# Applying Gaia and AUML to the Construction of Deliberative Agents Using a Hybrid System

Javier Bajo[1], Yanira de Paz[2], Quintín Martín[3], Juan M. Corchado[2]

[1]Universidad Pontificia de Salamanca, Compañía 5 37002, Salamanca, Spain
jbajope@upsa.es
[2]Departamento Informática y Automática Universidad de Salamanca
Plaza de la Merced s/n 37008, Salamanca, Spain
{yanira, dantetapia, corchado}@usal.es
[3]Departamento Estadística, Universidad de Salamanca
Plaza de la Merced s/n 37008, Salamanca, Spain
qmm@usal.es

**Abstract.** This paper presents a deliberative agent that incorporates a hybrid system as a reasoning motor in the frame of CBR systems. To solve this problem the agent incorporates neural networks to implement the stages of the CBR system. Our agent can acquire knowledge and adapt itself to environmental changes. The hybrid system has been applied for evaluating the interaction between the atmosphere and the ocean. The system has been tested successfully, and the results obtained are presented in this paper.

## 1. Introduction

Agents and multiagent systems are adequate for developing applications in dynamic, flexible environments. Agents can be characterized through their capacities in areas such as autonomy, communication, learning, goal orientation, mobility, persistence, etc. Autonomy, learning and reasoning are especially important aspects for an agent. These capabilities can be modelled in different ways and with different tools [1]. One of the possibilities is the use of Case Based Reasoning (CBR) systems. This paper presents a hybrid CBR based deliberative agent that incorporates neural networks to implement the retrieve, reuse, revise and retain stages of the CBR system. Our CBR-BDI agent [2] is the core of a distributed system which mission is to monitor the interaction between the ocean surface and the atmosphere. Initially the system has been used to evaluate and predict de quantity of $CO_2$ exchanged in the North Atlantic Ocean. The aim of this work is to obtain an architecture that makes it possible to construct dynamic systems capable of growing in dimension and adapting its knowledge to environmental changes. Several architectures have been proposed for building deliberative agents, most of them based on the BDI model. In the BDI model the internal structure of an agent and therefore its ability to choose a course of action is based on mental attitudes. The advantage of using mental attitudes in the design and realization of agents and multi-agent systems is the natural (human-like) modelling and the high abstraction level. The BDI model uses Beliefs as information attitudes, Desires as motivational attitudes and Intentions as deliberative attitudes for each agent. The method proposed in [3][4] facilitates the CBR systems incorporation as a reasoning engine in BDI agents, which makes it possible for an agent to have at its disposal a learning, adaptation and a greater degree of autonomy than a pure BDI architecture [4]. BDI agents can be implemented by using different tools. One very interesting tool is Jadex [5], a BDI reasoning engine that can be used on top of different middleware infrastructures such as JADE [6]. Jadex agents deal with the concepts of beliefs, goals and plans. Beliefs, goals and plans are objects that can be created and handled within the agent at execution time. Jadex has the advantage of allowing programmers to include their own deliberative mechanisms. In our case this mechanism will be a CBR system. Moreover our system will benefit from all the communication advantages that JADE provides.

In this study the decision to carry out an analysis and design for our MAS was using a combination of elements from the Gaia [7] and Agent Unified Modelling Language (AUML) [8][9][10] methodologies. Gaia is an uncomplicated methodology that allows a simple analysis and initial design, through which the problem can be studied at a general level. The advantage is that it is possible to obtain a quick, low-detailed study. On the other hand, the problem arises once the Gaia design has been completed and the level of abstraction is found to be too high. As far as AUML is concerned, the final design is sufficiently accurate for immediate implementation, but it begins the study of the problem at a level that is overly specific and detailed level.

In the next section we review the relationships that can be established between CBR and BDI concepts. Section three describes the environmental problem that motivates most of this research. Section four describes the multiagent based system developed, paying special attention to the CBR-BDI agent constructed. Finally the conclusions and some preliminary results are presented.

