i.e. an agent responsible of retrieving the agent information and make the interface appear on demand. This second impersonation is indeed called *shadow agent.* This mechanism requires just two things: the definition of the data structure and functionalities to be made visible and a suitable communication protocol between the agent and its shadow.

Part III

Software agents in e-commerce

7. SOFTWARE AGENTS IN VIRTUAL SOCIETIES

As we have seen in previous chapters, software agents are a chance to reinterpret modern information systems, takling complex issues like distributeness, interoperability and mobility right from the first move in the project.

The power of software agents has not only has this influence, but has also inspired new challenging thoughts about software and its role in the human society. More and more enthusiastically, the research community is drawing attention to software agents as representatives of humans in the virtual world. In no doubts this perspective poses new questions about the deployment of software agents and the properties a multi-agent system platform should guarantee and enforce. While using software agents for automating information processing can be seen as an effort to advance the quality of information systems, conceiving systems were software agents acts on the part of human (and thus every action may bring liability for the human into concern) needs a more careful consideration and analysis. To make a parallel, we now need to set up a ruled system just like the driving code is: everybody may use apiece of technology within a precise framework of enforced rule. Not respecting the rules means getting fined or worse. The ruled system in a virtual world serves the purpose of allowing interaction and exchange of goods, i.e. promoting e-commerce. We view e-commerce as the ensemble of virutal activities which are fired by *entities* interacting on the web. Until now entities have been understood as humans or software componenets directly managed by users. Software agents are entities that after being started can decide autonoumously which action sould be better undertaken next.

The goal of this part is to define a framework whithin which concepts related to human interaction are applied to software agents, bearing in mind the perculiarities of a virtual world. This will bring us to consider a very important consequence of interaction, coordination. Coordination is in fact a central issue in agent technology and one of the main motivation software agents keep their promise of next enabling technology.

7.1 Approach

The main attitude of agents we consider in this part is autonomy. As pointed out in [MCT01], at least three general models for autonomous agents are developed in the literature. A first approach includes a number of systems that roughly focus on goal-based planning or on qualitative decision theory (see [Bou94]). A second line of research is mainly aimed to provide a cognitive account of agents by specifying their mental states and motivational attitudes, such as the BDI model (see [RG91]). The third option is specifically oriented to model societies of agents by means of normative concepts such as obligation, permission, power and so on (see [CD00, APS02, LN04]).

We focus on the third of the above mentioned approaches to multi-agent systems. This research assumes that as in human societies, also in artificial societies normative concepts may play a decisive role, allowing for the flexible co-ordination of intelligent autonomous agents. It has been argued, in addition, that the adoption of a normative perspective would allow a substantial progress in the creation of agent societies, a progress that would be even more important for societies where humans and agents interact (see [APS02]).

Some significant steps in this direction have been accomplished in recent years (we mention the proceedings of the DEON conferences, which show how normative logic has been moving into the direction above indicated). In particular we will refer here to the tradition of research which starts with the work of Scandinavian logicians and legal theorists, such as Kanger, Lindhal, and Pörn (see for a review [Elg97], and continues with the work of Carmo, Jones, Sergot, and their colleagues ([SCJ97, Jon96]).

Of course, there are number of ways according to which the issue of the role of normative concepts in MAS can be approached. Among them, a formal-theoretical investigation seems to be of great interest. In particular, a logic-oriented approach is useful insofar as it allows to make more rigorous normative notions as those analyzed by philosophers and sociologists and potentially relevant for modelling MAS. In this perspective, a precise logical analysis of normative notions such as obligations, institutions, responsibilities, delegation, powers, and so forth, is one precondition for the development of norm-governed societies. In fact, describing and modelling norm-governed organizations and societies of agents means manipulating and making inferences over the normative concepts that are required to account for such organizations. In its turn, this presupposes to have an accurate and suitable formal representation of those concepts. As recently pointed out, simple conceptual analysis of the structure of organizations of agents.

7.2 Basic concepts

Our aim is to provide a formal analysis of some conceptual preconditions that, we believe, any normative-based approach to the idea of co-ordination of agents should take into account. The idea of normative co-ordination is based on the assumption that (human and artificial) agents can achieve flexible co-ordination by conferring normative positions to other agents. Those positions can include not only duties and permissions, but also powers, as for instance powers of creating further normative positions on the head of other agents. In particular we will characterize three ideas.

First, the idea of declarative power, which consists in the capacity of the power-holder of creating normative positions, involving other agents, simply by "proclaiming" such positions. The idea of declarative power provides a general facility though which autonomous agents can shape their own normative environment. If agents are to be really autonomous (in the sense in which one legally speaks of "private autonomy") they must go beyond the possibility of activating institutional connections between pre-determined actions and pre-determined results: they must be empowered to state what normative relations they want to hold between them, and to achieve those effects by doing so. This is performed by what is usually called a declaration of will or intention: the interested agents state the results they want to achieve, in the appropriate form, and the institution within which they are operating makes so that exactly those results are achieved (usually assuming that certain conditions are satisfied).

Such an empowerment of autonomous agents also corresponds to the needs of a complex self-organising society, where it is not possible to establish in advance all normative relations between agents. In such a society it must be left to agents themselves to decide what normative relations are appropriate to their needs, or required for the fulfillment of their tasks. In the law, this normative self-organization typically happens through contracts (a contract is a declarative act jointly performed also by all parties whose status is going to be changed by the declaration they are performing). Single contracts usually cannot be exhaustively classified as of the types of acts which theories of institutional acts usually distinguish (commissive, commands, etc.): a single contract usually, at once, establishes new duties (for example, the obligation to pay the price), creates new rights (for example, the right to receive the price, or to be delivered the goods), transfers existing rights (for example, the property of the goods), and so forth. In fact contracts put into focus a new dimension of autonomy: private autonomy, or contractual autonomy, by which one means the possibility of realizing the legal effects the parties wish, just by stating those effects.

Secondly, the idea of representation, which is the representative's capacity of acting in the name of his principal. An agent that has the power of making the type of statements we described above, may however not be in condition of directly exercising this power (he may lack the time, the opportunity, etc.). However also in this regard, there is no need to impose a regulation from above: an autonomous agent must rather be able to delegate to other agents the exercise of his own powers. So autonomy is further enhanced by instrument of representation, which basically concerns the situation “where a principal is held to declarations, especially contracts, made on his behalf” [ZK92]. As it is argued, the essential aspect of representation is the grant of an authority or of a power: the representative’s declarations can directly bind the principal, since they count as if they were the principal’s declarations (contrary to the fact that one person’s declaration normally can only bind that person).

Thirdly, the idea of mandate, which corresponds to the mandatee’s duty to act as the mandator has requested. In most cases, one subject confers representation to another, by accompanying it with a mandate, that is with the obligation of exercising (and of exercising in a certain way) the power of representation. So, in general terms, the idea of mandate concerns instead the situation where one agent (the mandator) has commanded another agent (the mandatee) to do something on his account. Usually a mandate presupposes that the mandator has authority over the mandatee (for example, being his employer), or that a contract has been signed between them for the execution of a specific business. Therefore, the mandator’s requests generate the mandatee’s duty to act in such a way as the mandator has requested, in order to satisfy the interests (or to achieve the goals) of the mandator.

Summing up, there is evidentely a connection among the three concepts. The notion of declarative power is the basic one. Representation is usually created by an exercise of such a power, and so is a mandate. Additionally, it is not uncommon that representation and mandate go together with each other: whenever a principal confers an agent the power to represent her, usually the principal also binds the agent so that he acts in certain specific ways, or there is a legal relation which provides the background for the exercise of the representation. Consider, for example, the case when the employee in a shop represents his employer, and makes in his name contracts with the clients. In such a case, the authority of the representative is linked to his duties as an employee, and he is bound to exercise his authority according to such duties. However, it is possible that there is representation without mandate (that the agent has the power to act in the name of the principal, without the obligation to do so).

The notions we want to investigate originate from a legal background. Power, representation and mandate are indeed notions we can find in every legal system, though they may be differently regulated. These notions do not exhaust the idea of normative co-ordination. However, we believe that they belong to the basic building blocks for such an approach to be specified. They may indeed be useful both for determining the relations and interactions between a user and its agents, or between autonomous agents.

7.3 Actions and obligations

Let us first outline the logic adopted here to deal with the concepts of action and obligation.

As it was already said, our approach falls within the well-known Kanger-Lindahl-Pörn logical theory designed to account for agency and organised interaction (see [Elg97]). More precisely, our aim is to extend and take advantage of what developed by F. Santos, A. Jones and J. Carmo in [SC96, SCJ97] (in the following SJC). Despite some limitations (for a critical discussion, see [Elg97, Roy00]), such an approach seems to be well-suited for our purposes because actions are viewed at a very abstract level and are simply taken to be relationships between agents and states of affairs. In addition, it is permitted to easily combine action concepts with other (e.g., normative) modalities.

Let us recall the set of action concepts discussed by SJC. In short, they use three kinds of action operators: E, G and H. The first is the well-known operator expressing direct and successful actions: a formula like E_iA means that the agent i brings it about that A. SJC accept the following schema for E:

$$E_iE_jA \rightarrow \neg E_iA \tag{7.1}$$

for which E_iA expresses the idea that the agent i brings it about that A directly and personally. We think that this is a reasonable reading of the operator E. In particular, this assumption may be viewed as a principle of rationality for for modeling co-ordination in institutional organisations: It is counterintuitive that the same agent brings it about that A and brings it about that somebody else achieves A. The second one corresponds to indirect and successful actions so that the reading of G_iA is that i ensures that A. Note that the G operator differentiates from E for the following axiom schema:

$$G_iG_jA \rightarrow G_iA \tag{7.2}$$

Finally, the intended meaning of H is such that H_iA means that i attempts to make it the case that A. The idea is that H is not necessarily successful. Following their approach, the logic for such operators is provided by the following axiom schemas and rules.

