ALZ-MAS: Alzheimer's special care multi-agent system

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Abstract. This paper presents a multi-agent based solution for Alzheimer's residential health care. The carers work in a very dynamic environment and the use of planning agents helps them to adapt to changes and optimizes their working day. The ALZ MAS system includes agents that take care of the patients and of the security of the environment. Some of the agents use RFID technology to control the location of the patients, necessary to create and execute dynamic plans and to guarantee the security of the residence. The deliberative agents used cooperate with each other and have learning capabilities. This paper also shows how to construct multi-objective driven agents using a case-based reasoning methodology.

1 INTRODUCTION

Agents and multi-agent systems (MAS) have become increasingly relevant for developing distributed and dynamic open systems. MAS have been successfully applied in fields such as electronic commerce, medicine, oceanography, robotics, etc. ALZ MAS (ALZheimer Multi-Agent System) is developed with the aim of improving the efficiency of Alzheimer residences and increasing the quality of life for its patients. This paper presents an implemented prototype and analyses the initial results obtained after its implantation.

The proposed ALZ MAS incorporates multi-objective deliberative agents. We are mainly interested in the development of deliberative agents using case-based reasoning (CBR) systems, as a way to implement an adaptive system to provide assistance and health care support for elderly and people with disabilities [4, 15]. Agents, in this context, must be able to respond to events, take the initiative according to their goals, communicate with other agents, interact with users, and make use of past experiences to find the best plans to achieve goals. This paper proposes the use of a special type of CBR system for the development of deliberative agents. The Case-base Planning (CBP) is a CBR system specially designed for planning construction. The method proposed starts by identifying agent roles and goals, following the form of CBR systems in the design and implementation of the agent architecture, which facilitates learning and adaptation, and therefore a greater degree of autonomy than that found in pure BDI (Believe, Desire, Intention) architecture. BDI deliberative agents are systems with representations that are directed towards the action model [9]. As mentioned above, such agents may incorporate a case-based reasoning (CBR) motor [10], which constitutes the base of a planning system that is based on previous plans, CBP [13] [19].

This type of model meets the conditions needed to introduce a representation and a reasoning based on the action [29]. A CBR-BDI agent [15] uses case-based reasoning as a reasoning mechanism, which allows it to learn from initial knowledge, to interact autonomously with the environment, as well as with users and other agents within the system, and to have a large capacity for adaptation to the needs of its surroundings. We shall refer to the CBR-BDI agents specialized in generating plans as CBP-BDI agents, in which a plan is defined as a sequence of document collection and delivery points.

The BDI agents have been implemented using Jadex [29]. Jadex is a BDI reasoning engine and can be used on-top of different middleware infrastructures such as JADE [6]. The 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. A belief can be any type of java object and is stored in the beliefs base. A goal represents a motivation that influences the agent behaviour. A plan is a Java procedure and is executed in order to achieve goals. Jadex has the advantage of allowing programmers to include their own deliberative mechanisms. In our case, this mechanism will be a CBR system. Moreover we will have all the communication advantages that JADE provides (including the LEAP add-on).

This paper also analyses the residential health care problem and the possibilities of Radio Frequency Identification (RFID) as a technology used to obtain the patient location needed to generate plans and for security purposes. Other possibilities offered by technology will then be described, in particular for patient care. The ALZ MAS architecture will be presented and an explanation will be given of how the deliberative planning agents have been implemented and designed. The case study is then presented and the results and subsequent conclusions will be analyzed.

2 RESIDENTIAL HEALTH CARE PROBLEM

One of the most important target groups for domotic systems are the disabled and elderly [22]. There is an ever growing need to supply constant care and support to this section of the community [14] and the drive to find more effective ways to provide such care has become a major challenge for Europe [11] and its scientific community [14].

During the last three decades the number of Europeans over 60 years old has risen by about 50%. Today they represent more than 25% of the population and it is estimated that in 20 years this percentage will rise to one third of the population, meaning 100 millions of citizens [11]. This situation is not exclusive to Europe, since studies in other parts of the world show similar tendencies. In the United States of America, people over 65 years old are the fastest growing segment of the population [2] and it is expected that in 2020 they will represent about 1 of 6 citizens [11] totaling

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69 million by 2030. Furthermore, over 20% of people over 85 years old have a limited capacity for independent living, requiring continuous monitoring and daily care [2].

The importance of developing new and more reliable ways to provide care and support to the elderly is underlined by this trend [11], and the creation of secure, unobtrusive and adaptable environments for monitoring and optimizing health care will become vital [2]. Cesta, *et al.* [14] consider that tomorrow's health care institutions will be equipped with intelligent systems capable of interacting with humans. Multi agent systems and architectures based on intelligent devices have recently been explored as supervision systems for medical care [2] and for the elderly or Alzheimer patients, these intelligent systems aim to support them in all aspects of daily life [14], predicting potential hazardous situations and delivering physical and cognitive support [3]. These systems represent a very sensitive domain, since they deal with data of a critical nature concerning individuals, raising issues of security, and the need to guarantee a highly reliable service that is universally accepted by society [12].

The development of this distributed multiagent system requires the use of secure communication networks and identification technology. Wireless Fidelity (WI-FI) networks with security mechanisms such as Wired Equivalent Privacy (WEP) offer many possibilities with a reduced infrastructure and low installation costs. The first implantable Radio Frequency Identification (RFID) chip for human use, developed by VeriChip, has been recently approved by the FDA (Unites States Food and Drug Administration) for medical use [31]. The system is based on a 125 kHz radio signal [31] capable of penetrate solid objects, except those made of metal, to read 15 digit ID numbers, [32] stored within a small electronic circuit called "transponder" and covered with a glass capsule of 11mm in length and 2.1mm in diameter. The ID number is impossible to alter because the encoding process of the number itself uses 38 bits of information, which allows 490 billion possible ID numbers [23].

