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Next issue (October 2004):
"Software Process Technologies"
(The full schedule of **UP**GRADE is available at our website)

A World of Agents

Guest Editors: Pedro Cuesta-Morales, Zahia Guessoum, Juan-Carlos González-Moreno, and Juan Pavón-Mestras

Joint monograph with Novática*

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An Agent-Based Architecture for Developing Internet-Based Applications

Juan M. Corchado-Rodríguez, Rosalía Laza-Fidalgo, and Luis F. Castillo-Ossa

This paper presents a practical application of an agent-based architecture which has been developed using the methodological framework defined by case-based reasoning systems. The deliberative agents developed within the framework of this research have been used to construct a multi-agent architecture used in an industrial application. The developed architecture is presented together with the results obtained.

Keywords: Agent-based Architecture, CBR-BDI Agents, Case-based Reasoning Systems, Industrial Application, Multi-Agent System.

1 Introduction

Deliberative agents are used in the development of web-based dynamic systems due to their capabilities such as autonomy, reactivity, pro-activity, social ability, reasoning, learning, and mobility, among others [12]. Several architectures have been proposed for building such agents, most of them based on the BDI (Beliefs, Desires and Intentions) model [10]. In this model, agents have mental attitudes of beliefs, desires and intentions. In addition, they have the capacity to decide what to do and how to do it according to their attitudes. Beliefs represent the agent's information state – what the agent knows about itself and its environment; desires are its motivation state – what the agent is trying to achieve–, while intentions represent the agent's deliberative states – intentions are sequences of actions – and can be identified as plans [8]. A BDI architecture has the advantage that it is intuitive, and it is relatively simple to identify the process of decision-making and how to perform it. Furthermore, the notions of belief, desires and intentions are easy to understand. However, its main drawback lies in the need to find a mechanism that permits its efficient implementation, as has been analysed in [2].

In order to overcome implementation problems, we propose the use of a Case-Based Reasoning (CBR) system for the development of deliberative agents. The proposed method facilitates the automation of their construction. Implementing agents in the form of CBR systems also facilitates learning and adaptation, and therefore a greater degree of autonomy than with a pure BDI architecture [7][6]. If a proper correspondence between the three mental attitudes of BDI agents and the information manipulated by a CBR system is established, an agent with beliefs, desires, intentions and a learning capacity will be obtained.

Section 2 discusses the relationships which can be established between CBR and BDI concepts. The e-business multi-agent architecture developed is presented in Section 3. Finally we present our conclusions in Section 4.

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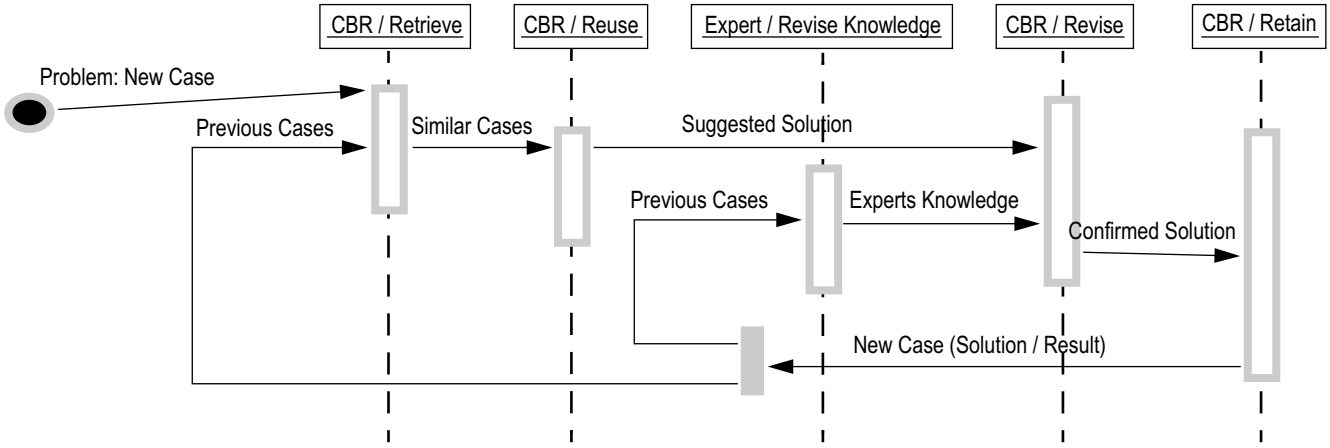

Figure 1: UML Sequence Diagram Describing a CBR Life-cycle.