Some interaction axioms from [SCJ97] are listed here below:

$$E_iA \rightarrow G_iA \tag{7.3}$$

$$G_iE_jA \rightarrow G_iG_jA \tag{7.4}$$

$$E_iE_jA \rightarrow E_iG_jA \tag{7.5}$$

$$G_iA \rightarrow G_iE_iA \tag{7.6}$$

In addition, SJC also accept:

$$G_iA \rightarrow H_iA \tag{7.7}$$

$$E_iG_jA \rightarrow E_iH_jA \tag{7.8}$$

$$G_iG_jA \rightarrow G_iH_jA \tag{7.9}$$

$$H_iE_jA \rightarrow H_iG_jA \tag{7.10}$$

$$H_iG_jA \rightarrow H_iH_jA \tag{7.11}$$

Let us focus now on the operator H. In general, one of the main reasons why H is useful in a normative domain is that it is not necessarily successful, and therefore it may be used to model the idea of normative influence, that is the influence which is exercised by imposing obligations over an agent. Such an influence is not necessarily successful for the reason that OG_jA does not imply that A: an obligation does entail its fulfilment.

First of all, let us define a suitable logic for obligations. Besides the well-known drawbacks connected with the treatment of logical structures such as contrary-to-duty obligations, it may be argued that Standard Deontic Logic (SDL) is not adequate for combining deontic and action operators. For example, in SDL OE_iA implies that OA, which we feel unacceptable: The fact that i is obliged to bring it about that A should not entail that A is in general obligatory. For similar reasons, $OE_iE_jA \rightarrow OE_jA$ is a theorem of SDL. However, also this principle cannot be accepted because the personal obligation on i should not imply a personal obligation on j [Roy00]. For obvious reasons, we will not enter here into a discussion about which axiomatisation is suitable for modeling deontic concepts (see, e.g., [MW93, GG02]). To avoid the just mentioned problems, it suffices to assume that the logic for O contains only the following axioms

$$(OA \wedge OB) \rightarrow O(A \wedge B) \tag{7.12}$$

$$OA \rightarrow \neg O \neg A \tag{7.13}$$

and is closed under classical logical equivalence (see [JK01]).

Given the above premise, we can represent normative influence by way of expressions like E_iOG_jA. In this regard SJC, accept the following axiom:

$$E_iOG_jA \rightarrow H_iG_jA \tag{7.14}$$

We believe that the principle (7.14) is quite reasonable insofar as, as we said, normative influence is a special kind of not necessarily successful influence over agents. On the other hand, we have some doubts concerning a further principle advanced in [SCJ97]. SJC propose the following axiom (though relativised to the counts-as operator $\Rightarrow_s$, which we discuss in the following section):

$$(G_iOG_jA \wedge G_jA) \rightarrow G_iA \tag{7.15}$$

Actually, they point out that (7.15) is not a logical principle but it can be adopted or not depending on the nature of the institution considered[1]. Even in this case, we believe that such a principle is too strong. In fact, even within an institution, $\neg G_i A$ should be consistent with both $G_i O G_j A$ and $G_j A$ since it is possible that j pays no attention to the obligation that i has imposed upon him, (and even that he does not know of his obligation). For example, suppose that a military commander orders his soldiers to kill their prisoners. Assume that the order does not reach one soldier (who is fighting in a far away place), but that this soldier still kills a prisoner, according to his autonomous decision. We do not believe that in any reasonable institution, in such a case one may say that the commander ensured that the prisoner was killed, and consider him responsible for that.

In this perspective, we believe that it could be useful to introduce a new action operator EI to express that an agent attempts to make it the case that A by creating, directly of indirectly, a channel of deontic influence terminating with A.

The operator EI could be defined by means of an induction axiom as follows:

$$EI_i A \equiv G_i O G_j A \vee \bigvee_{j \in Ag_{\leq}}^{j \leq i} G_i O EI_j A \tag{7.16}$$

According to this analysis, the logic for EI should be characterised at least by the following axiom:

$$EI_i A \rightarrow H_i A \tag{7.17}$$

It is also worth noting that a hierarchy between agents can play an important role in characterising EI. Suppose $\prec$ stands for a such a relation of hierarchy[2]. Thus, if we want to make sure that the hierarchy of agents of a given organisation is rational, the following formula should hold:

$$(E_i O G_j A \wedge E_j O G_i A \wedge i \prec j) \rightarrow \bot \tag{7.18}$$

We should also have that

[1]In other words, (7.15) is changed into $(G_i O G_j A \wedge G_j A) \Rightarrow_s G_i A$. According to the same intuition, notice that they also adopt another axiom schema, that is $(O G_j A \wedge A) \Rightarrow_s G_j A$.

[2]See Section 7.5.2 for its formal definition.

$$(EI_iA \wedge E_jOG_iA \wedge i \prec j) \rightarrow \bot \tag{7.19}$$

In other words, both explicit and implicit "circular" chains of deontic control are not permitted.

7.4 The counts-as link

7.4.1 Jones and Sergot's analysis

A. Jones and M. Sergot [Jon96] (abbreviated as JS in the following) have developed a formal approach to the notion of institutionalised power by introducing a new conditional connective '$\Rightarrow_s$'. Such a connective is intended to express the 'counts as' connection holding in the context of an institution s as described, notably, by Searle [Sea95]. In other words, when applied to action description, a conditional $A \Rightarrow_s B$ says that action A counts as action B. Notice that this is frequently used in the law: when there is a set of rules which link a certain legal effect to action (or situation) B, and the law wants the same effects to be linked also to a different action (or situation) A, then the law says that A counts as B (for the purpose of the achievement of those effects).

Following Chellas' terminology [Che75], the logic provided by JS for $\Rightarrow_s$ is a classical (but not normal) conditional logic[3]. In addition, it is characterised by the following axiom schemas:

$$((A \Rightarrow_s B) \wedge (A \Rightarrow_s C)) \rightarrow (A \Rightarrow_s (B \wedge C)) \tag{7.20}$$

$$((A \Rightarrow_s B) \wedge (C \Rightarrow_s B)) \rightarrow ((A \vee C) \Rightarrow_s B) \tag{7.21}$$

and, possibly, by

$$(A \Rightarrow_s B) \rightarrow ((B \Rightarrow_s C) \rightarrow (A \Rightarrow_s C)) \tag{7.22}$$

JS's analysis is then integrated by introducing the normal **KD** modality D_s. This is suggested to express all constraints on s among which the link 'counts as'

[3]In other words, the logic for $\Rightarrow_s$ contains the rules RCEA and RCEC but not RCM.

is included. In other words, D_sA means that A is "recognised by the institution s" [SCJ97]. Accordingly, it is adopted the following schema:

$$(A \Rightarrow_s B) \rightarrow D_s(A \rightarrow B) \tag{7.23}$$

Besides the general meaning of D_s, one of the main consequences of D_s is to make possible a restricted version of detachment of the consequent of $\Rightarrow_s$. In fact, by accepting

$$(A \Rightarrow_s B) \rightarrow (A \rightarrow D_sA) \tag{7.24}$$

it can be derived that

$$(A \Rightarrow_s B) \rightarrow (A \rightarrow D_sB) \tag{7.25}$$

In other words, if $A \Rightarrow_s B$ and A, then B should be the case in s, namely D_sB.

7.4.2 A new proposal

In this section, we will provide a fresh characterisation of the counts-as connection that, though preserving most properties of the model of JS, adopts a different perspective.

Rather than introducing a separate logic for the counts-as connection, and then linking it with a D_s logic (relativised to the particular institution under consideration), we use one conditional operator $\Rrightarrow$ to express any normative connections or constants, in any institutions.

In addition, we will use the D_s operator as in [Jon96] but we will apply it to the consequent of such conditional links, in order to relativise this consequent to the particular institution under consideration. We argue that any institution can only state what normative situation holds for itself, given certain conditions, but according to a general type of conditionality. Actually, we can have different types of facts between which a conditional link may hold with regard to an institution s: (1) links between brute facts and s-facts (raising one's hand is making a bid), (2) links between s-facts and other s-facts (making a bid is a contractual offer) , (3) links between s'-facts and s-facts, where s' is an institution different from s (a catholic or muslim marriage counts as a civil marriage).

By applying the D_s modality to the antecedents or to the consequents of our conditionals we can easily express and clearly distinguish all those connections.

The logic for $\Rrightarrow$ contains besides classical propositional logic, the following axioms

$$A \Rrightarrow A \tag{7.26}$$

$$(A \Rrightarrow B) \wedge (A \wedge B \Rrightarrow C) \rightarrow (A \Rrightarrow C) \tag{7.27}$$

$$(A \Rrightarrow B) \wedge (A \Rrightarrow C) \rightarrow (A \wedge B) \Rrightarrow C) \tag{7.28}$$

$$(A \Rrightarrow C) \wedge (B \Rrightarrow C) \rightarrow (A \vee B) \Rrightarrow C) \tag{7.29}$$

and is closed under the usual inference rules

$$\frac{A \equiv B}{(A \Rrightarrow C) \rightarrow (B \Rrightarrow C)} \tag{$RCEA$}$$

and

$$\frac{(A_1 \wedge \cdots \wedge A_n) \rightarrow B}{(C \Rrightarrow A_1 \wedge \cdots \wedge C \Rrightarrow A_n) \rightarrow (C \Rrightarrow B)} \tag{RCK}$$

Let us give now a suitable characterisation of the "institutional modality" D_s. We believe that the logic for such an operator should be closed under logical equivalence and contain the following axiom schemas:

$$D_s A \rightarrow \neg D_s \neg A \tag{7.30}$$

$$(D_s A \wedge D_s B) \rightarrow D_s(A \wedge B) \tag{7.31}$$

Notice that we do not accept the necessitation rule. Since the intended meaning of this modality is to express the domain of the institutional facts holding in a given institution, the lack of necessitation is reasonable: it sounds strange that $\top$ is an institutional fact for any institution s.

Finally, on the basis of $\Rrightarrow$ we can define a relativised operator $\Rrightarrow_s$ operator, which behaves similarly to $\Rightarrow$ of JS. For this purpose we need to combine a link

$A \Rrightarrow D_s B$ from a brute fact to an institutional fact, and a link $D_s A \Rrightarrow D_s B$ from an institutional fact to another institutional fact.

