# Agent-based alarm management in a Palliative Care Unit*

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## Abstract

*Multi-Agent Systems* and *Information and Communication Technologies* are being used in the Spanish research project *PalliaSys* to improve the management of the clinical data of the patients at the *Palliative Care Unit* of the *Hospital de la Santa Creu i Sant Pau* in Barcelona. In this paper we explain the experiences acquired in the development of that project concerning to how intelligent agents can continuously monitor the evolution of the health status of palliative patients and raise alarms automatically when certain conditions defined by doctors are met.

## 1 Introduction

Nealon and Moreno ([Nealon and Moreno, 2003]) have argued that the main properties of *agents* and *multi-agent systems* ([Weiss, 1999], [Wooldridge, 2002]) make them an appropriate technology to be used to solve problems in the health care area. In particular agents should be autonomous, proactive, sociable, reactive and use AI techniques. Multi-agent systems employ distributed knowledge and problem solving techniques, that are suitable for dynamically decomposing complex problems. There are many recent works suggesting the application of agents in this domain (see e.g. [Shankararaman, 2000], [Cortés *et al.*, 2002], [Moreno, 2003], [Moreno and Garbay, 2003], [Moreno and Nealon, 2003] and [Cortés *et al.*, 2004]). These works explore the application of agents and multi-agent systems in a wide range of problems, such as organ and tissue transplant coordination, management of hospital internal tasks, patient scheduling, personalised and secure access to medical information, decision support systems, patient monitoring, elderly care, community care and personalised e-learning. It must be stressed, though, that most of these works are still quite preliminary and academical, and, as described in detail in [Nealon and Moreno, 2003], there are still many important - scientific, technical, social, professional, even legal - issues that must be addressed before agent-based systems can be designed, implemented, deployed and used routinely in hospital settings.

A recent scientific trend suggests that it would be very useful to join the intelligent performance of multi-agent systems with the flexible access to information through new Information and Communication technologies. Following this line of thought it is possible to predict a future scenario dominated by *ambient intelligence*, in which ubiquitous agents will communicate wirelessly to provide intelligent services to users (see e.g. [Cortés *et al.*, 2003] for a proposal to use agents to provide home care services).

In previous papers ([Riaño *et al.*, 2002], [Moreno *et al.*, 2004]) we reported the initial steps of the Spanish research project *PalliaSys*, in which agent technology and Information and Communication Technologies will be used to improve the management of the clinical data related to the palliative patients of the *Hospital de la Santa Creu i Sant Pau* in Barcelona. In this paper we extend our previous works and we describe how some agents of the *PalliaSys* system are continuously monitoring the health status of palliative patients and adapt and send immediate alerts to all the personnel involved in the care process when an alarm situation is detected.

The rest of the paper is organised as follows. First, we review briefly the aims of *PalliaSys* and the architecture of the multi-agent system which is being implemented within this project. After that we focus on the main contribution of the paper, which is the definition of a novel agent-based alarm management mechanism within this system. The paper concludes with a brief discussion and an outline of future lines of work.

## 2 PalliaSys project

The main objective of the *PalliaSys* project is to design, build and deploy a computerised system for improving the management of the data stored in the *Palliative Care Unit (PCU)* of a big hospital. This unit is specialised in dealing with people with terminal illnesses, and its aim is to ease their pain in the final phase of their lives. Depending on the initial medical diagnosis, the patient can be treated in the PCU, in another unit of the hospital (e.g. Oncology), in a specialised hospice associated to the hospital, or at home. This distributed situation implies that many people with different roles are involved in the supervision and medical control of these patients: the PCU doctors, doctors associated with other units

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or to a hospice, the medical teams that make visits at the patients' homes, the informal carers (relatives, neighbours, friends) of the person, and patient themselves. Due to the highly distributed character of palliative care, it is particularly interesting to have a computer system that allows the exchange of information among the medical professionals that participate in the treatment of a patient. The *PalliaSys* system is also addressed towards the patients that are staying at their homes, so that they have the possibility to access some services without having to go to the hospital.

### 2.1 Basic goals of the *PalliaSys* project

One of the basic aims of the *PalliaSys* system is to improve the process of gathering and collecting the information of the palliative patients. The data will be stored in a central data base located at the PCU of the medical centre. The system will provide to the users that participate in the care of a palliative patient a secure and authenticated access to their patients data .

The second goal of the project is to improve the information at disposal of doctors and patients. Using a multi-agent system we will be able to continuously monitor the status of each of the patients and proactively provide personalised, detailed and up-to-date information to the PCU doctors. This is the main topic of this paper.