2 Constructing Deliberative Agents using a Case-based Reasoning System

Case-based reasoning (CBR) systems solve new problems by adapting solutions that have been used to solve similar problems in the past. This knowledge is stored in the memory (the case base) of the CBR system in the form of cases or problems. As shown in Figure 1, the CBR system performs a reasoning cycle that consists of four sequential phases: retrieve, reuse, revise, and retain [1]. Each of these activities can be automated, which means that the whole reasoning process can be automated to a certain extent [3]. Accordingly, it is possible for agents implemented using CBR systems to reason autonomously and therefore to adapt to environmental changes.

The proposal presented in this paper defines a direct mapping from the concept of an agent to the reasoning model. In the present model, intentions are cases, which have to be retrieved, reused, revised and retained. The structure of the CBR system has been designed around the concept of a case. A case is made up of three components: the problem, the solution, and the result obtained when the proposed solution is applied [2]. The problem defines the situation of the environment at a given moment. The solution is the set of states undergone by the environment as a consequence of the actions that have been carried out within it. And the result shows the situation of the environment once the problem has been solved. This can be expressed as follows:

Case: <Problem, Solution, Result> (< > sequence, [ ] optional)
Problem: initial_state
Solution: sequence of <action, [intermediate_state]>
Result: final_state

A BDI agent is defined in terms of its beliefs, desires and intentions:

Belief: state
Desire: set of <final_state>
Intention: sequence of <action>

The relationship between CBR systems and BDI agents can be established by implementing cases as beliefs, intentions and desires which bring about the solution of the problem. The

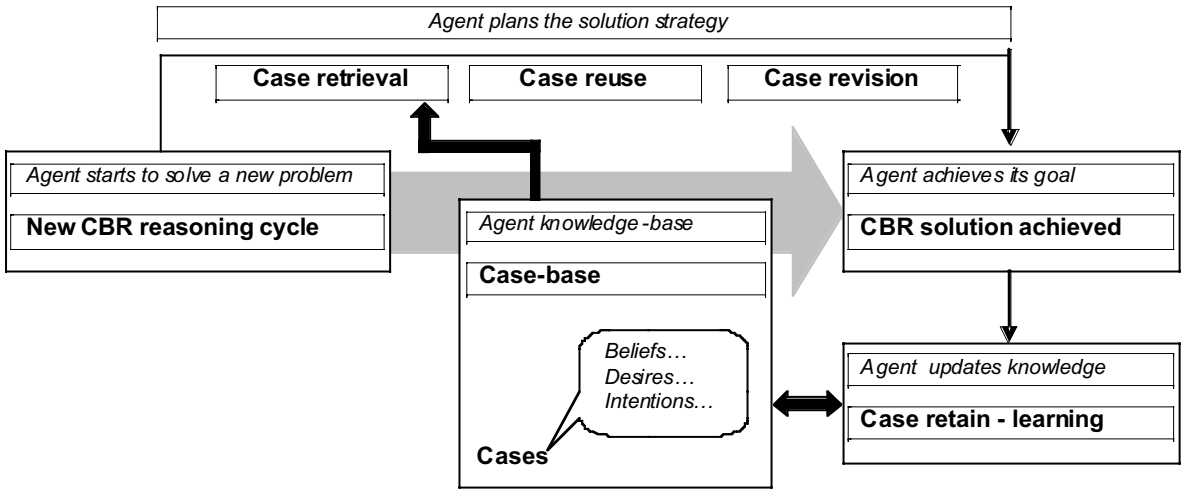

Figure 2: CBR-BDI Agent Integration Diagram.