## 2. CBR-BDI Agents

The purpose of case-based reasoning (CBR) is to solve new problems by adapting solutions that have been used to solve similar problems in the past. The deliberative agents, proposed in the framework of this investigation, use this concept to gain autonomy and improve their problem-solving capabilities. A CBR-BDI agent is composed of a reasoning cycle that consists of four sequential phases: retrieve, reuse, revise and retain. Each of these activities can be automated, which implies that the whole reasoning process can be automated to a certain extent [4]. Accordingly, agents implemented using CBR systems could reason autonomously and therefore adapt themselves to environmental changes. The CBR system is completely integrated into the agents' architecture. The CBR-BDI agents incorporate a "formalism" which is easy to implement, in which the reasoning process is based on the concept of intention. Intentions can be seen as cases, which have to be retrieved, reused, revised and retained. This makes the model unique in its conception and reasoning capacities. The structure of the CBR system has been designed around the concept of a case. A straight relationship between CBR systems and BDI agents can also be established if the problems are defined in the form of states and actions.

The relationship between CBR systems and BDI agents can be established by implementing cases as beliefs, intentions and desires which lead to the resolution of the problem. As described in [11], in a CBR-BDI agent, each state is considered as a belief; the objective to be reached may also be a belief. The intentions are plans of actions that the agent has to carry out in order to achieve its objectives [3], so an intention is an ordered set of actions; each change from state to state is made after carrying out an action (the agent remembers the action carried out in the past, when it was in a specified state, and the subsequent result). A desire will be any of the final states reached in the past (if the agent has to deal with a situation, which is similar to a past one, it will try to achieve a similar result to the previously obtained one).

| **Case: <Problem, Solution, Result>** | **BDI agent** |
|---|---|
| Problem: initial_state | Belief: state |
| Solution: sequence of <action, [intermediate_state]> | Desire: set of <final_state> |
| Result: final_state | Intention: sequence of <action> |

## 3. Air Sea Interaction Problem

In recent years a great interest has emerged in climactic behaviour and the impact that mankind has had on the climate. One of the most worrying factors is the quantity of $CO_2$ present in the atmosphere. $CO_2$ is one of gases produced by the greenhouse effect, and contributes to the fact that the Earth has a habitable temperature, provided that its quantity is limited. Without carbon dioxide, the earth would be covered in ice. On the other hand, excess $CO_2$ blocks the heat transfer into the atmosphere, acting as an infrared radiation absorbent, preventing heat from leaving the atmosphere, therevy causing excessive warming of the planet [12]. Until only a few years ago, the photosynthesis and breathing processes in plants were considered as the regulatory system that controls the presence of $CO_2$ in the atmosphere. However, the role played by the ocean in the regulation of carbon volume is very significant and so far remains indefinite [13]. Current technology offers the possibility of obtaining data and estimates that were beyond expectations only a few years ago. These data offer insights into the biological processes which govern the sink/source conditions for carbon dioxide [13][14]. Based on the knowledge acquired, we will be able to make predictions on the future behaviour of the atmosphere.

The goal of our project is to construct a model that calculates the global air-sea flux of $CO_2$ exchanged between the atmosphere and the surface waters of the ocean, as well as the global budgets of $CO_2$ for the whole oceanographic basin. In order to create a new model for the $CO_2$ exchange between the atmosphere and the oceanic surface a number of important parameters must be taken into consideration: sea surface temperature, air temperature, sea surface salinity, atmospheric and hydrostatic pressures, the presence of nutrients and the wind speed vector (module and direction). These parameters can be obtained from oceanographic ships as well as from satellite images. Satellite information is vital for the construction of oceanographic models, and in this case, in order to produce estimates of air-sea fluxes of $CO_2$ with much higher spatial and temporal resolution, using artificial intelligence models than can be achieved realistically by direct in situ sampling of upper ocean $CO_2$. In order to handle all the potentially useful data to create daily models in reasonable time and at a reasonable cost, it is necessary to use automated distributed systems capable of incorporating new knowledge. Our proposal is presented in the following section.

## 4. Multiagent System for the Air-Sea Interaction

The option we have chosen to get a suitable analysis and design was to use a mixed methodology with concepts from the Gaia [7] and AUML [8][9][10] methodologies. Our aim is to take advantage of the strengths of both concepts. The Gaia methodology is based on organizational criteria that allows a quick and effective analysis and design. The results obtained after applying Gaia consist of a high abstraction level of complexity. At that moment, the Gaia design must be adapted so that AUML techniques can be applied. Figure 1 shows the steps followed during our development process. It can be seen that Gaia is used to obtain a high level analysis and design and AUML is applied then to obtain a detailed low level design.