In this perspective, we state the following definition:

$$(A \Rrightarrow_s B) =_{def} (A \Rrightarrow D_s B) \wedge (D_s A \Rrightarrow D_s B) \tag{7.32}$$

7.4.3 A comparison

Let us now compare the behavior of our logic to the original proposal of JS. Let us first focus on the commonalities.

Basically, the main commonality between the two approaches is that both allow for the detachment of institutional consequents from brute facts and count-as conditionals: as in JS's approach $D_s(B)$ follows from A and $A \Rightarrow_s B$, according to (7.24, and 7.25), so in our approach $D_s(B)$ follows from A and $A \Rrightarrow_s B$, according to definition (7.32) (which implies $A \Rrightarrow D_s(B)$) and inference rule (**??**). In addition, we accepted for our definition of $\Rrightarrow_s$ a great part of the axiom schemas introduced by JS for $\Rightarrow_s$. In particular theorems corresponding to axioms 7.20 and 7.21 can be derived in our system, on the basis of definition 7.32.

Let us now consider the differences between the two systems.

One significant difference between our approach and JS's system is that our approach allows for non-monotonic reasoning. We believe that non-monotonicity should be an essential property for the count-as link, but also in general for any normative conditional. This is the reason why we would like to treat it in a uniform way. Consider the following two examples.

In an auction if the agent i raises one hand, this may count as making a bid. However, this does not hold if i raises one hand *and* scratches his own head. However, we still want to have that "i's raising one hand 'counts as' i's making a bid" and the fact that i raised one hand imply that i made a bid.

As an example that does not deal with count-as connections, consider the classical fact that if one causes a damage, than one is liable, but this does not happens if one is acting in self defence.

It seems clear to us that the type of non-monotonic reasoning involved the two example is exactly the same.

The main reason why JS's approach cannot appropriately deal with non-monotonicity is that it is joins two logical systems, the $\Rightarrow_s$ and the D_s logics, the second of which is monotonic. It is always possible to jump from the one into the other, by using the axiom (7.23). Since the second, monotonic system is used for the count-as detachment ((7.23)-(7.25), then this is necessarily monotonic. Even if $\Rightarrow_s$ logic were defeasible, defeated conclusions could be reinstated by moving into the D_s logic. In addition, note that JS's $\Rightarrow_s$ logic includes transitivity, by (7.22), which implies monotonicity (see [KLM90]). As a matter of fact, as an alternative to (7.22), they also propose

$$(A \Rightarrow_s B) \rightarrow ((B \Rightarrow_s C) \rightarrow D_s(A \rightarrow C) \tag{7.33}$$

which would solve the transitivity problem, but still would not overcome the above critique.

A second significant difference between the two approaches concerns weakening of the consequent. As JS pointed out, this property should not hold for the count-as link: it is quite odd that, in an auction, 'raising one hand counts as making a bid' implies the sentence 'raising one hand counts as making a bid or drinking some water'. However, the combination of the count-as and the D_s logics, which is a normal modality **KD** leads to the weakening of institutional consequences: A and $A \Rightarrow_s B$ imply $D_s(B)$, which implies $D_s(B \vee C)$. For example, in JS's system

$$(raising\_one\_hand) \Rightarrow_s (making\_a\_bid)$$

implies

$$D_s((raising\_one\_hand) \rightarrow ((making\_a\_bid) \vee (drinking\_some\_water)))$$

In our system weakening of institutional consequences does not hold, since we define D_s in terms a non-normal **D** modality without necessitation and axiom **K**, thus avoiding that D_s is closed under logical consequence[4].

In fact, the **K** schema was needed in JS's approach to guarantee detachment of institutional consequents through material implications modalised by D_s.

Obviously, because of the new characterisation of D_s and of our definition of the count-as link, the adoption RCK for $\Rrightarrow$ is not problematic since it determines the closure of $\Rrightarrow$ under logical consequence only when the consequent is not modalised by D_s.

7.5 Proclamation and declarative power

On the basis of the notions introduced in the previous section, we will now analyse a phenomenon which has a major importance in legal and similar institutions: this is the decentralised intentional creation of new normative positions. We will first describe the actions (i.e., proclamations) which maybe used to create those positions, and then we will consider the institutional rules making those actions effective, and finally we will analysis the power which these rules attribute (declarative power).

7.5.1 The notion of proclaiming

The idea of proclaiming is used to cover all those speech acts by which a subject makes a statement expressing a certain proposition, and this statement has the function (purpose, point or objective) of making this proposition true. So, we say that one subject i proclaims that A when i makes a statement which expresses A, and has the function of realising A.

Of course, a plethora of works have been put forward to give a formal account of speech acts theory (see, e.g., [CP88, SV85, CL90]). More recently, a number of

[4]The reader who feels this choice unsatisfactory has a different option. It is enough to give up the necessitation rule for D_s. In this way, axiom **K** can be retained, thus obtaining a quasi-normal system [Seg71, ch. 3]. However, this option will not be considered here.

different agent communication languages have been devised. Let us mention two of the most popular approaches, that is FIPA ACL [fIPA] and KQLM [FFMM94].

In a great part of works on speech acts (see also [Jon90, CDJT99, Sin, Col00]), what we model as proclamations is represented through different types of speech acts (commissives, permissives, agreements, etc.), each one characterised by its own specific semantics. On the contrary, we view all those performatives as instances of just one speech act, since their differences, from our perspective, only pertain to the content which is proclaimed. This provides a simpler framework for institutional performatives. The framework is simpler since the logic of all institutional performatives is exhausted by the simple logic of the (modal) operator of proclaiming. In this way, it is also permitted to easily combine speech acts with other formalisms such as those described in the previous sections.

According to our analysis, the type of speech act we have so defined has some interesting peculiarities.

First, note that it is neutral in regard to intention-based [Gri89] and non intention-based theories of speech acts [Jon90]. By saying that the proclamation that A has the function to achieve A we do not specify how the notion of function is to be characterized: it may be determined by the intention of the speaker, by the intention attributed to the speaker by its interlocutor, by a shared convention, by a communication protocol, etc. What is sufficient, for our purpose, is that the act has a word to world direction of fit [SV85], that is that has the function to change the normative world to make it fit the content of the act.

Secondly, note that a proclamation is not necessarily effective (it does not necessarily produce A). When the notion of function is interpreted with reference to the intention of the speaker it necessarily involves an attempt to achieve A, but this attempt may not be successful. Whether it is successful or not, within a certain institutional context, depends on whether that institution makes it effective. It is up to the institutional rules to establish whether i's proclamation that A, in the conditions in which it is made, produces A or not.

Thirdly, as we have alluded to, the idea of proclaiming is neutral in regard to what is proclaimed. So a proclamation can play the role usually attributed to many different speech acts. A proclamation of i can be an attempted commissive, as when its content is OE_iA, an attempted command, when refers to OE_jA, with j different from i, an attempt to free oneself from an obligation, as where its argument is $\neg OE_iA$.

The notion of proclaiming is formalised by the operator *proc*. Such an operator will be indexed by agents. In this way, $proc_iA$ means that i proclaims that A. As said, *proc* is not necessarily successful and so we do not accept:

$$proc_iA \rightarrow A \tag{7.34}$$

On the other hand, it is reasonable that the logic for this operator is closed under logical equivalence and is characterised at least by the following axiom:

$$(proc_iA \wedge proc_iB) \equiv proc_i(A \wedge B) \tag{7.35}$$

Of course, we have also to accept the following axiom schema:

$$proc_iA \rightarrow H_iA \tag{7.36}$$

A matter we think deserves special attention is about the intended effects of *proc*. A discussion of this question concerns how to represent the notion of institutional power. For our purposes, it is worth distinguishing in particular two kinds of power: the power to ascribe obligations and the power of conferring powers to ascribe obligations.

Well, let us consider when a proclamation is effective. Unfortunately, there is not much that we may say in general. We may just say that a proclamation is effective if the concerned institution provides for its effectiveness, i.e. the institution recognises that, by proclaiming A, one produces the normative state A. This means that, if the concerned institution has (or possibly implies) a rule: $proc_iA \Rrightarrow_s E_iA$[5], then, for the

[5]Where, as we argued, $proc_iA \Rrightarrow_s E_iA$ is an abbreviation of $(proc_iA \Rrightarrow D_sE_iA) \wedge (D_sproc_iA \Rrightarrow D_sE_iA)$.

institution it holds that, by proclaiming that A, i produces A. In other words, for the institution i's proclamation that A counts as (or generates) i's production of A. Note that according to the action logic above presented, E_iA implies A. Therefore when a $proc_iA$ is effective A should follow. When an institution provides for the effectiveness of a proclamation to the effect that A, we say that the subject of the proclamation has a declarative power with respect to A:

$$DeclPow_iA =_{df} proc_iA \Rrightarrow_s E_iA \tag{7.37}$$

According to (7.37), if an agent i has the power over j to ascribe the obligation to achieve A, the following formula holds:

$$proc_iOG_jA \Rrightarrow_s E_iOG_jA \tag{7.38}$$

More generally, i's power to ascribe an obligation also concern the creation of a deontic channel according to a specific hierarchy. This means that i is empowered to oblige other agents:

$$(proc_iOEI_jA \Rrightarrow_s E_iOEI_jA) \tag{7.39}$$

It is immediate to see that the following formula can be proved from (7.39:

$$(proc_iOG_jA \Rrightarrow_s EI_iA) \tag{7.40}$$

On the other hand, i has the power to delegate the power to make it the case that A if we have that

$$(proc_i(proc_jA \Rrightarrow_s E_jA)) \Rrightarrow_s E_i(proc_jA \Rrightarrow_s E_jA) \tag{7.41}$$

Thus we are ready to define the notion of power to delegate powers of ascribing obligations. Following (7.41), this can be trivially done as follows:

$$(proc_i(proc_jOG_kA \Rrightarrow_s E_jOG_kA)) \Rrightarrow_s E_i(proc_jOG_kA \Rrightarrow_s E_jOG_kA) \tag{7.42}$$

or, more generally,

$$(proc_i(proc_jOEI_kA \Rrightarrow_s E_jOEI_kA)) \Rrightarrow_s E_i(proc_jOEI_kA \Rrightarrow_s E_jOEI_kA) \tag{7.43}$$

We may also have a kind of power, which includes both the power of conferring a power creating a normative position (an obligation or its negation) and also the power of transferring to others a similar power. We define this type as a sort of recursive power *RecDeclPow*. It can be formalised following a similar idea as that expressed in (7.16) for *EI*. In other words,

$$\begin{aligned} &RecDeclPow_i(OG_kA) \equiv \\ &DeclPow_i(OG_kA) \wedge (\bigwedge_{j \in Ag_{\leq}}^{k \leq j \leq i} DeclPow_i(RecDeclPow_j(OG_kA))) \end{aligned} \tag{7.44}$$

The above formula means that the holder i of the recursive declarative power is enabled to exercise his power in two ways. The first capacity $DeclPow_i(OG_kA)$, enables i to make so that k is obliged to realize A. The second capacity $DeclPow_i(RecDeclPow_j(OG_kA))$ enables i to transfer to another agent j the same recursive declarative power which i possesses. This latter notion is useful in those cases in which an organization is extended over multiple levels, and the top level wants to delegate not only the performance of the action, but also the command to perform it.