Finally, another important goal of *PalliaSys* is to make an accurate intelligent analysis of the historical data gathered in the PCU, by applying novel data mining and machine learning techniques. For instance, it is feasible to define patient models, using unsupervised machine learning techniques such as clustering, or to analyse the medical evolution and the flows of different types of patients, and create models of these evolutions that allow to make predictions on the future states of patients. These models might be created using techniques of inductive machine learning (some previous works on the analysis of the flow of patients within different units of a hospital are available in [Riaño and Prado, 2001] and [Riaño and Prado, 2002]). We also intend to develop algorithms that can construct automatically medical protocols, from the models of patients and evolutions obtained in the previous steps (a first step in the construction of medical guidelines is done in [Riaño, 2003]). The definition and implementation of all these data analysis techniques is one of the current tasks within the project. At the moment, the coordinators of Palliative Care Units do not have any information of this kind, and it could be very valuable for them.

### 2.2 Multi-agent system architecture

In this section we describe the *PalliaSys* system and its different components. The basic architecture of *PalliaSys* is shown (in a simplified form) in fig. 1 in the next page.
Two main parts may be distinguished within the system:

1. *Information and Communication Technologies*, which will be used by patients at their homes to provide or view their personal medical data, send requests or receive information from doctors.

   In the current prototype, patients can send information through a web page or with a mobile phone, via WAP. In the final version of the system other communication means (e-mails, SMSs, PDAs) will be considered.

2. A *multi-agent system*, which will be used to securely manage the clinical data, keep track of the status of the palliative patients and analyse their evolution.

In the system, we can find four types of agents:

- The *Data Base Wrapper*. This agent controls the access to the data base of the PCU, in which all the information of the palliative patients is stored. It receives all the data that has to be stored in the data base, as well as all the requests of information. It includes authentication mechanisms that ensure that only properly authorised agents can read or modify the clinical data (in the line of those suggested in the *HeCaSe* system, [Moreno *et al.*, 2003]). Some preliminary security mechanisms, such as the definition of different kinds of users, the assignment of different permissions to each of them, the use of logins and passwords, the encryption of messages using a public key infrastructure and the use of SSL (*Secure Socket Layer*) have already been implemented.
- One *Doctor Agent* for each doctor of the PCU. This agent runs in the desktop computer of the doctor. It provides a graphical interface that allows the doctor to easily obtain the information of his/her patients, request information from the data base, control the schedule of visits, or check, as will be detailed below, if the system has raised any alert regarding the deterioration of the health of a patient.
- One *Patient Agent* for each patient. Each of these agents is responsible for continuously monitoring the evolution of the patient. These agents must check whether patients send the periodic reports concerning their health status or not; they also send reminders to patients if they forget to send their reports on time or if they have a scheduled visit with a doctor. An interesting feature is that if the *Patient Agent* detects any problem (e.g. the degree of pain has increased heavily in the last auto-evaluation, or the patient has failed to send a report on time), it can send a warning to the *Doctor Agent* responsible for that patient, so that appropriate measures (e.g. a phone call or a visit to the patient's home) are taken. A detailed explanation of the alarm management system is given in the next section of the paper.
- The multi-agent system also includes an agent, the *Data Analyser*, specialised in Data Mining, Knowledge Discovery and Machine Learning techniques. Its main task is to perform an intelligent analysis of the evolution of the patients and uncover interesting and useful medical knowledge, as has been commented above. Moreover, the head of the PCU has the administrative duty of writing an annual report detailing all the activity of the unit within the last 12 months. This work has been always done manually, and it is very time-consuming. The *Data Analyser* also provides the manager with all the statistical information he needs to fill this report (figures, statistics, comparisons with previous years, etc.).