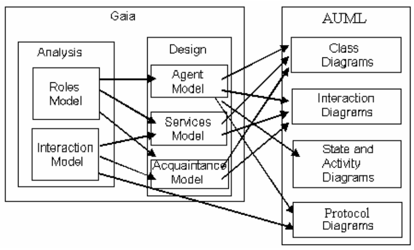


**Fig. 1.** Methodology used for the development process

### 4.1. Gaia Analysis and Design

Gaia is a methodology for agent-oriented analysis and design. The Gaia methodology is both general, in the sense that it is applicable to a wide range of multi-agent systems, and comprehensive, in the sense that it deals with both the macro-level (societal) and the micro-level (agent) aspects of systems. Gaia is founded on the view of a multi-agent system as a computational organisation consisting of various interacting roles [7]. Gaia analysis involves two models, the role model and the interaction model. Based on the requirements of the air-sea interaction problem, six roles are defined: The STORING role deals with the obtaining and storing of permanent data in the approporiate data bases. The PROCESSING role transforms the satellite images into cases. The DATACAPTURING role obtains data coming from Vessels. The CONSTRUCTAPARTIAL$CO_2$MODEL role deals with the generation of models. The OBTAIN$CO_2$EXCHANGE role calculates the $CO_2$ exchange rate by means of the use of the models available. The AUTOEVALUATION role evaluates a model by comparing its parameters with the real data obtained through the Vessels' sensors. Finally, the PROCESSINGINFORMATION role allows a user to interact with the system.

As far as interaction model is concerned, dependences and relationships between roles must be established. Each interaction between two roles is modelled by means of a protocol. In our MAS the following interaction protocols are required: ObtainNewModelSuper, ObtainNewModelAuto, ObtainStore, ObtainStModel, ObtainNewModelStoring, ObtainInsituData, ObtainConstructData, ObtainVessel, ObtainEvaluationSuper, ObtainEvaluationDC, Activate/Deactivate Sensors, Delete EPROM, ChangeStore, ChangeCase, ObtainVesselData and ObtainStExchange.

As far as the Gaia design is concerned, the aim is to reduce the abstraction level so that traditional techniques can be applied. Three models are studied: agent model, service model and acquaintance model [7]. Figure 2 shows the acquaintance model for our system. Each agent communicates with the other agents. For example, the Vessel agent communicates with the SuperUser and Store agents.

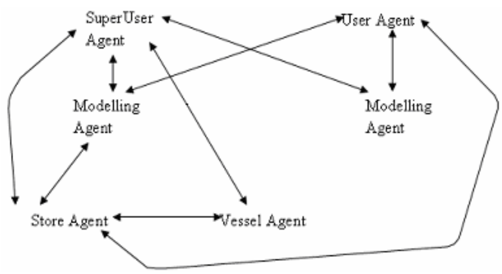


**Fig. 2.** Gaia acquaintance model for the air-sea interaction MAS.

### 4.2. Detailed AUML Design

AUML is a methodology that works at a highly detailed level, maybe too highly detailed in its initial stages if the problem we are working with is of a significant size. The AUML design provides class diagrams for each agent, collaboration or sequence diagrams for each interaction, state and activity diagrams to represent internal states and protocol diagrams to model communicative acts [2].

Once the architecture proposed has been studied, it would seem a good idea to deepen the Modelling agent – in the form of a deliberative agent that uses a hybrid CBR reasoning mechanism –. This agent will have two principal functions. The first one is to generate models which are capable of predicting the atmospheric/oceanic interaction in a particular area of the ocean in advance. The second one is to permit the use of such models. In Figure 3 we can see how the reasoning cycle of a CBR system is included among the activities. This reasoning cycle must correspond to the sequential execution of some of the agent roles. The agent carries out roles to generate models such as Jacobean Sensitivity Matrix (JSM), Pondered Weigh Technique (PWT), Revision Simulated Equation (RSE), and other roles that allow it to operate with the models calculated, like Forecast Exchange Rate, Evaluate Model or Consult model. The roles used to carry out the stages of the CBR cycle are now described.