7.5.2 Hierarchy among agents

As we have alluded to in the previous sections, to deal with the notion of power we need to introduce an explicit relation of hierarchy $\prec$ among agents. How to characterise $\prec$? In [DW95], for instance, it is suggested that the power relation should correspond to a partial ordering on the class of agents.

This characterisation is too weak for our purposes. What about a total ordering? It is clearly too strong: usually, an institution does not require that, for each pair of agents, one is superior to the other. A reasonable condition is then that $\prec$ corresponds to a total ordering with clusters. In other words, we have that, for every two agents i and j such that

- $i \in Ag_m$ and $j \in Ag_n$;

- $Ag_m \subseteq Ag$ and $Ag_n \subseteq Ag$;
- $Ag_m \cap Ag_n = \emptyset$;

either $i \prec j$ or $j \prec i$.

It is worth noting that this ordering is also dependent on the operator *proc* and the connective $\Rrightarrow_s$. In particular, it seems to be intuitive to reformulate the declarative power of an agent i to ascribe obligations $\mathit{DeclPower}_i OG_j A$ by stipulating that $\neg j \prec i$.

On the other hand, something stronger can be accepted. For instance, new hierarchical relations between agents can be made explicit:

$$\mathit{DeclPower}_i OG_j A \Rrightarrow_s i \prec j \tag{7.45}$$

We think that also (7.45) is quite reasonable. If an agent i has the power to ascribe obligations to another agent j, this mean, at least defeasibly, that i is superior to j. However, accepting (7.45) could raise some problems for a semantic treatment of $\prec$. In fact, since we have the detachment for $\Rrightarrow_s$, (7.45) permits to infer new hierarchical relations between agents. How to deal with question?

As usual, an action can be conceived as a transition between two states. Obviously, a speech act is a very special kind of action. In this perspective, we have to consider the dynamic corresponding to institutionalised speech acts, in particular *proc* whose argument is either an obligation (e.g., OA or $OE_j A$) or an attribution of power (e.g., $i \prec j$). Those actions transform the state actual at the time of utterance in a state where the content of the speech act holds. Semantically, we can analyse this kind of acts by means of two dimension hierarchical fibred models. Shortly and roughly a two dimensional hierarchical model is a possible world structure where the points of the outer logic are models of the inner logic and the points are related by a fibring function. For the application at hand we can adopt a revision function as the fibring function of the model. In other words, each time we can detach $i \prec j$ from $\mathit{DeclPower}_i OG_j A \Rrightarrow_s i \prec j$ it is possible to define via the fibring function another model where $i \prec j$ holds (see [GG98] for the technical details).

7.5.3 Empowering autonomous agents

A fundamental aspect of a norm-governed society consists in the allotment of permissions and obligations to its members. This is the way in which such a society restrains and organizes the actions of its members. However, in an autonomous society (autonomous means establishing laws for one-self) the agents themselves must be able of creating those permissions and obligations. The decisive aspect of an autonomous social organization consists therefore in the empowerment of its agents, that is in establishing how agents may create what normative relations. In our model agents are empowered by attributing them appropriate declarative powers. This should enable agents to create the normative relations they need, and in this way to co-ordinate their behaviors. The failure to provide a viable allocation of such powers may threaten the survival of society. For example, if each self interested agents were given an unlimited power to unilaterally create obligation on the head of other agents, society would soon collapse, since everybody would soon be covered with an unsustainable workload, obligations would no longer be fulfilled, conflicts would explode, and trust would fade away. In the following we will sketch some features of a viable allocation of powers, which gives each agent the maximum of power consistent with the attribution of the same power to other agents.

Multi-lateral Proclaims (Contracts)

A declarative power may be jointly exercised by more than one party. If so, the proclamation will be an action performed by a set of agents. In very general terms, we may call such an action a contract. For example the making of a contract through which j takes the obligation towards k to provide a piece of music m and

k undertakes the obligation toward j to pay the price p, can be represented by the following proclamation[6]:

$$proc_{\{j,k\}}(O_k E_{\{j\}}(deliver(m)) \wedge O_j E_{\{k\}}(pay(p))) \tag{7.46}$$

Such joint proclaims are usually performed by two acts, the first of which is called offer, and the second acceptance. This combination is considered as a joint declaration (even when there is a delay between offer and acceptance). So we may want to say that the combination of an offer and an acceptance counts as making a contract. In cases where contracts are limited to the creation of reciprocal obligations we can express this as follows:

$$\mathit{offer}_{\{j\},\{k\}}(A,B) \wedge accept_{\{j\},\{k\}}(A,B) \Rrightarrow proc_{\{j,k\}}(O_k E_{\{j\}} A \wedge O_j E_{\{k\}} B) \tag{7.47}$$

If j offers to k to make a contract with reciprocal obligations having content A and B, and k accepts, this counts as making the contract. If the parties have the power to make an effective contract, the joint declaration generates within the institution the obligations for the parties involved in the contract:

$$D(O_k E_{\{j\}} A \wedge O_j E_{\{k\}} B) \tag{7.48}$$

where D is the "institutional" modality introduced in (7.32). The operators *offer* and *accept* are two committing declarative acts, that can be defined using the non committing declarative acts *proposal* and *agree*.

$$proposal_{\{j\},\{k\}}(A,B) = proc_{\{j\}}(O_k E_{\{j\}} A \wedge O_j E_{\{k\}} B) \tag{7.49}$$

$proposal_{\{j\},\{k\}}$ is a declaration of j where she proposes to ascribe to herself the obligation towards k to do A, and to k the obligation towards herself to do B. On

[6]Notice that our reading is different from that proposed, e.g., by Herrestad and Krogh [HK95]. They view a contract relation as follows: $O^i E_i B \wedge O_j E_i B$. The first conjunct is an ought-to-do statement expressing that i has the obligation to do B; the second corresponds to an ought-to-be statement saying that j requires i to perform B. We think this approach is intuitively unsatisfactory since it lacks to make explicit a strong logical relation between the two conjuncts. We solve this problem by saying that the conjunction of directed obligations is proclaimed jointly by both parties. For a criticism of Herrestad and Krogh's approach, see [TT99].

the other hand, agreeing means to make a proclamation when the other party has already made a proclamation in which it is proposed a specific contractual content:

$$agree_{\{k\},\{j\}}(A,B) = proposal_{\{j\},\{k\}}(A,B) \wedge proc_{\{k\}}(O_j E_{\{k\}} B) \tag{7.50}$$

(7.50) means that k recognizes j's proposal and agrees with its content. More precisely, given j's proposal, k agrees with binding herself to the obligation towards j to do B.

We are now able to introduce *offer* and *accept* formally. We have an offer when

$$\begin{aligned} &offer_{\{j\},\{k\}}(A,B) = proposal_{\{j\},\{k\}}(A,B) \wedge \\ &(agree_{\{k\},\{j\}}(A,B) \Rrightarrow proc_{\{j,k\}}(O_k E_{\{j\}} A \wedge O_j E_{\{k\}} B)) \end{aligned} \tag{7.51}$$

i.e., j proposes the content of the contract to k and she is aware that the acceptance of it by k will create the respective obligations. Accordingly, k's acceptance is formalized as follows:

$$accept_{\{k\},\{j\}}(A,B) = offer_{\{j\},\{k\}}(A,B) \wedge proc_{\{k\}}(O_j E_{\{k\}} B) \tag{7.52}$$

In other words, *accept* indicates that k accepts the legally binding offer of j. Since k's proclamation is done in presence of j's proposal (see (7.51)), such a proclamation determines k's agreement with the content (A,B). In addition, the second conjunct of (7.51) ensures that the offer and the acceptance are binding within the concerned institution.

Empowerment to Commit Oneself

We may consider giving every agent the power of creating obligations for itself, i.e., the power of making effective promises, or of committing itself. If our agents are autonomous, this power should be equally given to each of them. However, this may seem too liberal: j's obligation, towards k to perform A implies the permission toward k to perform that action. So, k's consent seems to be required. We can propose a general rule attributing all agents the power of committing themselves to other agents through a contract:

$$\forall j,k\ (DeclPow_{\{j,k\}}(O_k E_{\{j\}} A)) \tag{7.53}$$

which means that every couple of agents has the power of establishing any obligation between them, simply by proclaiming it. In other words, we empower all our agents to make effective promises (with the consent of the promisee).

Empowerment to Remit Obligations and Give Permissions

It is reasonable to assign every agent j the power of freeing any other agent k from obligations toward j, even without k's consent. For example, if j is no longer interested in k's performance, j should be allowed to free k from that performance. In fact, if j is able to look after itself and an obligation on k was originally created to promote j's interest, then j should be empowered to choose whether to cancel that obligation or not:

$$\forall j,k\ (DeclPow_{\{j\}}(\neg O_j E_{\{k\}} A) \wedge DeclPow_{\{j\}}(\neg O_j \neg E_{\{k\}} A)) \tag{7.54}$$

Accordingly, this formula also enables an agent to give any permission towards itself:

$$\forall j,k\ (DeclPow_{\{j\}}(P_j E_{\{k\}} A)) \tag{7.55}$$

So, for example, if agent j has the obligation towards k not to access a certain piece of information, k has the power of permitting that j accesses the information, according to 7.55. This is a very libertarian approach, but is appropriate for autonomous agents, e.g, in the commercial domain.