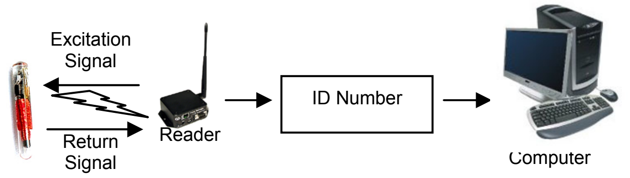


Figure 1. Reader excites coil in chip, which powers to send encoded data back to reader as modulated RF signal. Reader decodes signal, displays number, and sends to computer or PDA.

Transponders are passive devices, meaning they carry no batteries and remain inactive most of the time, energized by a low-power radio beam sent by a compatible reading device [23].

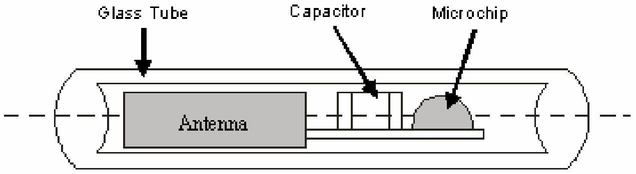


Figure 2. Diagram of the internal structure of an implantable transponder.

WatchMate from VeriChip is a system using this technology, designed for Alzheimer patients or sufferers of other cognitive illnesses. The system consists of a transponder mounted on a bracelet worn on the patient's wrist or ankle, and several sensors installed over protected zones, with an adjustable capture range up to 6 meters. If a monitored user approaches one of the protected zones the alarm is triggered off, reading the user's ID, with and informing a central computer [32]. Moreover the frequency range used by the transponders is perfectly compatible with the frequency used by our mobile devices. The transponders use a 125 kHz signal while Wi-Fi or Bluetooth PDAs and Bluetooth phones use 2.4 GHz signals. As such, one of the major problems for using wireless devices, electromagnetic interference, can be easily resolved.

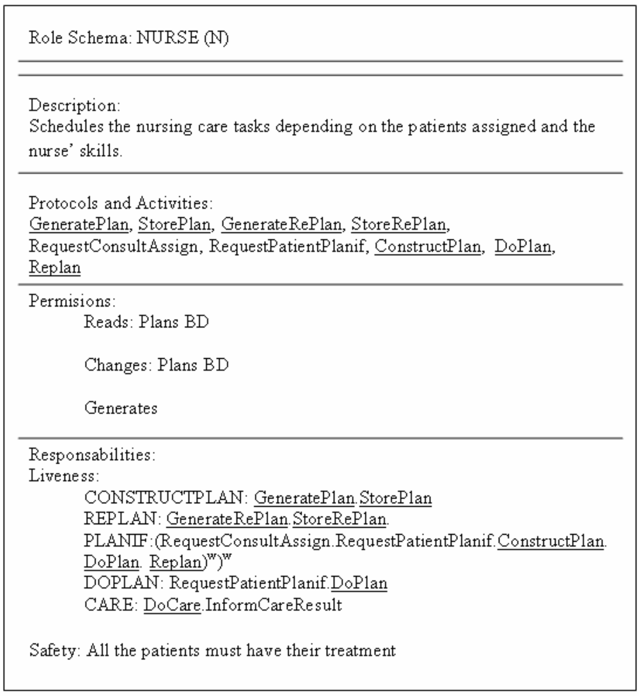
This technology has been used to construct the ALZ MAS prototype presented in this paper to improve the quality of life of the Alzheimer patients of the Santísima Trinidad Residence in Salamanca.

3 ALZ MAS ARCHITECTURE

There are, at present, a great number of methodologies: Gaia [33], AUML [5] [26] [27], MAS-CommonKADS [20], MaSE [16], ZEUS [25], MESSAGE [17], TROPOS [10], etc. for agent analysis and design. The problem with these methodologies is that generally they are not fully developed and present a number of limitations. For this study, the option chosen to define an appropriate analysis and design methodology for the problem to be resolved was Gaia [33]. Gaia is a methodology for very general analysis and design and therefore applicable to a very wide range of multiagent systems. It also allows the user to have a wide knowledge of the multiagent systems both at an organizational (social) level and at a detailed level for each agent.

Through the Gaia analysis, two models are obtained: the role model and the interaction model. Studying the requirements of the problem we have come to the conclusion that five roles are needed: the Patient role manages the patient's personal data and behaviour (monitoring, location, daily tasks, and anomalies); the Doctor role treats patients; the Nurse role schedules the nurse's working day obtaining dynamic plans depending on the tasks needed for each assigned patient; the Security role controls the patients' location and manages locks and alarms; and finally, the Manager role manages the medical record database and the doctor-patient and nurse-patient assignment. As can be seen in Figure 3, the Nurse role is composed of responsibilities, permissions, activities and protocols [33]. It is authorized to read and change Plans DB, and is responsible for the planning, nursing care and patient rights. Moreover, it must maintain a successful connection with plans DB and ensure that the patients receive their treatment.

As far as an interaction model is concerned, the dependences and relations between roles are described as follows. Each interaction in which two roles are involved requires protocols (described in the roles model). In the SMA presented in this work a number protocols have been considered: request a treatment, inform about monitoring data, inform about care results, request a doctor assignment, request a nurse assignment, inform about assignment, request a patient's daily plan, inform about a patient's daily tasks, request a patient location, inform a nurse about a lock activation, report alarm activation, request doctor situation, doctor reports on his schedule, request a nurse situation, nurse reports situation, patient reports an anomaly, patient reports on personal data and previous medical records.



Role Schema: NURSE (N)

Description:
Schedules the nursing care tasks depending on the patients assigned and the nurse' skills.

Protocols and Activities:
GeneratePlan, StorePlan, GenerateRePlan, StoreRePlan, RequestConsultAssign, RequestPatientPlanif, ConstructPlan, DoPlan, Replan

Permisions:
Reads: Plans BD

Changes: Plans BD

Generates

Responsabilities:
Liveness:
CONSTRUCTPLAN: GeneratePlan.StorePlan
REPLAN: GenerateRePlan.StoreRePlan.
PLANIF:(RequestConsultAssign.RequestPatientPlanif.ConstructPlan.DoPlan. Replan)^{w})^{w}
DOPLAN: RequestPatientPlanif.DoPlan
CARE: DoCare.InformCareResult

Safety: All the patients must have their treatment

Figure 3. Gaia roles model: Nurse role.