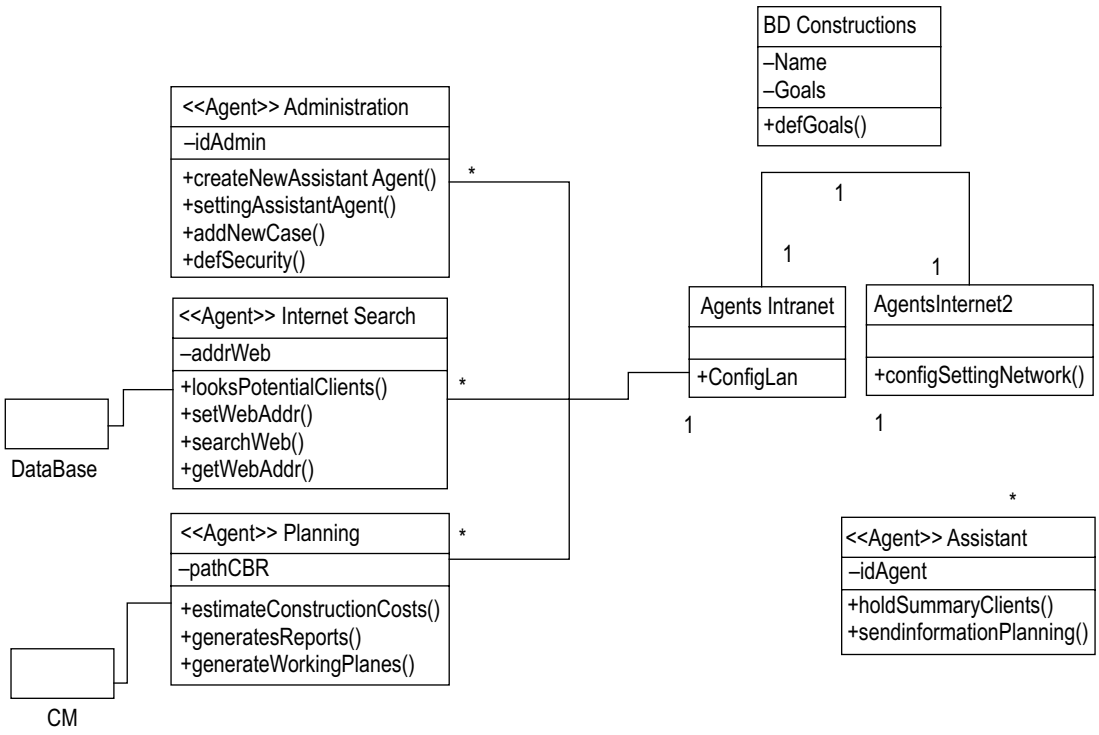

Figure 3: AUML Class Diagram Representing the Organization of the Multi-Agent System.

obvious relationship between BDI agents and CBR systems can be seen in Figure 2. When the *agent starts to solve a new problem*, with the intention of *achieving a goal*, a new CBR reasoning cycle starts which makes it possible to obtain the solution. The retrieval, reuse and revision phases of the CBR system facilitate the construction of the *agent plan*. The *agent's knowledge-base* is the case-base of the CBR system which stores the cases, which are *past beliefs, desires and intentions*. The *agents* work in dynamic environments and their *knowledge-base* has to be adapted and updated continuously; the retain phase of the CBR system takes care of this aspect.

3 Design of CBR-BDI Agents

Given the architecture and definition of CBR-BDI agents, the development of a Multi-Agent System (MAS) can follow the process defined by any agent-oriented methodology which considers the identification of deliberative agents, their responsibilities and goals, their roles in the organization, and the specification of interactions and protocols. Here we concentrate on the design of deliberative agents capable of learning and adapting to new situations by using the architecture proposed in the previous section. To set up an agent using this architecture we need to identify an initial set of beliefs, desires and intentions and include them in the agent's case-base in the form of cases. Next, a number of metrics for the retrieval, reuse, revision and retain steps have to be defined, and rules that describe the Expert's knowledge must be established, if available. Once the agent has been initialised, it starts the reasoning process and the four steps of the CBR system are run sequentially and continuously until its goal is achieved (or there is sufficient evidence of a failure situation).