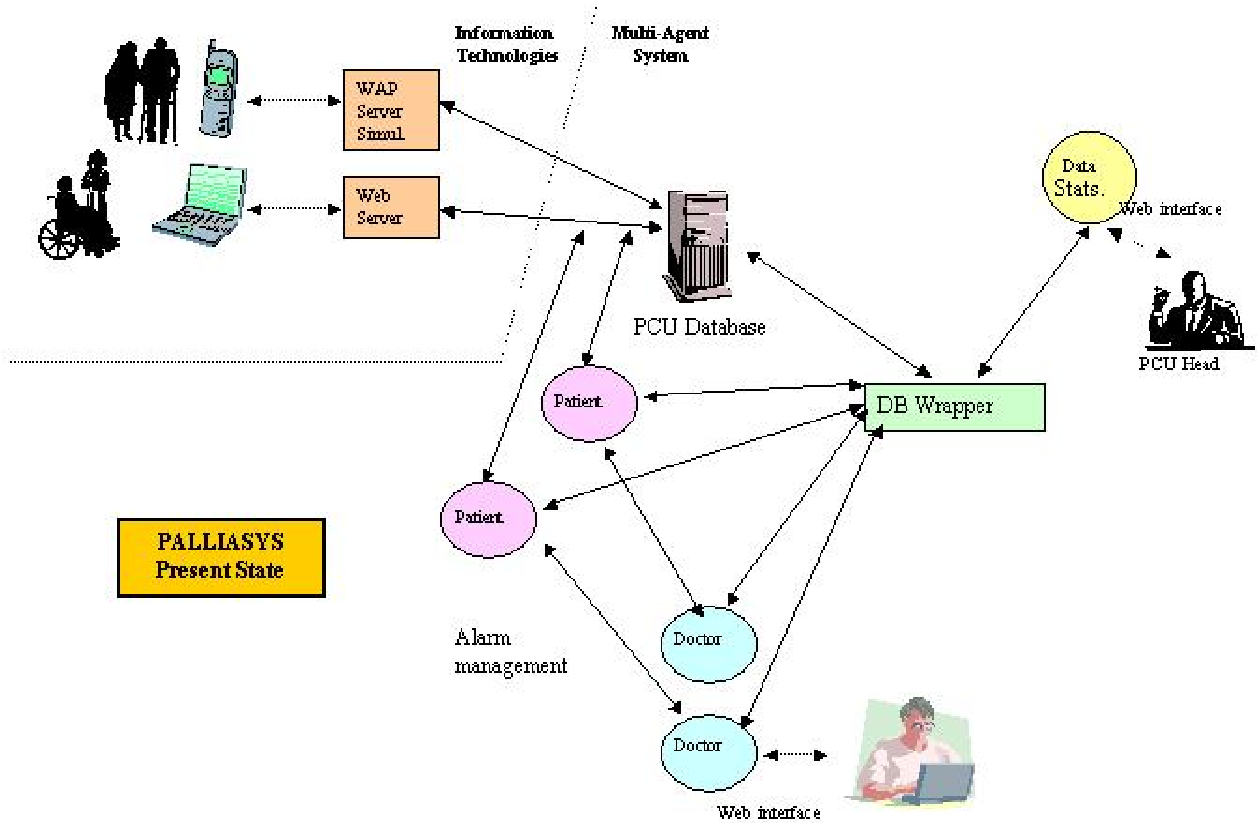


Figure 1: Architecture of PalliaSys

## 3 Agent-based alarm management

At present, all the patients that are being cared under the supervision of the PCU doctors have to make periodic visits to the hospital, to be examined by the doctors and to have their evolution controlled. In each visit patients have to fill in an *auto-evaluation form*. In this document they have to rate (with a value between 0 and 10) ten different subjective aspects related to their health: the degrees of pain, weakness, depression, anxiety, vomit, sleepiness, hunger, well-being, breathing problems and dried mouth. During the visit, the doctor checks all the values and completes them with his/her expert assessment about the same concepts. In addition, the doctor also evaluates the so-called *complexity criteria* (personal characteristics of the patient, special medical problems, therapeutic strategies, family issues). Finally, the doctor can take some decisions concerning the care of the patient, such as ordering further clinical tests, modifying the patient treatment, or changing the location of the patient (for example, hospitalise the patient in a hospice if his/her health has deteriorated too much).

One of the aims of *PalliaSys* is to ease the process of collecting the information of the auto-evaluations from the patients, so that they can send this information periodically from their homes (f.i. every week) without having to go to the hospital so often. The idea is to put at their disposal different Information and Communication Technologies, such as web forms, SMSs, e-mails, mobile phones, PDAs, so that each patient can choose the communication way that is more comfortable or easy to use for him/her. The same communication channels may also be used to receive information from the system (e.g. a reminder of a visit).

There are around 500 new patients in the PCU of the Hospital de la Santa Creu i Sant Pau in every year, so the quantity of data generated by weekly auto-evaluations is quite large, and it is a very time consuming task for doctors to study all this information and to analyse the evolution of each patient in the last weeks or months. That's why doctors suggested that it could be very useful for them to have a way of analysing automatically all this information and alerting them when an anomalous situation occurs.

### 3.1 Definition of personalised alarms

The fact of having a different *Doctor Agent* for each doctor of the PCU allows us to personalise the use of the system for each of them. In particular, each doctor may define his/her own *"alarm situations"*, taking into account his/her preferences and the personal characteristics of the patients. Alarms may be defined at two different levels:

- *General alarms*

  They are defined by the PCU head, through his personal *Doctor Agent*, and they have to be applied to all the patients of the unit. These alarms correspond to situations that demand an immediate response, according to the policy of the PCU.