For example, Figure 4 shows the protocols needed for the interaction between a nurse and a patient when the nurse wants to know the tasks required for the patient. The nurse role executes a protocol RequestPatientPlanif through which is able to make a request to the patient role. The patient role acts to give a suitable response to the nurse role and executes the InformPlanif protocol to communicate the planned tasks to the nurse role.

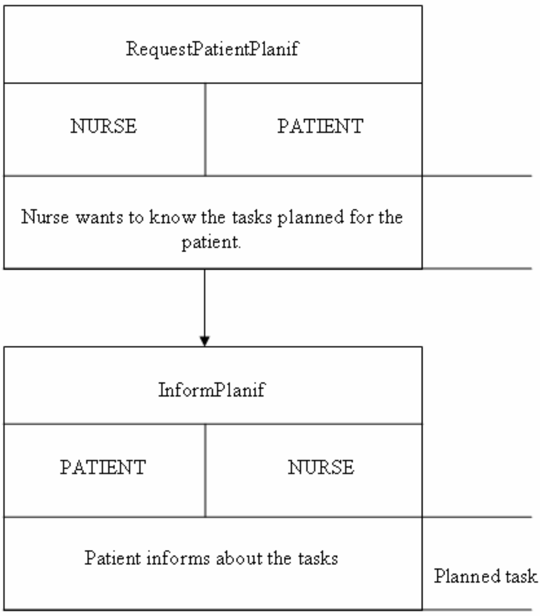


Figure 4. Gaia interaction model: The nurse role requests a patient's daily plan.

Once the analysis has been finalised, the Gaia design is carried out. Traditional techniques of software engineering are not followed in terms of detailing the analysis to the extent that a direct implementation can be made. Instead, the level of abstraction is reduced so that traditional techniques can be applied. In the design process three models are considered: agent model, services model and acquaintance model [33].

As can be seen in Figure 5, the agent model shows the types of agents that are going to appear in the system, as well as the number of instances for each agent type that can be executed within the execution time. Four types of agents are used in the MAS: a patient agent, which plays the Patient role and has multiple instances at execution time (at least one); a Doctor agent that plays the Doctor role; a nurse agent that plays the Nurse role; and finally, a manager agent that plays the Manager and Security roles. At execution time there is only one instance of the manager agent.

Figure 6 presents the acquaintance model where it is possible to observe the relationships that can be established between the different agent types of our multi-agent system.

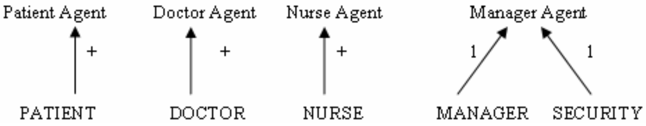


Figure 5. Gaia agent model for the residence care problem.

A patient agent can communicate to a doctor agent, a manager agent and a nurse agent to achieve its objectives. The doctor agent needs to interact with the patient agent to order a treatment and receive periodic reports, with the manager agent to consult medical records and assigned patients, and with the nurse agent to ascertain the patient evolution. The manager agent communicates with the patient agent, the doctor agent and the nurse agent. Finally, the nurse agent communicates with the doctor agent, the manager agent and the patient agent in order to generate optimal plans that can be executed by the nurse (person).

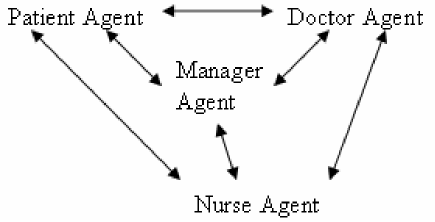


Figure 6. Gaia acquaintance model for the residence care problem.

The patient and doctor agents are BDI deliberative agents; the manager agent is a CBR-BDI agent which uses case-based reasoning as a reasoning mechanism for doctor-patient and nurse-patient assignment. The core of the system is the nurse agent, the CBP-BDI agent. This planning agent is explained in detail in the next section.

4 PLANNING AGENT

The nurse agents have been implemented as deliberative CBP-BDI agents [13] [19], which are agents specialized in generating plans. The aims of these agents are: to plan the nurse's working time dynamically, to maintain the standard working reports about the nurse's activities, and to guarantee that the patients assigned to the nurse are given care. These agents also take control of the working hours of each nurse, who should not work more than 8 hours on a normal working day. These agents incorporate a case-based planning (CBP) system, as mentioned in the introduction of the paper.

The purpose of a CBR system is to solve new problems by adapting solutions that have been used to solve similar problems in the past [1], and the CBP systems are a variation of the CBR systems, based on the plans generated from each case. The deliberative agents, proposed in the framework of this investigation, use this concept to gain autonomy and improve their problem-solving capabilities. In a CBP-BDI agent, each state is considered as a belief; the objective to be reached may also be a belief [18]. The intentions are plans of action that the agent has to carry out in order to achieve its objectives [8] [9], so an intention is an ordered set of actions; each change from state to state is made after carrying out an action (when it was in a specified state, the agent remembers the action carried out in the past 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 that previously obtained). Next, the CBP planner used for the Nurse Agent to find a plan to give daily nursing care in the residence is presented. Nursing care is a very dynamic problem where the plan carried out by a nurse can very often be affected by several variables. For example, the time estimated for a nurse to spend in indirect attention (clean, control, reports, visits) may change depending on the patient, nurse habits, date, etc. So, in this scenario, it seems to be very important to provide the Nurse agent with a dynamic replanning capability that allows a nurse plan to adapt to the continuous environmental changes.