The abovementioned architecture has been used to develop an information system for a construction company, D&B Constructions, that specializes in installing heating and air conditioning systems over a wide area of northwest Spain. They have a sales force which is constantly growing, which means that new salespeople are taken on board without much experience in many cases. Up until now the salespeople had to visit customers on demand, take note of their problems, and then contact an engineer or an experienced salesperson to estimate the job price and the personnel and material required to carry out an installation. The proposed multi-agent system supports salespeople, and in particular the inexperienced personnel, while they are visiting customers, by providing advice in drawing up offers, and especially in the estimation of the cost of new installations.

CBR-BDI agents have been implemented using JADE (Java Agent DEvelopment Framework) and JADE-LEAP. The *specialised agents* run on the company Intranet and the *assistant agents* run on a mobile device (mobile phone or PDA). Also, in a system of these characteristics, data security has to be taken into consideration. A Role-based Access Control with elements that allow the certification of operations has been implemented to ensure data security and protection of information (similar to the one used in [4] This security system protects the databases and the information stored in the system from external agents or unauthorised personnel.

When modelling a multi-agent system, one of the first aspects to consider is organization. It is not in the scope of this

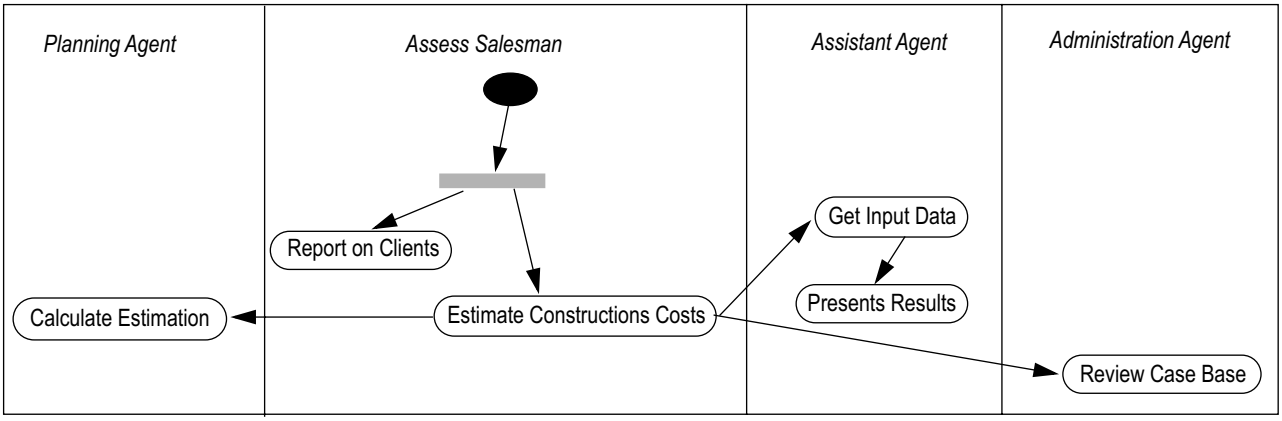

Figure 4. AUML Activity Diagram for the Goal assess salespeople.

paper to describe the different methodologies proposed for defining an organization, but so as to be able to understand the structure of the system, we describe its overall behaviour and the interactions between participating agents. Figure 3 shows the system organization together with the agents' attributes and their functionality. The organization identifies the types of agents and resources in the system, how are they grouped, and the relationships between them. There are two groups of agents: those that run on the intranet (the *planning agent*, the Internet search agent, and the administration agent), and those that will normally run on remote Internet connected nodes (the *assistant agents*):