Empowerment to Command

It would be unreasonable to give all agents the power of commanding whatever action to any other agent. The power of commanding needs to be restricted only to specific cases, such as when one agent is hierarchically superior to another. A power of commanding held by superiors over inferiors would be conferred by the following rule[7]:

$$\forall j, k\ (j \prec k \Rightarrow \mathit{DeclPow}_{\{j\}}(O_j E_{\{k\}} A)) \tag{7.56}$$

where $\prec$ corresponds to a hierarchical relation between agents. Notice that '$\Rightarrow$' stands for the generic normative connection we have alluded to. In many types of societies, further restriction would be opportune, if the boss is not be a total dictator over its subordinates. A total power of commanding may be, however, the right empowerment for a human user over its agents.

Empowerment to Renounce to Power

It may seem reasonable to give agents also the power to renounce to their powers. In general terms this would be expressed by the following general empowerment:

$$\forall j\ (\mathit{DeclPow}_{\{j\}}(\neg \mathit{DeclPow}_{\{j\}} A)) \tag{7.57}$$

Empowerment to Empower

We give our agents a further chance to develop their societal relationships if we give them the power of conferring a power. For example, the formula below expresses the idea that j has the power of creating l's power of creating the obligation that k realizes A.

$$\forall x\ (\mathit{DeclPow}_{\{j\}}(\mathit{DeclPow}_{\{l\}}(O_x E_{\{k\}} A))) \tag{7.58}$$

What kinds of empowerment to empower can be allocated to our agents, according to a general rule? A very liberal choice would consist in stating that each agent has the power of giving other agents the powers he has for itself.

$$\forall j, k\ (\mathit{DeclPow}_{\{j\}} A \Rightarrow \mathit{DeclPow}_{\{j\}}(\mathit{DeclPow}_{\{k\}} A)) \tag{7.59}$$

[7]For a formal treatment of hierarchies among agents in the current setting, see [GGRS02].

So, for example, since each agent j has the power of committing itself according to (7.53), according to (7.59), j also has the power of submitting itself to another agent k, giving k the power to commanding j. This will be done via the following proclamation:

$$proc_{\{j\}}(DeclPow_{\{k\}}O_kE_{\{j\}}A) \tag{7.60}$$

Note that according to the definition above, when j gives to k a power which was previously possessed by j, j does not lose its power: both j and k can now exercise it. Obviously, empowerment may lead to cycles. Agent j_1 empowers j_2 to A, ..., agent j_n empowers j_1 to A. However, this is no problem: the latter empowerment simply is redundant, since j already possessed that power (unless it has renounced its power when conferring that power to another agent).

Recursive Empowerment

Finally, it is possible to confer our agents a further kind of power, which includes both the power of conferring a power to create a normative position and also the power of transferring to others a similar power. We define this type a recursive declarative power (which is a special case of formula (53) in [GGRS02]):

$$\begin{aligned} RecDeclPow_{\{j\}}(O_jE_{\{k\}}A) = DeclPow_{\{j\}}(O_jE_{\{k\}}A) \wedge \\ DeclPow_{\{j\}}(RecDeclPow_{\{l\}}(O_jE_{\{k\}}A) \end{aligned} \tag{7.61}$$

The above formula means that the holder j of the recursive declarative power is enabled to exercise his power in two ways. The first capacity,

$$DeclPow_{\{j\}}(O_jE_{\{k\}}A) \tag{7.62}$$

enables j to make so that k is obliged to realize A. The second capacity

$$DeclPow_{\{j\}}(RecDeclPow_{\{l\}}(O_jE_{\{k\}}A)) \tag{7.63}$$

enables j to transfer to another agent l the same recursive declarative power which j possesses. This latter notion is useful in those cases where an organization is developed in multiple levels, and the top level wants to delegate not only the performance of the action, but also the command to perform it. The exercise of this power may lead to cycles, but again, this is no problem (the agent who started the cycle may consider having another try), or better it is a problem that it is up to the concerned agents to solve, according to their view of their own interest.

Specific Limitations to Empowerment

In the previous pages, we have sketched the constitution of a liberal, or better a libertarian society, where every agent is considered to be fully able to look after its interest, and where any normative relation can be created via the consent of the interested parties. In many real life contexts, and in particular in legal institutions, various limitations to individual freedom are provided, for a number of reasons: preventing frauds, protecting the weaker party, preventing the parties from making mistakes. Unfortunately, there is not much that we may say in general in regard to such limitations. It depends on the particular institutional what exceptions are made to the libertarian framework we sketched above. Consider, for example, the regulations which require a proclamation to a certain effects to be performed in certain specific ways (e.g., contracts concerning real estates have to be made in writing, or through deeds, unilateral promises are binding only if they serve an interest of the promisor, testaments have to be signed, etc.). We will not investigate here those special conditions, nor the way in which our formalism need to be extended to cope with them. This will be a matter of future research.

7.6 The framework applied to the contract net protocol

In this section, we show how the framework can formalize a well-known trading scenario, the contract-net protocol. As informal specification of the contract-net protocol we assume that proposed in [PKA01]. For short, a contractor sends a call for proposal to a set of prospective workers. In general, some workers answer to the proposal, by offering to do the job, some do not. Among the answers received by the timeout, there be refusals and offers. At this stage, the contractor chooses the best offer according to some parameters. Then, it accepts the offer of the winner and rejects the others. The winner must perform the contracted task and inform the contractor after the execution.

There are some constraints which govern the process of contracting. First, a worker can only offer to accomplish a task which it is able to accomplish. Second, a worker can only offer to accomplish a task which has been proposed to him. Third, a contractor can only accept an offer when he has the resources for paying for the price.

We may view these constraints in two ways. One perspective is to consider them to introduce conditions for the validity (effectiveness) of contracts stipulated between a contractor and a worker. This would mean that if the contractor has no money, or the worker is unable, or the contract was not preceded by a proposal, then the contract would be invalid. This would be an exception to our definition of multi-lateral proclaims, namely that the joint declaration of the interested parties is sufficient for the effectiveness of the contract.

In this representation we adopt a different approach. Those constraints express obligations on the parties, which they may violate at their risk (incurring in possible sanction) but which do not imply the ineffectiveness of their contracts. Note that this is what happens in the law: the fact that a party is unable to execute a contract determines the liability of that party (for failure to perform its contractual duties), rather than the invalidity of the contract.

First, observe that the content of the contract (which is proposed, offered and accepted) is always $O_c E_{\{w\}} performed(t) \wedge O_w E_{\{c\}} paid(p)$, which means that the worker w undertakes, toward the contractor, the obligation to perform the task t, while the contractor c undertakes, towards the worker w, the obligation of paying the price p.

We write $cfp_c^W(X)$ to mean that contactor c calls for proposals (of making a contract) having content X from any worker $w \in W$. Note that a call for proposals is a special case of '*proposal*', as previously described, and corresponds to

$proposal_{\{c\},\{w\}}(X)$ for any $w \in W$. We write $offer_{\{w\},\{c\}}(X)$ to mean that worker w offers contactor c to conclude a contract with content X. Similarly, we write $accept_{\{c\},\{w\}}(X)$ to mean that contractor c accepts to conclude a contract with worker w having content X.

Here is how we represent those constraints:

1. if a worker agent cannot perform a task, then it is not permitted to offer to perform it[8]:

$$\begin{aligned} &\forall w, c, t\ ((worker(w) \wedge \neg can_{\{w\}}(performed(t))) \Rightarrow \\ &\qquad \neg P(offer_{\{w\},\{c\}}(E_{\{w\}}performed(t), E_{\{c\}}paid(p)))) \end{aligned} \tag{7.64}$$

2. if a task has not been proposed, a worker agent is not permitted to offer for it:

$$\forall w, c\ (worker(w) \wedge \neg cfp_c^W(X) \Rightarrow \neg P(offer_{\{w\},\{c\}}(X))) \tag{7.65}$$

3. if a contractor agent cannot pay the price for which a worker has offered to perform the task than it is not permitted to accept the offer:

$$\begin{aligned} &\forall c, w, t, p\ (contractor(c) \wedge \neg can_{\{c\}}(paid(p)) \Rightarrow \\ &\qquad \neg P_w(accept_{\{c\},\{w\}}(E_{\{w\}}performed(t), E_{\{c\}}paid(p)))) \end{aligned} \tag{7.66}$$

We can now move to show a typical sequence of messages (in our framework, proclamations) that compose the contract net protocol. First the contractor issues a proposal of a contract the terms of which state that the worker has the obligation to print a copy of the book *War and Peace* (t) and the contractor has the obligation to pay Euro 20 (p) for it.

$$cfp_c^W(E_{\{w\}}performed(t), E_{\{c\}}paid(p)) \tag{7.67}$$

As a consequence, now, workers, who are able to print the book are allowed to make offers. This assumes that what is not forbidden is allowed. Let us assume that

[8]The expression '*can*' may be viewed as the operator *Ability* described in [Elg97].

worker w returns an offer, intended as a (possibly committing) counter-proposal to (7.67):

$$\mathit{offer}_{\{w\},\{c\}}(E_{\{w\}}\mathit{performed}(t), E_{\{c\}}\mathit{paid}(p')) \tag{7.68}$$

where p' =15 Euro. Let us now assume that this is the best offer c has received, so that it accepts it (this implies c's agreement; see Section 4.2).

$$\mathit{accept}_{\{c\},\{w\}}(E_{\{w\}}\mathit{performed}(t), E_{\{c\}}\mathit{paid}(p')) \tag{7.69}$$

From (7.68) and (7.69) the following is obtained (within the institution):

$$D(\mathit{proc}_{\{c,w\}}(O_c E_{\{w\}}\mathit{performed}(t) \wedge O_w E_{\{c\}}\mathit{paid}(p'))) \tag{7.70}$$

This means that the parties have made a contract. The contract is effective according to the general principles. In fact, according to the logical properties of proclamation, (7.70) implies the following

$$D(\mathit{proc}_{\{c,w\}}(O_c E_{\{w\}}\mathit{performed}(t)) \wedge \mathit{proc}_{\{c,w\}}(O_w E_{\{c\}}\mathit{paid}(p'))) \tag{7.71}$$

Finally, according to axioms (7.53) and (**??**) (see note **??**)we obtain (within the institution) that w is obliged to do the job and c is obliged to pay for it:

$$D(O_c E_{\{w\}}\mathit{performed}(t) \wedge O_w E_{\{c\}}\mathit{paid}(p')) \tag{7.72}$$

Once the contractor agent has decided which offer fits its needs the most, he has also to communicate his refusals to the losers w' [9]:

$$\begin{aligned} \forall w' \ (&\mathit{proposal}_{\{w'\},\{c\}}(E_{\{w'\}}\mathit{performed}(t), E_{\{c\}}\mathit{paid}(p'')) \wedge \\ &\mathit{proc}_{\{c\}}(\neg O_{w'} E_{\{c\}}\mathit{paid}(p''))) \end{aligned} \tag{7.73}$$

7.7 Future developments: applications and computational issues

In this section we will briefly indicate two developments and applications of the framework we have previously defined.