Let $E = \{e_0, \cdots, e_n\}$ the set of tasks that the nurse is assigned to.

$$a_j : \begin{array}{ccc} E & \rightarrow & E \\ e_i & \rightarrow & a_j(e_i)=e_j \end{array} \qquad (1)$$

An Agent plan is the name given to a sequence of actions (1) that, from a current state e_0, defines the path of states through which the agent passes in order to offer the nurse the optimum path according to each nurse's characteristics. Below, in (2), the dynamic relationship between the behaviour of the agent and the changes in medium is modelled. The behaviour of agent A can be represented by its action function $a_A(t) \quad \forall t$, defined as a correspondence between one moment in time *t* and the action selected by the agent,

$$Agent\ A = \{a_A(t)\}_{t \in T \subseteq N} \qquad (2)$$

From the definition of the action function $a_A(t)$ it is possible to define a new relationship that collects the idea of an agent's action plan (3),

$$p_A : \begin{array}{ccc} TxA & \rightarrow & A \\ (t, a_A(t)) & \rightarrow & p_A(t) \end{array} \qquad (3)$$

in the following way,

$$p_A(t_n) = \sum_{i=1}^{n} a_{iA}(t_i - t_{i-1}) \qquad (4)$$

Given the dynamic character desired for the planning agent, for a definition of the agent plan, the continuous extension of the previous expression (4) is proposed, in other words (5) –

$$p_A(t_n) = \int_{t_0}^{t_n} a_A(t)dt \qquad (5)$$

The variation of the agent plan $p_A(t)$ will be provoked essentially by: changes that occur in the medium that force the initial plan to be modified, and the knowledge from the success and failure of the plans that were used in the past, and which are favoured or punished via learning. O indicates the objectives of the agent and O' are the results achieved by the plan. R are the total resources and R' are the resources consumed by the agent. The efficiency of the plan (6) is the relationship between the objectives attained and the resources consumed

$$E_{ff} = \frac{\#(O' \cap O)}{\#R'} \qquad (6)$$

where # means cardinal of a set. The objective is to introduce an architecture for a planning agent that behaves – and selects its actions – by considering the possibility that the changes in the environment block the plans in progress. This agent is called MRPI (most re-plan-able Intention agent) because it continually searches for the plan that can most easily be re-planned in the event of interruption. Given an initial point e_0, the term planning problem will be used to describe the search for a way to reach a final point $e_i \equiv e^* \in E$ that meets a series of requirements. Given a discrete variable X that can take values of a numerable set represented as

$$X = \{x_i\}_{i \in N} \qquad (7)$$

It is possible to define the associated accumulated variable (8), that can be denoted as $Ac(X)$, for a new variable that is constructed by assigning each of the possible values x_i taken by variable X, the total of previous results. If X is discrete, the value i-th of the variable $Ac(X)$ is defined as

$$Ac(x_i) = \sum_{j=1}^{i} x_j \quad \forall x_i \in X \qquad (8)$$

If the variable X is continuous and its values in the interval $[a,b]$, it is represented by function $x(t)$; the variable $Ac(X)$ at a point $x_i \in [a,b]$ is defined:

$$Ac(x_i) = \int_a^{x_i} x(t)dt \quad \forall x_i \in [a,b] \tag{9}$$

Given a problem E and a plan p(t) functions Ob and Rc accumulated from the objectives and costs of the plan (10) can be constructed. For all time points t_i two variables can be associated:

$$Ob(t_i) = \int_a^{t_i} O(t)dt \;\; Rc(t_i) = \int_a^{t_i} R(t)dt \tag{10}$$

This allows us to construct a planning space (or space representing the environment for planning problems) as a vectorial hyperdimensional space where each axis represents the accumulative variable associated with each objective and resource. The planning space, defined in this way, conforms to the following properties:

1. Property 1: The representations of the plans within the planning space are always monotonously growing functions. Given that $Ob(t)$ and $Rc(t)$ are functions defined as positive, function $p(t)$ expressed at these coordinates is constant or growing.
2. Property 2: In the planning space, the straight lines represent plans of constant efficiency. If the representations of the plans are straight lines, the slope of the function is constant, and coincides with the definition of the efficiency of the plan.

$$\frac{d}{dt}p(t) = cte \Leftrightarrow \lim_{\Delta \to 0} \frac{\Delta O(t)}{\Delta R(t)} = cte \tag{11}$$

In an n-dimensional space, the extension of the straight concept line is called a geodesic curve. In this sense the notion of geodesic plans can be introduced, defined as those that maintain efficiency at a constant throughout their development.

The concept of a geodesic plan can be better understood through the idea of a *"plan of minimum risk"*. Given a problem, the agent must search for the plan that determines a solution with a series of restrictions $F(O;R) = 0$. In the plans base those plans that are initially compatible with the problem faced by the agent, with the requirements imposed on the solution according to the desires, and in the current state [1] are sought. If all the possible plans are represented $\{p_1, \cdots, p_n\}$ within the planning space, a subset of states that the agent has already attained in the past in order to resolve similar problems will be obtained.

With the mesh of points obtained (generally irregular) within the planning space and using interpolation techniques, a working hyperplan $h(x)$ can be obtained (that encapsulates the information on the set of restrictions from restored experiences), from which geodesic plans can be calculated and with which variation calculation can be applied. Suppose, for simplicity's sake, that a planning space of dimension 3 with coordinates $\{O, R_1, R_2\}$ is taken into account. Between the point e_0 and the objective points $f_s f = \{e_1, \cdots, e_m\}$ and over the interpolation surface $h(x)$, the Euler Theorem [18] [21] guarantees that the expression of the geodesic plans will be obtained by resolving the system of equations in (12):

$$\begin{cases} \dfrac{\partial L}{\partial R_1} - \dfrac{d}{dO}\dfrac{\partial L}{\partial R_1'} = 0 \\ \dfrac{\partial L}{\partial R_2} - \dfrac{d}{dO}\dfrac{\partial L}{\partial R_2'} = 0 \end{cases} . \tag{12}$$

where R_i is the function accumulated R, O is the function of accumulated O and L is the distance function on the hyperplan $h(x)$,

$$L = \int_h dl \tag{13}$$

In order to obtain all the geodesic plans that, on the surface $h(x)$ and beginning at e_0, allows us to reach any of the points $e^* \in f_s f$, a condition of the surroundings must be imposed: the initial point is $e_0 = (O_0, R_0)$.