- The planning agent is the only CBR-BDI agent used in this system. The other agents in the system do not have a CBR-BDI architecture because they are responsible for carrying out tasks that do not require reasoning. The planning agent estimates the construction cost, and the personnel and material required to carry out a construction project. It also generates reports about customers (or potential customers) using the information stored in the company databases and that obtained by the Internet search agent. The planning agent generates working plans using its incorporated CBR system.
- The Internet search agent incorporates a web search engine that looks continuously for potential customers and information about them, new suppliers and products. This agent starts looking from a predetermined web address and searches for others using Web optimized natural language processing strategies based on a combination of the grammatical characterization of words and statistical decision techniques. This agent is monitored and guided by a marketing expert. We are also currently studying the possibility of implementing this agent as a CBR-BDI agent to achieve more autonomy and efficiency.
- Assistant agents (there can be as many agents as salespeople and experienced engineers) are interface agents that facilitate the communication between salespeople and the planning agent, and between engineers and the planning agent. They also hold summary information about the customers visited by the salespeople.
- Finally, the administration agent is an assistant agent providing interface to different administration functions, such as the setting up of a new assistant agent, access to the case-base, the inclusion of new cases in the case-base, the definition of security protocols, etc.

The organization also determines the overall goals of the system, which will be later decomposed into more concrete goals for each participating agent. In this example, the main goal of the agent organization is to *Assess Salespeople*. This goal can break down in others, for instance, *Estimate Construction Costs* and *Report on Customers*. Agents in the organization collaborate to accomplish these goals. For instance, for the goal *Estimate Construction Costs*, the assistant agent takes input data and presents the results to the salesperson, the planning agent calculates the cost estimate, and the Administration agent assists the expert to review the case base (see Figure 4).

There is one assistant agent for each salesperson. Before a salesperson visits a customer, the assistant agent provides a description of the customer by comparing some data provided by the salesperson (e.g., name, address, and activity) with previous queries using relaxed K-nearest neighbour algorithms [11]. This information is related to previous building work carried out for the customer, his financial status, comments about him noted by the firm's personnel during previous relations with this customer, location information, and other potentially useful data. This information is especially valuable when an inexperienced salesperson starts a negotiation process. If the assistant agent cannot help the salesperson or if the salesperson demands more information, the assistant agent contacts the planning agent which searches for information about the customer in its case-base. This agent also interrogates the Internet search agent asking for information about customers. The Internet Search agent obtains information from predefined web sites, and this information is analysed and indexed using an Internet optimized natural language processing algorithm, as mentioned above [4]. Information about potential customers, new materials and suppliers is sent to the Administration

Agent, which can be interrogated by any of the Construction Company managers, engineers or sales supervisors. They can then use this pruned information to target new business. The administration agent is therefore an interface agent that facilitates the interaction between the users (Company managers) and the rest of the elements of the system: agents, databases and even salespeople.

4 Conclusions

The system has been successfully evaluated. The planning agent has been fed with 2,320 cases related to the installation of heating systems, which were selected to cover a wide spectrum of possible installations that the company could carry out. The system has been interrogated on 2,458 occasions up until February 2004. In 97% of the system interrogations the estimate by the CBR-BDI agent differed by less that 5% from the one given by an expert salesperson, and in 2% of the enquires, it differed by less than 10%. Only 1% of the time did the agent output differ by more than 10% from the expert estimate. These errors can be minimised during the review phase in which an experimented engineer reviews the agent proposal. Company experts have estimated that the use of this agent-based system has reduced the cost of installation sales by up to 23%, and the time to sale by up to 38%.

With regard to typical BDI agent architectures, CBR-BDI agents make it possible to build agents with learning capabilities, which makes them more flexible to adapt to changing environment. The developer can use BDI concepts in the modelling of agents, while at the same time obtaining an efficient mechanism to specify an agent's behaviour with the ability to solve new problems. The results of the use of the multi-agent system described in this paper show how single agents can be developed with this technology, and how such agents can be successfully used to construct an efficient agent-based system for e-business.

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