[9]The following formula expresses c's disagreement. Its definition can be intuitively formulated from the formula (7.50).

A first aspect regards a possible and concrete application of the framework in the in the area of Digital Rights Management (DRM), a field that has drawn attention from both the scientific community and industry in the last few years. DRM is intended as a pool of technologies for data security and protection, copyright protection and access control. DRM addresses the management of digital resources, including their publishing, manipulation and transferring. DRM is ultimately one key enabling technology for marketing intellectual products, such as music, images and e-books, on the Internet [KGG$^+$01]. As a first approach, we have already looked at the eXtensible rights Markup Language (*XrML*), an XML-based grammar for specifying rights related to digital resources [xrm]: *XrML* is in fact an *XML* grammar intended for terming licenses related to digital resources. Licenses establish which rights are granted to which parties and the conditions by which digital resources can be operated. Our first results are promising (see [GRS03, GR04a]). We have already provided a simple extension of the set of elements of *XrML* language to cover some types of normative positions required by our logical framework. Subsequently, a prototype, based on this extension, has been built using the *JADE* multi-agent system platform [Boa04] (see [GR04a]). The result is a system that can be used to make agents negotiate the exchange of goods. Although the system seems to be a good test bed for some virtual marketplace scenarios, limitations of the system are due to the nature of *XrML*: every concept contained in a license must be understood by the counterparts in the negotiation and this implies that every *XrML* tag must be *explicitly* dealt with the parser. The future work will thus focus on devising a suitable inference engine, so that agents can reason about rules reaching a more flexible behavior. This should also permit to embed into the language and express more complex normative concepts than those already added to standard *XrML*.

A second line of research consists in developing a computational framework, based on the logical intuitions we have described here, and which should be able to treat the basic mechanisms of institutional agency and normative co-ordination. Also in this regard we have some first, but interesting, results. We have already proposed a computationally oriented model based on Defeasible Logic. Defeasible logic has been developed by Nute [Nut94] with a particular concern about computational efficiency and developed over the years by [ABGM00]. The reason being ease of implementation, flexibility [ABGM00] (it has a constructively defined and easy to use proof theory which allows us to capture a number of different intuitions of non-monotonicity) and it is efficient: it is possible to compute the complete set of consequences of a given theory in linear time. At the moment, we have provided two extensions of standard Defeasible Logic. The first incorporates the notions of "counts as" and agency, the second combines agency, BDI concepts and obligations [GR04b]. Our future work will be devoted to developing a unique framework which is able to deal with the cognitive component (BDI concepts), agency, and normative notions ("counts as" and deontic operators). In addition, thanks to the nice computational features of the logic, we plan to investigate how the framework can lead to real implementations.

Conclusions

Throughout the thesis we tackled issues related to multi-agent systems implementation.

We first draw attention to how such systems could be modeled, proposing a possible extension to UML, a popular notation for designing software systems. This approach has two advantages in our opinion: it builds up on existing knowledge, thus facilitating the learning of AUML and it does not rely on any specific underlying methodology, making the notation adoptable in many situations.

We then discussed the implementation of two projects, namely Wink and Sewasie, where multi-agent systems were developed to meet the application requirements. The purposes was to test agent technology on the field, using state-of-the-art tools (such as JADE). This experience has suggested improvements and limitations of agent technology, making us understand what gaps should be filled next. In particular we consider interoperability, high-level communication and mobility strong features of agents, which really make possible the construction of more advanced information systems. Drawbacks are to be considered in the number and quality of tools available. At the same time, we studied how to add features like for instance persistence support (at testing level) and the concept of shadow agents, which may easy multi-agent system development. We hope also that, as the experiences were conducted while the agent specifications were under discussion in the scientific community, that our work may have served as testbed for the discussion.

Finally, we tackled also the deployment of software agents in settings where they will represent persons, i.e. software agents will be legally bounded to persons. This is again another facet of agent technology. According to our view this could be realized some day only if there is a precise legal framework within which to ascribe agent interactions.

Future work comprises many directions among which we would give priority to (i) investigating fields of application of agent technology outside integration information systems, like sensor networks and data stream management systems and (ii) design and build application where the agent middleware is coupled with inference engines with the aim of providing more intelligent solutions and systems.

Bibliography

Chapter 2

[Aus62] J. L. Austin. *How to Do Things with Words.* Harvard University Press, Cambridge, Massachussets, USA, 1962.

[Boo94] G. Booch. *Object-Oriented Analysis And Design With Application.* Addison-Wesley, 2nd edition, 1994.

[Con] World Wide Web Consortium.

[dL96] Mark d'Inverno and Michael Luck. Formalising the contract net as a goal-directed system. In *Proceedings of the 7th European workshop on Modelling autonomous agents in a multi-agent world : agents breaking away*, pages 72–85. Springer-Verlag New York, Inc., 1996.

[FFMM94] T. Finin, R. Fritzson, D. McKay, and R. McEntire. KQML as an Agent Communication Language. In N. Adam, B. Bhargava, and Y. Yesha, editors, *Proceedings of the 3rd International Conference on Information and Knowledge Management (CIKM'94)*, pages 456–463, Gaithersburg, MD, USA, 1994. ACM Press.

[FG97] Stan Franklin and Art Graesser. Is it an agent, or just a program?: A taxonomy for autonomous agents. In *Proceedings of the Workshop on Intelligent Agents III, Agent Theories, Architectures, and Languages*, pages 21–35. Springer-Verlag, 1997.

[HR95] Barbara Hayes-Roth. An architecture for adaptive intelligent systems. *Artif. Intell.*, 72(1-2):329–365, 1995.

[Ld95] Michael Luck and Mark d'Inverno. A formal framework for agency and autonomy. In Victor Lesser and Les Gasser, editors, *Proceedings of the First International Conference on Multi-Agent Systems (ICMAS-95)*, pages 254–260, San Francisco, CA, USA, 1995. AAAI Press.

[Mae95] Pattie Maes. Artificial life meets entertainment: lifelike autonomous agents. *Commun. ACM*, 38(11):108–114, 1995.

[New82] A. Newell. The knowledge level. *Artificial Intelligence*, 18:87–127, 1982.

[OPB00] J. Odell, H. Parunak, and B. Bauer. Extending uml for agents, 2000.

[Pit04a] Jeremy Pitt, editor. *The Open Agent Socieites*, chapter Cristiano Castelfranchi and Rino Falcone. Social Trust Theory. John Wiley and Sons, 2004.

[Pit04b] Jeremy Pitt, editor. *The Open Agent Socieites*, chapter Cristiano Castelfranchi and Rino Falcone. Adjustable Social Autonomy. John Wiley and Sons, 2004.

[RN03] St. Russell and P. Norvig. *Artificial Intelligence - A Modern Approach.* Prentice Hall International Series in Artificial Intelligence. Prentice Hall, 2003. RUS s 03:1 1.Ex.

[Sea69] J. Searle. *Speech Acts: An Essay in the Philosophy of Language.* Cambridge University Press, Cambridge, Massachussets, USA, 1969.

[WJK00] Michael Wooldridge, Nicholas R. Jennings, and David Kinny. The gaia methodology for agent-oriented analysis and design. *Autonomous Agents and Multi-Agent Systems*, 3(3):285–312, 2000.

Chapter 3

[Arg79] Tilak Argewala. Putting petri nets to work. *Computer*, pages 85–94, 1979.

[Bau02] Bernhard Bauer. Uml class diagrams revisited in the context of agent-based systems. In *Revised Papers and Invited Contributions from the Second International Workshop on Agent-Oriented Software Engineering II*, pages 101–118. Springer-Verlag, 2002.

[Ber] Sonia Bergamaschi. Experiencing auml for the wink multi-agent.

[BGGV03a] S. Bergamaschi, G. Gelati, F. Guerra, and M. Vincini. Experiencing auml for the wink milti-agent system,. In *Proceedings AIIA and TABOO Workshop: From Object to Agents (WOA03), 10-11 Settembre 2003, Villasimius*, 2003.

[BGGV03b] S. Bergamaschi, G. Gelati, F. Guerra, and M. Vincini. Wink: a web-based enterprise system for collaborative project management in virtual enterprises. In *Proceedings 4th International Conference on Web Information Systems Engineering (WISE), Roma Italy, 10-12 December 2003*, 2003.

[BMO00] B. Bauer, J. Muller, and J. Odell. An extension of uml by protocols for multiagent interaction, 2000.

[Boo94] G. Booch. *Object-Oriented Analysis And Design With Application.* Addison-Wesley, 2nd edition, 1994.

[BTS$^+$04] Mihai Boicu, Gheorghe Tecuci, Bogdan Stanescu, Dorin Marcu, marcel Barbulescu, and Cristina Boicu. Design principles for learning agents. In *Proceedings of the AAAi-04 Workshop on Intelligent Agent Architectures: Combining the Strengths of Software Engineering and Cognitive Systems.* AAAI Press, 2004.