Using variation techniques expressions for all the geodesic plans that, beginning at e_0 allows us to attain the desired point are obtained. Once plans have been obtained that will create efficient solutions between the current state and the set of solution states, we will be able to calculate the plan around it (along its trajectory) by a denser distribution of geodesic plans (a greater number of geodesic plans in its environment). The tool that allows us to determine this is called the minimum Jacobi field associated with the solution set [24]. $g_0 : [0,1] \to S$ be a geodesic over a surface S. Let $h : [0,1]x[-\varepsilon, \varepsilon] \to S$ be a variation of g_0 so that for each $t \in (-\varepsilon, \varepsilon)$, the set $\{h_t(s)\}_{t \in (-\varepsilon, \varepsilon)}$:

- $h_t(s) \quad \forall t \in (-\varepsilon, \varepsilon)$ are geodesic in S.
- they begin at $g_0(0)$, in other words, they conform to $h_t(0) = g_0(0) \quad \forall t \in (-\varepsilon, \varepsilon)$.

In these conditions, taking the variations to a differential limit, the equation (14) is obtained:

$$\lim_{t \to 0}\{h_t(s) = g_0(s+t)\} = \lim_{t \to 0}\{h(s,t)\} = \frac{\partial g_0}{\partial t}\Big|_{(s,0)} = \frac{dg_0}{ds} \equiv J_{g_0}(s) \tag{14}$$

The term $J_{g_0}(s)$ is given to the Jacobi Field of the geodesic g_0 for the set $\{g_n(x)\}_{n \in N}$, and in the same way that the definition has been constructed, a measurement is given for the distribution of the other geodesics of $\{g_n(x)\}_{n \in N}$ around g_0 throughout the trajectory. Given a set of geodesics, some of them are always g^* that, in their environment, have a greater distribution than other geodesics in a neighbouring environment. This is equivalent to saying that it presents a variation in the distribution of geodesics lower than the others and therefore the Jacobi Field associated with $\{g_n(x)\}_{n\in N}$ reaches its lowest value at J_{g^*}.

Let's return to the MRPI (most-re-plan-able intention agent) agent problem that, following the recuperation and variation calculation phase, contains a set of geodesic plans $\{p_1,\cdots,p_n\}$. If the p^* that has a minimum Jacobi field value is selected we can guarantee that in the event of interruption it will have around it a greater number of geodesic plans in order to continue. This suggests the following definition: Given a problem with certain restrictions $F(O;R)=0$, the geodesic plan p^* with minimum associated Jacobi field associated with the set $\{g_n(x)\}_{n\in N}$ can be called the most re-plan-able solution. In this way, the behaviour model G for the MRPI agent is defined.

$$G(e_0,p_1,\cdots,p_n)=p^* \Leftrightarrow \exists n\in N / J_{g_n} \equiv J_{g^*} = \underset{n\in N}{Min}\, J_{g_n} \qquad \textbf{(15)}$$

If the plan p^* is not interrupted, the agent will reach a desired state $e_j \equiv e^* \in f_s f \quad j\in\{1,\cdots,m\}$. Below, in the learning phase, a weighting $w_f(p)$ is stored. With the updating of weighting $w_f(p*)$, the planning cycle of the CBP (Cased Based Planning) motor is completed. Below, it is possible to see what happens if $p*$ is interrupted. Let's suppose that the agent has initiated a plan $p*$ but at a moment $t>t_0$, the plan is interrupted due to a change in the medium. The geodesic planning (the section of plans with a constant slope in the planning space) meets the conditions of the Bellman Principle of Optimality [7], in other words, each one of the plan's parts is partially geodesic between the selected points. This guarantees that if g_0 is geodesic for interrupted e_0 in t_1, because e_0 changes to e_1, and g_1 is geodesic to e_1 that is begun in the state where g_0 has been interrupted, it follows that: $g=g_0+g_1$ is geodesic to $e=e_0(t_1-t_0)+e_1(t_2-t_1)$

The dynamic process follows the CBP cycle recurrently: each time a plan finds itself interrupted, it generates from the state reached so far, the surroundings of the plans from the case base and adjusts them to the new problem. With this it calculates the geodesic plans and selects the one which meets the minimum conditions of the associated Jacobi field. In this way the dynamic planning model of the agent G(t) is characterised as shown in the Figure 7.

A minimum global Jacobi field J(t) also meets Bellman's conditions of optimality [7], in other words, a minimum global Jacobi field, must select minimum Jacobi fields "in pieces".

$$J_{\min}(t)=\{J_{\min}(t_1-t_0),J_{\min}(t_2-t_1),\cdots,J_{\min}(t_n-t_{n-1})\} \qquad \textbf{(16)}$$

If on the one hand, successive Jacobi fields generate one Jacobi field, and on the other hand, minimum Jacobi fields generate a minimum Jacobi field, the MRPI agent that follows a strategy of replanning $G(t)$ as indicated in order to survive a dynamic environment, generates a global plan $p^*(t)$ that, faced with all possible global plans $\{p_n(t)\}_{n\in N}$, presents a minimum value in its Jacobi field $J_{g^*}(t)\equiv J_{p^*}(t)$. Up to this point, an agent has been formally defined that seeks plans within a dynamic environment to lend it greater capacity for replanning.