Jacobean Sensitivity Matrix (JSM) is the role in charge of carrying out the retrieval stage. In order to do this it needs to use a method that guarantees the recuperation of cases whose characteristics are similar to the current problem. The Jacobean Sensitivity Matrix (JSM) is used in this case for data clustering and retrieval [15]. The Jacobean Sensitivity Matrix method is a novel approach for feature selection. It can be used to visualize and extract information from complex, and highly dynamic data. The model is based on the principal component analysis and is used to identify which input variables have more influence in the output of the neural network used to perform the principal component analysis. The neural network identifies the beliefs stored by the agent that can be more useful to solve a given problem. Pondered Weigh Technique (PWT) is the role where the reuse is carried out by using the cases selected during the retrieval stage. The cases are pondered [16] and the bigger weight is given to the one that more resembles the current problem. Finally, the Revision Simulated Equation (RSE) role implements the revision stage where oceanographers validate the proposed solution.

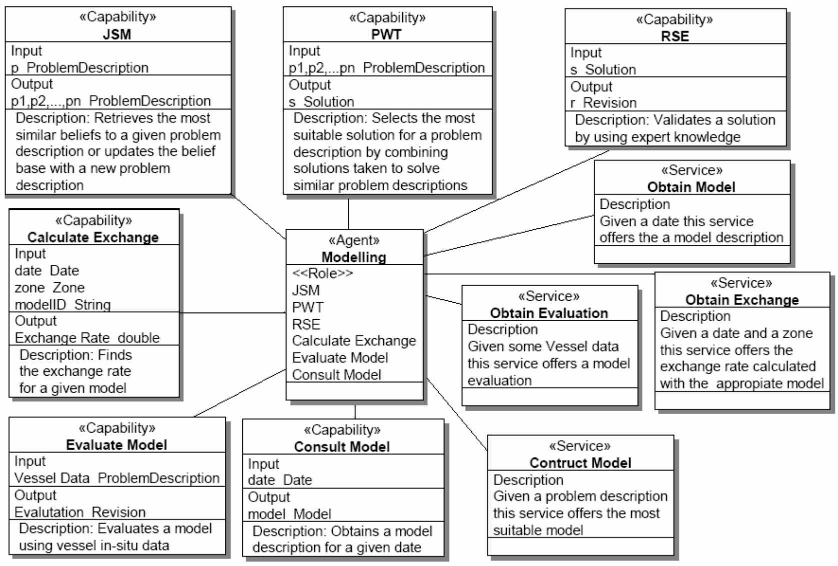


**Fig. 3.** Class diagram for the Modelling agent.

Once the design was complete, the implementation was carried out. The platform used was Jadex. The Modelling agent was constructed using Jadex and the rest of the agents that compose the MAS were constructed with JADE.

## 5. Results and Conclusions

The system described above was tested in the North Atlantic Ocean during 2005. Although the system is not fully operational and the aim of the project is to construct a research prototype and not a commercial tool, the initial results have been very successful from the technical and scientific point of view. The construction of the distributed system has been relatively simple using previously developed CBR-BDI libraries [2][11][17]. From the software engineering point of view AUML [8][9][10] and Gaia [7] provide an adequate framework for the analysis and design of distributed agent based systems. The formalism defined in [4] facilitates the straight mapping between the agent definition and the CBR construction.

The fundamental concept when working with a CBR system is the concept of case, and it is necessary to establish a case definition. A case in our problem, managed by the Modelling agent, is composed of the attributes described in Table 1. Cases can be viewed, modified and deleted manually or automatically by the agent (during its revision stage). The agent plans (intentions) can be generated using different strategies since the agent integrates different algorithms.

**Table 1.** Cases values.

| **Case Field** | **Measurement** |
|---|---|
| DATE | Date |
| LAT | Latitude |
| LONG | Longitude |
| SST | Temperature |
| S | Salinity |
| WS | Wind strength |
| WD | Wind direction |
| Fluo_calibrated | fluorescence calibrated with chlorophyll |
| SW pCO2 | surface partial pressure of CO2 |

The system has been tested during the last three months of 2005 and the results have been very accurate. Table 2 presents the results obtained with the Multiagent systems and with mathematical Models [14] used by oceanographers to identify the amount of $CO_2$ exchanged. The numerical values represent the million of Tonnes of carbon dioxide that have been absorbed (negative values) or generated (positive value) by the ocean during each of the three months.