[CCF$^+$99] R. Cost, Y. Chen, T. Finin, Y. Labrou, and Y. Peng. Modeling agent conversations with colored petri nets. In *Working Notes of the Workshop on Specifying and Implementing Conversation Policies*, pages 59–66, Seattle, Washington, May 1999.

[CCF$^+$00] Rost S. Cost, Ye Chen, Tim Finin, Yannis Labrou, and Yun Peng. Using colored petri nets for conversation modeling. In Frank Dignum and Mark Greaves, editors, *Issues in Agent Communication*, pages 178–192. Springer-Verlag: Heidelberg, Germany, 2000.

[Dem95] Y. Demazeau. From interactions to collective behaviour in agent-based systems, 1995.

[dL96] Mark d'Inverno and Michael Luck. Formalising the contract net as a goal-directed system. In *Proceedings of the 7th European workshop on Modelling autonomous agents in a multi-agent world : agents breaking away*, pages 72–85. Springer-Verlag New York, Inc., 1996.

[fIPA] Foundation for Intelligent Physical Agents.

[FO00] K Fernandes and Michel Occello. A recursive approach to build hybrid multi-agent systems. In *Proceedings of the III Iberoamerican Workshop on Distributed Artificial Intelligence and MultiAgent Systems, SBIA/IBERAMIA*. LNAI Springer-Verlag, 2000.

[FW94] M. Fisher and M. Wooldridge. Specifying and executing protocols for cooperative action. In *Proceedings of International Working Conference on Cooperating Knowledge-Based Systems (CKBS)*, Keele, U.K., 1994.

[Gro] Object Management Group.

[HK98] T. Holvoet and T. Kielmann. Behaviour specification of parallel active objects. *Parallel Computing*, 24(7):1107–1135, 1998.

[Hol91] Gerard J. Holzmann. *Design and validation of computer protocols.* Prentice-Hall, Inc., 1991.

[Hol95] Tom Holvoet. Agents and petri nets. *Petri Net Newsletter*, (49):3–8, October 1995.

[Hug02a] M. Huget. Agent uml class diagrams revisited, 2002.

[Hug02b] M. Huget. Extending agent uml protocol diagrams, 2002.

[IGCGV98] Carlos Argel Iglesias, Mercedes Garijo, Centeno-Gonzalez, and Juan R. Velasco. Analysis and design of multiagent systems using mas-common kads. In *Proceedings of the 4th International Workshop on Intelligent Agents IV, Agent Theories, Architectures, and Languages*, pages 313–327. Springer-Verlag, 1998.

[IGG99] Carlos Iglesias, Mercedes Garrijo, and José Gonzalez. A survey of agent-oriented methodologies. In Jörg Müller, Munindar P. Singh, and Anand S. Rao, editors, *Proceedings of the 5th International Workshop on Intelligent Agents V : Agent Theories, Architectures, and Languages (ATAL-98)*, volume 1555, pages 317–330. Springer-Verlag: Heidelberg, Germany, 1999.

[Jen92] Kurt Jensen. *Coloured Petri Nets. Basic Concepts, Analysis Methods, and Practical Use*, volume 1. Springer Verlag, 1992.

[Jen94] Kurt Jensen. *Coloured Petri Nets. Basic Concepts, Analysis Methods, and Practical Use*, volume 2. Springer Verlag, 1994.

[Jen97] Kurt Jensen. *Coloured Petri Nets. Basic Concepts, Analysis Methods, and Practical Use*, volume 3. Springer Verlag, 1997.

[KIO95] Kazuhiro Kuwabara, Toru Ishida, and Nobuyasu Osato. Agentalk: Coordination protocol description for multiagent systems. In Victor Lesser, editor, *Proceedings of the First International Conference on Multi–Agent Systems*, page 455, San Francisco, CA, 1995. MIT Press.

[MKC01] John Mylopoulos, Manuel Kolp, and Jaelson Castro. UML for agent-oriented software development: The tropos proposal. *Lecture Notes in Computer Science*, 2185:422–??, 2001.

[Mod03a] FIPA TC Modeling. Fipa modeling: Interaction diagrams, 2003.

[Mod03b] FIPA TC Modeling. Fipa specification class diagrams, 2003.

[MW97] Daniel Moldt and Frank Wienberg. Mulit-agent systems based on coloured petri nets. In *Proceedings of the 18th International Conference on Application and Theory of Petri Nets (IACATPN-97)*, volume 1248, pages 82–101. Springer-Verlag: Lecture Notes in Computer Science, 1997.

[Ode02] James Odell. Agent and objects compared. *Journal of Object Technology*, 1(1):41–53, 2002.

[OPB00] J. Odell, H. Parunak, and B. Bauer. Extending uml for agents, 2000.

[PC96] Martin Purvis and Stephen Cranefield. Agent modelling with petri nets. In *Proceedings of the Symposium on Discrete Events and Manufacturing Systems*, pages 602–607. IEEE-SMC, 1996.

[Pet81] James Lyle Peterson. *Petri Net Theory and the Modeling of Systems.* Prentice Hall PTR, 1981.

[Smi80] R. G. Smith. The contract net protocol: High-level communication and control in a distributed problem solver. *IEEE Transactions on Computers*, 29(12), 1980.

[Spi89] J. M. Spivey. *The Z notation: a reference manual.* Prentice-Hall, Inc., 1989.

[SW00] Gurdip Singh and Jun Wu. Modular object-oriented design of distributed protocols. In *Proceedings of the International Conference on Technology for Object Oriented Languages and Systems (TOOLS).* IEEE Press, 2000.

[WJK00] Michael Wooldridge, Nicholas R. Jennings, and David Kinny. The gaia methodology for agent-oriented analysis and design. *Autonomous Agents and Multi-Agent Systems*, 3(3):285–312, 2000.

Chapter 4

[Boa04] Jade Board. Jade security guide, 2004.

[Bri01] Chris Britton. *IT architectures and middleware: strategies for building large, integrated systems.* Addison-Wesley Longman Publishing Co., Inc., 2001.

[DSW97] K. Decker, K. Sycara, and M. Williamson. Middle-agents for the internet. In *Proceedings of the 15th International Joint Conference on Artificial Intelligence*, Nagoya, Japan, 1997.

[FIP02] FIPA. Fipa subscribe interaction protocol specification, 2002.

[fIPA] Foundation for Intelligent Physical Agents.

[fIPA02a] Foundation for Intelligent Physical Agents. Fipa abstract architecture specification, 2002.

[fIPA02b] Foundation for Intelligent Physical Agents. Fipa request interaction protocol specification, 2002.

[fIPA04] Foundation for Intelligent Physical Agents. Fipa agent management specification, 2004.

[For82] C. L. Forgy. Rete: A fast algorithm for the many pattern/many object pattern match problem. *Artificial Intelligence*, 19:17–37, 1982.

[FPV98] Alfonso Fuggetta, Gian Pietro Picco, and Giovanni Vigna. Understanding Code Mobility. *IEEE Transactions on Software Engineering*, 24(5):342–361, 1998.

[GHB00] Mark Greaves, Heather Holmback, and Jeffrey Bradshaw. What is a conversation policy? In *Issues in Agent Communication*, pages 118–131. Springer-Verlag, 2000.

[Mye02] Judith M. Myerson. *The Complete Book of Middleware*. Auerbach, 2002.

[NAS84] NASA. C language integrated production system, 1984.

[RN03] St. Russell and P. Norvig. *Artificial Intelligence - A Modern Approach*. Prentice Hall International Series in Artificial Intelligence. Prentice Hall, 2003. RUS s 03:1 1.Ex.

[SCB$^+$98] I. Smith, P. Cohen, J. Bradshaw, M. Greaves, and H. Holmback. Designing conversation policies using joint intention theory, 1998.

[SCS94] David Canfield Smith, Allen Cypher, and Jim Spohrer. Kidsim: programming agents without a programming language. *Commun. ACM*, 37(7):54–67, 1994.

[SPVG01] Katia Sycara, Massimo Paolucci, Martin Van Velsen, and Joseph Andrew Giampapa. The retsina mas infrastructure. Technical Report CMU-RI-TR-01-05, Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, March 2001.

[SR96] S.L. Star and K. Ruhleder. Steps toward an ecology infrastructure: Design and access for large information spaces. *Information Systems Research*, 7(1):111–134, 1996.

[SS00] Onn Shehory and Katia Sycara. The RETSINA communicator. In Carles Sierra, Maria Gini, and Jeffrey S. Rosenschein, editors, *Proceedings of the Fourth International Conference on Autonomous Agents*, pages 199–200, Barcelona, Catalonia, Spain, 2000. ACM Press.

[WS00] H. Wong and K. Sycara. A taxonomy of middle-agents for the internet, 2000.

[ZMM99] Giorgos Zacharia, Alexandros Moukas, and Pattie Maes. Collaborative reputation mechanisms in electronic marketplaces. In *Proceedings of the Thirty-second Annual Hawaii International Conference on System Sciences-Volume 8*, page 8026. IEEE Computer Society, 1999.

Chapter 5

[BBGV01] Domenico Beneventano, Sonia Bergamaschi, Francesco Guerra, and Maurizio Vincini. The MOMIS approach to information integration. In *ICEIS (1)*, pages 194–198, 2001.

[BCBV01] S. Bergamaschi, S. Castano, D. Beneventano, and M. Vincini:. Semantic integration of heterogeneous information sources. *Special Issue on Intelligent Information Integration, Data and Knowledge Engineering*, 36(1):215–249, 2001.

[BSBV97] Sonia Bergamaschi, Claudio Sartori, Domenico Beneventano, and Maurizio Vincini. Odb-tools: A description logics based tool for schema validation and semantic query optimization in object oriented databases. In *AI*IA '97: Proceedings of the 5th Congress of the Italian Association for Artificial Intelligence on Advances in Artificial Intelligence*, pages 435–438. Springer-Verlag, 1997.

[CAdV01] Silvana Castano, Valeria De Antonellis, and Sabrina De Capitani di Vimercati. Global viewing of heterogeneous data sources. *IEEE Transactions on Knowledge and Data Engineering*, 13(2):277–297, 2001.