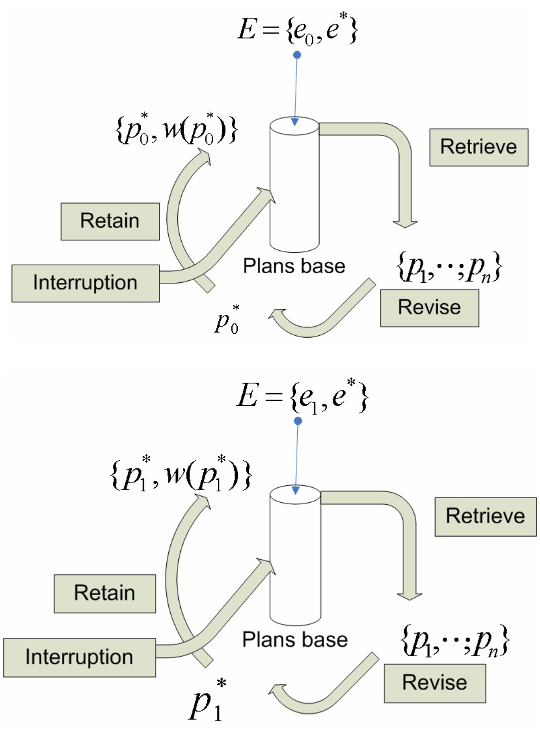


Fig. 7. Model for behaviour G(t).

5 ALZ-MAS CASE STUDY

Alzheimer's patients require special treatments, care and control. The number of patients with this disease is increasing in developed countries and there is a need for adapting the care centres to the needs of the patients and carers. The technology presented in this paper improves the security of the patients, facilitates the carers' activity and guarantees an adequate level of efficiency.

The Alzheimer Santísima Trinidad Residence of Salamanca has been interested in improving the services offered to its patients and has collaborated in the development of the technology presented here, providing their knowhow and experimenting with the prototype developed. From their point of view one of the most important requirements in residence care scenarios is to obtain robust systems with automated failure recovery in the presence of different kinds of problems.

The multiagent system characteristics make them appropriate for residences for the elderly. A multiagent system is a distributed system based on the cooperation of autonomous agents. The problem is solved in a distributed way, so that if a component (agent) fails, the rest of the system is able to continue working. Moreover, the agents in our ALZ-MAS have certain responsibilities through which an agent looks for integrity within the system. The agents monitor their behaviour and their communications. The most important activities carried out by the system agents are listed below:

1. Patient Agent
    - Every hour sends a copy of its memory base (patient state, goals and plans) to the manager agent in order to maintain backups.
    - Every half an hour the patient agent must monitor the patient state. The patient state is instantiated at execution time as a set of beliefs (each belief in Jadex [29] is a Java object) and these beliefs are controlled through goals that must be achieved or maintained. The beliefs that were considered to define a general patient state at the Santísima Trinidad Residence of Salamanca were: weight, temperature, blood pressure, feeding (diet characteristics and next time to eat), oral medication, parenteral medication, posture change, toileting, personal hygiene, and exercise. The beliefs and goals used for every patient depend on the plan (treatment) or plans that the doctors prescribes. The patient agent monitors the patient state by means of the goals. To ascertain whether a goal has been achieved or failed, it is necessary to maintain continuous communication with the rest of the ALZ MAS agents.
    - Every half an hour the patient agent must validate the patient location.
    - At least once per day, depending on the corresponding treatment or treatments, the patient agent must contact the nurse agent.
    - Depending on each treatment the patient agent must have periodic communication with the doctor agent.
    - The patient agent must ensure that all the actions indicated in the treatment are taken out.
2. Nurse Agent
    - The generated plans must guarantee that all the patients assigned to the nurse are given care.
    - The nurse can't exceed 8 working hours.
    - Every agent generates personalized plans depending on the nurse's profile and working habits.
3. Manager Agent
    - It must provide security for the patients and medical staff.
    - The patients, doctors and nurse assignment must be efficient.

With respect to the question of failure recovery, a continuous monitoring of the system is carried out. Every agent saves its memory (personal data) onto a data base. The most sensitive agents are the patient agents, so these agents save their state every hour. When an agent fails, another instance can be easily created from the latest backup. The database used must have redundancy and failure recovery, so Oracle [28] is used.

Nurses and some of the doctors install their corresponding agents on mobile devices, so a robust Wi-Fi network has been installed. The autonomy of the PDA's represented an initial problem (the batteries have an autonomy of two to three hours). This handicap was overcome by buying an extra set of batteries and chargers. Figure 8 shows a diagram of the first floor of the Santísima Trinidad Residence of Salamanca containing the main facility rooms, while all the patients' rooms are located in the second floor. This residence has capacity for 60 patients, an average of 6 nurses, one social worker and 5 more employees with other responsibilities. We selected 30 patients to test the system, so the hardware implemented at the Residence basically consisted of 42 ID door readers, one on each door and elevator, 4 controllers, one at each exit, one in the first floor hall and another in the second floor hall, and 36 bracelets, one for each patient and the nurses. The ID door readers get the ID number from the bracelets and send the data to the controllers which send a notification to the Manager Agent located in a central computer. To test the system 30 patient agents, 10 nurse agents, 2 doctor agents and 1 manager agent were instantiated.