**Table 2.** Million of tones of $C0_2$ exchanged in the North Atlanthic.

| | Oct. 04 | Nov. 04 | Dec. 04 | Jan. 05 | Feb. 05 |
|---|---|---|---|---|---|
| Multiagent System | -18 | 19 | 31 | 29 | 28 |
| Manual models | -20 | 25 | 40 | 37 | 32 |

The values proposed by the CBR-BDI agent are relatively similar to the ones obtained by the standard technique. While the CBR-BDI Modelling Agent generates results on a daily basis without any human intervention, the Casix manual modelling techniques require the work of one researcher processing data during at least four working days. Although the system proposed requires further improvements and more work the initial results are very promising. The framework generated facilitates the incorporation of new agents using different modelling techniques and learning strategies so that further experiments will allow us to compare these initial results with the ones obtained by other techniques.

**Acknowledgments.** This work has been supported by the Spanish MCYT TIC2003-07369-C02-02 project and the PML's CASIX project.

## References

1. Wooldridge, M., Jennings, N.R.: Agent Theories, Architectures, and Languages: a Survey. In: Wooldridge and Jennings, editors, Intelligent Agents, Springer Verlag. (1995) 1-22
2. Corchado, J.M., Laza, R.: Constructing Deliberative Agents with Case-based Reasoning Technology. International Journal of Intelligent Systems. Vol. 18 No.12 (2003) 1227-1241
3. Bratman, M.E.: Intentions, Plans and Practical Reason. Harvard University Press, Cambridge, M.A. (1987)
4. Glez-Bedia M., Corchado J.M., Corchado E.S., Fyfe C.: Analytical Model for Constructing Deliberative Agents, Engineering Intelligent Systems. Vol. 3 (2002) 173-185
5. Pokahr, A., Braubach L., Lamersdorf, W.: Jadex: Implementing a BDI-Infrastructure for JADE Agents, in: EXP - In Search of Innovation (Special Issue on JADE), Vol. 3, Telecom Italia Lab, Turin, Italy, September (2003) 76-85
6. Bellifime, F., Poggi, A., Rimasa, G.: JADE: a FIPA2000 compliant agent development environement. Proceedings of the 5th international conference on autonomous agents. ACM. (2001)
7. Wooldridge, M., Jennings, N.R., Kinny, D.: The Gaia Methodology for Agent-Oriented Analysis and Design. Journal of Autonomous Agents and Multi-Agent Systems, Vol. 3(3) (2000) 285-312
8. Bauer, B., Huget, M.P.: FIPA Modeling: Agent Class Diagrams. (2003)
9. Odell, J., Levy R., Nodine M.: FIPA Modeling TC: Agent Class Superstructure Metamodel. FIPA meeting and interim work. (2004)
10. Odell, J., Huget, M.P.: FIPA Modeling: Interaction Diagrams. (2003)
11. Corchado J.M., Pavón J., Corchado E.S, Castillo L.F.: Development of CBR-BDI Agents: A Tourist Guide Application. 7th European Conference on Case-based Reasoning 2004. Lecture Notes in Artificial Intelligence 3155, Springer Verlag. (2005) 547-559
12. Santamaría J., Nieto J.: Los agujeros del cambio climático. World Watch. No. 12 (2000) 62-65
13. Takahashi T., Olafsson J., Goddard J.G., Chipman D.W., Sutherland S.C.: Seasonal Variation of CO2 and nutrients in the High-latitude surface oceans: a comparative study. Global biochemical Cycles. Vol. 7, No. 4 (1993) 843-878
14. Lefevre N., Aiken J., Rutllant J., Daneri G., Lavender S., Smyth T.: Observations of pCO2 in the coastal upwelling off Chile: Sapatial and temporal extrapolation using satellite data. Journal of Geophysical research. Vol. 107 (2002)
15. Montaño J.J., Palmer, A.: Artificial Neural Networks, opening the black box. Metodología de las Ciencias del Comportamiento 4(1) (2002) 77-93
16. De Paz, Y.D.R.: Mixture Weibull distribution using artificial neural networks with censurated data PHD thesis, chapter 3. (2005)
17. Corchado J.M., Lees B.: A Hybrid Case-based Model for Forecasting. Applied Artificial Intelligence. Vol. 15 No. 2 (2001) 105-127