[Con] World Wide Web Consortium.

[EM03] J. Roberto Evaristo and Bjørn Erik Munkvold. Collaborative infrastructure formation in virtual projects. *Journal of Global Information Technology Management*, 6(2):9–47, 2003.

[Fel98] Christiane Fellbaum, editor. *WordNet An Electronic Lexical Database.* MIT Press, 1998.

[WZ99] Lutz Wegner and Christian Zirkelbach. Collaborative project management with a web-based database editor. In *Proceedings of the Fifth International Workshop on Multimedia INformaiton Systems*, 1999.

Chapter 6

[Con03] The Sewasie Consortium. Techniques for query reformulation, 2003.

[Con04] The Sewasie Consortium. Specification of agent technology for negotiation support, 2004.

[DS88] Randall Davis and Reid G. Smith. Negotiation as a metaphor for distributed problem solving. pages 333–356, 1988.

[fIJ] Hibernate Relational Persistence for Idiomatic Java. http://www.hibernate.org/.

[fIPA02] Foundation for Intelligent Physical Agents. Fipa request interaction protocol specification, 2002.

[MyS] MySql. http://www.mysql.org/.

[Sol] SolarMetric. http://www.solarmetric.com/.

[Wie92] G. Wiederhold. Mediators in the architecture of future information systems. *IEEE Computer*, 25:38–49, 1992.

[WS00] H. Wong and K. Sycara. A taxonomy of middle-agents for the internet, 2000.

Chapter 7

[ABGM00] Grigoris Antoniou, David Billington, Guido Governatori, and Michael J. Maher. A flexible framework for defeasible logics. *CoRR*, cs.AI/0003013, 2000.

[APS02] Alexander Artikis, Jeremy Pitt, and Marek Sergot. Animated specifications of computational societies. In *AAMAS '02: Proceedings of the first international joint conference on Autonomous agents and multiagent systems*, pages 1053–1061. ACM Press, 2002.

[Boa04] Jade Board. jade.cselt.it/, 2004.

[Bou94] Craig Boutilier. Toward a logic for qualitative decision theory. In Jon Doyle, Erik Sandewall, and Pietro Torasso, editors, *Principles of Knowledge Representation and Reasoning*, pages 75–86, 1994.

[CD00] Rosaria Conte and Chris Dellarocas, editors. *Social Order in Multiagent Systems: Workshop on Norms and Institutions in Multi-Agent Systems (Held in conjunction with Autonomous Agents'2000)*, Boston, Kluwer Academic Publishers, 2000.

[CDJT99] Cristiano Castelfranchi, Frank Dignum, Catholijn M. Jonker, and Jan Treur. Deliberative normative agents: Principles and architecture. In *Agent Theories, Architectures, and Languages*, pages 364–378, 1999.

[Che75] B.F. Chellas. Basic conditional logic. *Journal of Philosophical Logic*, 1975.

[CL90] P. R. Cohen and H. J. Levesque. Rational interaction as the basis for communication. In P. R. Cohen, J. Morgan, and M. E. Pollack, editors, *Intentions in Communication*, pages 221–255. MIT Press, Cambridge, MA, 1990.

[Col00] M. Colombetti. A commitment–based approach to agent speech acts and conversations. In *In Proc. Workshop on Agent Languages and Communication Policies, 4th International Conference on Autonomous Agents (Agents 2000)*, pages 21–29, Barcelona, Spain, 2000.

[CP88] Philip R. Cohen and C. Raymond Perrault. Elements of a plan-based theory of speech acts. *Distributed Artificial Intelligence*, pages 169–186, 1988.

[DW95] F. Dignum and H. Weigand. Communication and deontic logic, 1995.

[Elg97] D. Elgesem. The modal logic of agency. *Journal of Philosophical Logic*, 2(2):1–46, 1997.

[FFMM94] T. Finin, R. Fritzson, D. McKay, and R. McEntire. KQML as an Agent Communication Language. In N. Adam, B. Bhargava, and Y. Yesha, editors, *Proceedings of the 3rd International Conference on Information and Knowledge Management (CIKM'94)*, pages 456–463, Gaithersburg, MD, USA, 1994. ACM Press.

[fIPA] Foundation for Intelligent Physical Agents.

[GG98] Dov Gabbay and Guido Governatori. Dealing with label dependent deontic modalities. In P. McNamara, editor, *Norms, Logics and Information Systems. New Studies on Deontic Logic and Computer Science, Deon'98.* IOS Press, 1998.

[GG02] D. Gabbay and F. Guenthner, editors. *Handbook of Philosophical Logic (2nd edition)*, volume 8, chapter Deontic logic and contrary-to-duties, pages 265–343. Kluwer Academic Publishers, Dordrecht, Holland, 2002.

[GGRS02] G. Gelati, G. Governatori, A. Rotolo, and G. Sartor. Actions, institutions, powers. a logical framework. In *Proceedings of the International Workshop on Regulated Agent-Based Social Systems: Theories and Applications 2002 Workshop*, pages 69–79, 2002.

[GR04a] G. Gelati and R. Riveret. Drm in a multi-agent system marketplace. In *Proceedings of the Law for electronics Agents LEA 2004*, 2004.

[GR04b] Guido Governatori and Antonino Rotolo. Defeasible logic: Agency, intention and obligation. In *DEON*, pages 114–128, 2004.

[Gri89] H. Paul Grice. *Studies in the Way of Words.* Harvard University Press, Cambridge, 1989.

[GRS03] G. Gelati, A. Rotolo, and G. Sartor. A logic based analysis of xrml. In *Proceedings of the Law for electronics Agents LEA 2003*, 2003.

[HK95] Henning Herrestad and Christen Krogh. Obligations directed from bearers to counterparts. In *ICAIL '95: Proceedings of the fifth international conference on Artificial intelligence and law*, pages 210–218. ACM Press, 1995.

[JK01] A.J.I. Jones and Ch. Krogh, editors. *A Logical Framework. Basic and Composite notions for Reasoning about Norm, Action in Artificial Societies.* ALFEBIITE Deliverable D2, 2001.

[Jon90] A. I. J. Jones. Towards a formal theory of communication and speech acts. In P. R. Cohen, J. Morgan, and M. E. Pollack, editors, *Intentions in Communication*, Cambridge, MA, 1990. MIT Press.

[Jon96] Cliff Jones. Formal methods light. *ACM Computing Surveys*, 28(4es):121–121, 1996.

[KGG$^+$01] K. Kamyab, F. Guerin, Goulev, P., and E. Mamdani. Designing agents for a virtual marketplace. *AISB Journal*, 1(1):61–85, 2001.

[KLM90] Sarit Kraus, Daniel Lehmann, and Menachem Magidor. Nonmonotonic reasoning, preferential models and cumulative logics. *Artif. Intell.*, 44(1-2):167–207, 1990.

[LN04] Alessio Lomuscio and Donald Nute, editors. *Proceedings of Deontic Logic in Computer Science 7th International Workshop on Deontic Logic in Computer Science, DEON 2004*, Madeira, Portugal, 2004. Lecture Notes in Computer Science, Lecture Notes in Artificial Intelligence, Vol. 3065.

[MCT01] Dastani M.M., Jonker C.M., and J. Treur. A requirement specification language for configuration dynamics of multi-agent system. In *Proceedings of the 2nd International Workshop on Agent-Oriented Software Engineering, AOSE'01*, Berlin, Germany, 2001. Springer Verlag.

[MW93] J.-J. C. Meyer and R. J. Wieringa. Deontic logic: A concise overview. In J.-J. C. Meyer and R. J. Wieringa, editors, *Deontic Logic in Computer Science: Normative System Specification*, pages 3–16. Wiley, New York, 1993.

[Nut94] D. Nute. Defeasible logic. In D. M. Gabbay, C. J. Hogger, and J. A. Robinson, editors, *Handbook of Logic in Artificial Intelligence and Logic Programming-Nonmonotonic Reasoning and Uncertain Reasoning(Volume 3)*, pages 353–395. Clarendon Press, Oxford, 1994.

[PKA01] Jeremy Pitt, Lloyd Kamara, and Alexander Artikis. Interaction patterns and observable commitments in a multi-agent trading scenario. In *AGENTS '01: Proceedings of the fifth international conference on Autonomous agents*, pages 481–488. ACM Press, 2001.

[RG91] Anand S. Rao and Michael P. Georgeff. Modeling rational agents within a BDI-architecture. In James Allen, Richard Fikes, and Erik Sandewall, editors, *Proceedings of the 2nd International Conference on Principles of Knowledge Representation and Reasoning (KR'91)*, pages 473–484. Morgan Kaufmann publishers Inc.: San Mateo, CA, USA, 1991.

[Roy00] L. Royakkers. Combining deontic and action logics for collective agency. In J. Breuker et al., editor, *In Legal Knowledge and Information Systems (Jurix 2000).* IOS Press, Amsterdam, 2000.

[SC96] Filipe Santos and José Carmo. Indirect action, influence and responsibility. In *DEON*, pages 194–215, 1996.

[SCJ97] F. Santos, J. Carmo, and A. Jones. Action concepts for describing organised interaction. In R. A. Sprague, editor, *Thirtieth Annual Hawai International Conference on System Sciences*, pages 373–382, 1997.

[Sea95] J.R. Searle. *The Construction of Social Reality.* Penguin Press, Harmondsworth, 1995.

[Seg71] K. Segerberg. *An Essay in Classical Modal Logic.* Filosofiska studier, Uppsala, 1971.

[Sin] M. Singh. An ontology for commitments in multiagent systems: Toward a unification of normative concepts.

[SV85] J.R Searle and D. Vanderveken. *Foundations of Illucutionary Logic.* Cambridge University Press, Cambridge, 1985.

[TT99] Y.H. Tan and W. Thoen. A logical model of directed obligations and permissions to support electronic contracting. *International Journal of Electronic Commerce*, 3:87–104, 1999.

[xrm] xrml.org. Xrml specification.

[ZK92] K. Zweigert and H. Kötz. *Introduction to Comparative Law.* Clarendon, Oxford, 1992.