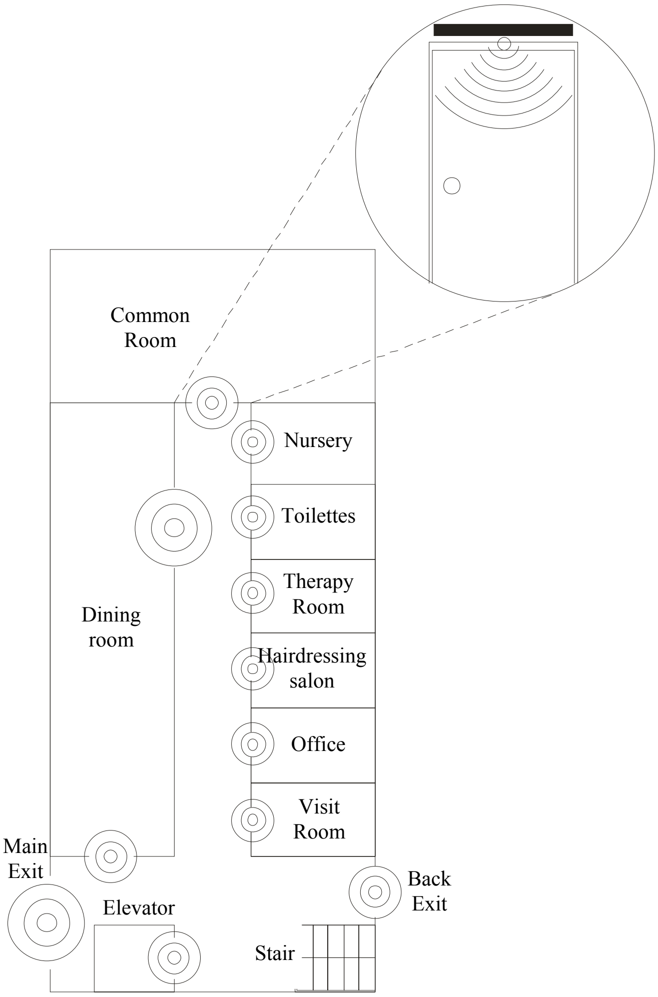


Figure 8. Sensor positioning in the first floor of the Santísima Trinidad Residence of Salamanca

Figure 9 shows the average number of nurses working simultaneously (over 24 hours a day) at the Residence before and after the implantation of the ALZ MAS prototype, with data collected from October 2005 to March 2006. The prototype was adopted on January 15th, 2006. The average number of patients was the same before and after the system implementation.

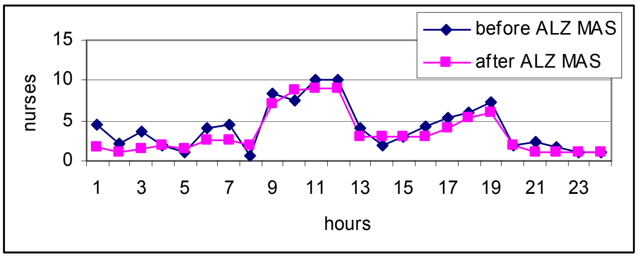


Figure 9: Number of nurses before and after the implantation of the ALZ MAS prototype at the Santísima Trinidad Residence of Salamanca

The tasks executed by nurses were divided in two categories: direct action tasks and indirect action tasks. The ALZ MAS can act on the indirect action tasks. During the first period, the problem was analysed, the residence was observed and data was retrieved. Finally an average of the time spent by nurses in the carrying out of the tasks for every patient, taking into account that a task depends on the dependency level of a patient and the nurse's skill. For direct action tasks, the following times were obtained for each patient: 35' cleaning, 18' feeding, 8' oral medication, 30' parenteral medication, 25' posture change, 8' toileting, 60' exercise and 10' others. For indirect action tasks, the results obtained after the observations let us conclude that the times spent daily were: 105' patient monitoring, 40' written reports, 45' visit passes and 60' other activities.

As can be seen, the ALZ MAS helped to decrease the number of nurses working simultaneously, providing free time to other nurses, which can be dedicated to the care of special patients, in learning or preparing new activities. Also the time spent by the carers on indirect attention tasks (Figure 10) was reduced substantially with the help of ALZ MAS.

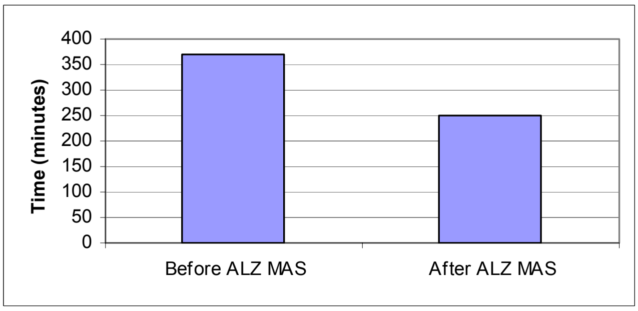


Figure 10. Time spent by the carers on indirect attention tasks.

The system facilitates the more flexible assignation of the working shifts at the residence; since the workers have reduced the time spent on routine tasks and can assign this time to extra activities. Their work is automatically monitored, as well as the patients' activities. The stored information may be analysed with knowledge discovery techniques and may help to improve the quality of life for the patients and the efficiency of the centre. The security of the centre has also been improved in two ways: the system monitors the patients and guarantees that each one of them is in the right place, and secondly, only authorised personnel can gain access to the residence protected areas.

6 CONCLUSIONS

In the future, health care for Alzheimer's patients, the elderly and people with other disabilities will require the use of new technologies that allow medical personnel to carry out their tasks more efficiently.

ALZ MAS has been presented in this paper with the aim of improving medical care and the supervision of patients who require constant attention in geriatric residences.

The CBP-BDI architecture presented in this paper solves one of the problems of BDI (deliberative) architectures, which is the lack of learning capacity. It also reduces the gap that exists between the formalization and the implementation of BDI agents. The reasoning cycle of the CBR systems helps the agents to solve problems, adapt to changes in the environment, and identify new possible solutions.

The use of Wi-Fi networks and implantable or external RFID technology in humans has shown great potential in this experiment, providing a high level of interaction among users, patients, and the multi-agent system.

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REFERENCES

[1] A. Aamodt and E. Plaza, *Case-Based Reasoning: foundational Issues, Methodological Variations, and System Approaches*, AICOM. Vol. 7., March, pp 39-59. (1994).

[2] C. Angulo, and R. Tellez, *Distributed Intelligence for Smart Home Appliances.* On: *Tendencies of data mining in Spain. Spanish Data Mining Network.* Barcelona, Spain. (2004).

[3] S. Bahadori, A. Cesta, G. Grisetti, L. Iocchi, R. Leone, D. Nardi, A. Oddi, F. Pecora, and R. Rasconi, *RoboCare: an Integrated Robotic System for the Domestic Care of the Elderly.* Proceedings of workshop on Ambient Intelligence. Pisa, Italia. (2003).

[4] J. Bajo, and J.M. Corchado, *Evaluation and monitoring of the air-sea interaction using a CBR-Agents approach.* ICCBR 6th Internacional Conference on Case-based Reasoning 2005. Lecture Notes in Artificial Intelligence (LNAI 3620), Springer Verlag. ISSN 0302-9743. pp.: 50-62. (2005).

[5] B. Bauer, and M.P. Huget, *FIPA Modeling: Agent Class Diagrams*. (2003).

[6] F. Bellifime, A. Poggi and G. Rimasa, *JADE: a FIPA2000 compliant agent development environement*. Proceedings of the 5th international conference on autonomous agents (ACM). (2001).

[7] R.E. Bellman, *Dynamic Programming. Princeton* University Press, Princeton, New Jersey. (1957).

[8] M.E. Bratman, D. Israel, and M.E. Pollack, *Plans and resource-bounded practical reasoning.* Computational Intelligence, 4. pages 349-355. (1988).

[9] M.E. Bratman, *Intentions, Plans and Practical Reason*. Harvard University Press, Cambridge, M.A. (1987).

[10] P. Bresciani, and P. Giorgini, and F. Giunchiglia, and J. Mylopoulos, and A. Perini, *TROPOS: An Agent-Oriented Software Development Methodology.* Technical Report DIT-02-015, Informatica e Telecomunicazioni, University of Trento. (2002).

[11] L. Camarinha-Matos, and H. Afsarmanesh, *Design of a virtual community infrastructure for elderly care. PRO-VE'02 – 3rd* IFIP Working Conference on Infrastructures for Virtual Enterprises. Sesimbra, Portugal. (2002).

[12] L. Camarinha-Matos, J. Rosas, and A. Oliveira, *A Mobile Agents Platform for Telecare and Teleassistance*. Proceedings of the 1st International Workshop on Tele-Care and Collaborative Virtual Communities in Elderly Care*, TELECARE 2004*. Porto, Portugal. (2004).

[13] J. Carbonell, *Learning by analogy: Formulating and generalizing plans from past experience*. In Michalski, R., Carbonell, J. and Mitchell, T. (Eds.). Machine Learning: An Artificial Intelligence Approach. Cambridge, MA, pp. 137-162. (1983).

[14] A. Cesta, S. Bahadori, G. Cortellesa, G. Grisetti, M. Giuliani, L. Locchi, G. Leone, D. Nardo, A. Oddi, F. Pecora, R. Rasconi, A. Saggese, and M. Scopelliti, *The RoboCare Project, Cognitive Systems for the Care of the Elderly*. Proceedings of International Conference on Aging, Disability and Independence (ICADI), Washington D.C., USA. (2003).

[15] J.M. Corchado, R. and Laza, *Constructing Deliberative Agents with Case-based Reasoning Technology*. International Journal of Intelligent Systems. Vol. 18 num. 12 pp.: 1227-1241. (2003).

[16] S. DeLoach, *Anlysis and Design using MaSE and AgentTool.* Proceedings of the 12th Midwest Artificial Intelligence and Cognitive Science Conference (MAICS). (2001).

[17] EURESCOM *MESSAGE: Methodology for engineering systems of software agents*. Technical report P907-TI1, EURESCOM. (2001).

[18] M. Glez-Bedia and J.M. Corchado, *A planning strategy based on variational calculus for deliberative agents*. Computing and Information Systems Journal. Vol 10, No 1, 2002. ISBN: 1352-9404, pp. 2-14. (2002).

[19] K. Hammond, *Case-Base Planning: Viewing Planning as a Memory Task*. Academic Press, New York. (1989).

[20] C. Iglesias, M. Garijo, J.C. Gonzalez and J.R. Velasco, *Analysis and Design using MAS-CommonKADS*. Inteligent Agents IV LNAI Volume 1365 Springer Verlag. (1998).

[21] J. Jost, and X. Li-Jost, *Calculus of variations*. Cambridge. University Press, U.K. (1998).

[22] J. Kleindienst, T. Macek, L. Seredi, and J. Sedivy, *Vision-Enhanced Multi-Modal Interactions in Domotic Environments*. IBM Voice Technologies and Systems. Czech Republic. (2004).

[23] F. Lalley, *Government Information Technology Issues 2004, A View to the Future.* Government Information Technology Executive Council (GITEC). Washington DC, USA. (2004).

[24] J.M. Lee, Riemannian *Manifolds. An introduction to Curvature*. Springer-Verlag, New Tork, Inc. (1997).

[25] H.S. Nwana, D.T. Ndumu, L.C. Lee, and J.C. Collins, *ZEUS: A Toolkit for Building Distributed Multi-Agent Systems*. Applied Artificial Intelligence Jounal, vol 1, nº13, pp. 129-185. (1999).

[26] J. Odell, R. Levy and M. Nodine, *FIPA Modeling TC: Agent Class Superstructure Metamodel.* FIPA meeting and interim work. (2004)

[27] J. Odell, and M.P. Huget, *FIPA Modeling: Interaction Diagrams*. (2003).

[28] Oracle Corporation. http://www.oracle.com.

[29] A. Pokahr, L. Braubach and W. Lamersdorf (2003) *Jadex: Implementing a BDI-Infrastructure for JADE Agents*, in: EXP - In Search of Innovation (Special Issue on JADE), Vol 3, Nr. 3, Telecom Italia Lab, Turin, Italy, September 2003, pp. 76-85. Jadex

[30] M.E. Pollack, *The uses of plans*. Artificial Intelligence ,57, pp. 43-68. (1992).

[31] ºSDSU (San Diego State University). *Radio Frequency Identification. Masters of Homeland Security*. http://projects.mindtel.com/2005/SDSU.Geol600.Sensor_Networks/03.RFID/. (2005).

[32] VeriChip HealthCare. WatchMate Wander Prevention, System Overview. http://www.verichiphealthcare.com/wanderprevention/watchmate/downloads.aspx. (2006).

[33] M. Wooldridge, and N.R. Jennings, and D. Kinny, *The Gaia Methodology for Agent-Oriented Analysis and Design*. Journal of Autonomous Agents and Multi-Agent Systems, 3 (3). pp. 285-312. (2000).