- *Doctor-specific alarms*

  Each doctor may define personal alarm situations, and may decide to apply them to only to one particular patient, to a set of patients, or to all of his/her patients. With this kind of personalised alarms, each doctor defines a very fine grained monitoring of the evolution of the health status of each of the patients that are under his/her responsibility. The doctor may adjust precisely the conditions on each patient that activate an alarm, taking into account the personal health characteristics of that patient and his/her evolution in the last weeks or months.

### 3.2 Alarm types

Regardless of whether an alarm is general or doctor-specific, there are two different types of alarms, depending on whether they are intended to analyse the data of a single auto-evaluation (*basic alarms*) or the evolution of the health status of a patient in a sequence of auto-evaluations (*evolution alarms*).

**Basic alarms**

In this kind of alarms, the only information that is evaluated is the one provided by the patient in the last evaluation sent to the system. Recall that the data in an auto-evaluation is simply a list of 10 integer numbers in the range [0-10], which provides a subjective measurement of the following ten different aspects related to the health state of the patient:

- pain
- weakness
- depression
- anxiety
- vomit
- sleepiness
- hunger
- well-being
- breathing problems
- dried mouth

A doctor may define a basic alarm such as the following:

$(Weakness > 7)$ and $(Pain > 8)$ : *Extreme weakness*

A doctor may consider abnormal a situation in which the degree of weakness is bigger than 7 and the degree of pain is bigger than 8, and may define a basic alarm, named *"Extreme weakness"*, to detect these conditions as soon as they arise. In the definition of a basic alarm doctors may use $>$ and $<$ to check if the value of any of the 10 evaluated aspects is too high or too low, and can combine the results of these comparison operators using the standard boolean connectives (conjunction, negation and disjunction). Furthermore, the doctor also has to associate a name (a label represented with a string of characters) to each alarm, so that when one of them is raised, the doctor can immediately notice which is the abnormal situation that has been detected.

After defining the *extreme weakness* situation shown above, a doctor may define another basic alarm such as the following:

$(Hunger < 3)$ and *Extreme weakness* : *Dangerous weakness*

In this case the doctor is defining a new alarm situation, called *Dangerous weakness*, which will be activated when a patient sends an auto-evaluation with high degrees of weakness and pain and a very low degree of hunger. This example shows how a simple alarm may be used in the definition of more complex alarms, allowing doctors to define a very precise, fine grained and fully personalised hierarchy of alarm situations. After defining a basic alarm, the doctor may decide to associate it to a single patient or to a group; thus, doctors may not only define their own alarm situations but also personalise the monitoring of each particular patient.

**Evolution alarms**

In many cases it may be more interesting to study the evolution of the health status of a patient, rather than simply analysing the values of a single auto-evaluation. For instance, if a patient reports a degree of pain 6, that may not seem very alarming; however, it can be quite abnormal if the week before the reported degree of pain was only 2.

An *evolution alarm* checks the degree of change of any of the ten aspects described in an auto-evaluation, taking into account the last $n$ auto-evaluations (*specific evolution alarms*) or the auto-evaluations that have been sent in the last $d$ days (*temporal evolution alarms*).

An example of a *specific evolution alarm* is the following:

Number of evaluations: 2.
$\Delta\, Weakness > 2$ : *Fast weakness increase*

This alarm, called *fast weakness increase*, would be activated whenever a patient reports a degree of weakness which is at least 3 units bigger than the one reported in the last auto-evaluation (e.g. the example described above with a sudden jump from 2 to 6).

In the case of *temporal evolution alarms*, the system checks the evolution of a patient in a certain period of time. An example of such an alarm is the following:

Period: 28 days.
$\Delta\, Pain > 4$ : *Extreme pain increase*

The *Extreme pain increase* alarm would be raised when, after receiving an auto-evaluation of a patient and analysing all the evaluations submitted in the previous 4 weeks, it may be noticed that the degree of pain has been continuously increasing in more than 4 units (e.g. that would be the case if we had the values of pain degree 2,3,5,7 in the reports received in the last 4 weeks).

As in the case of basic alarms, doctors can also combine the analysis of different aspects within an evolution alarm, and can also use a simple alarm in the definition of a more complex alarm. The doctor that defines the alarm can also choose to apply it to a single patient or to all of his/her patients.

As explained above, if a basic or evolution alarm is defined by the head of the Palliative Care Unit as general, it will be applied to all the patients of the PCU.

### 3.3 Alarm definition and activation

The management of alarms within *PalliaSys* follows these steps:

- *Definition*

  Each *Doctor Agent* (DA) provides a graphical interface through which his/her associated PCU doctor can define any of the doctor-specific alarms described previously. General alarms can only be defined by the PCU head, through his personal DA. The interface provides doctors with a set of useful functionalities; they can look up the alarms they have already defined, use existing simple alarms to define more complex alarms, assign alarms to a specific patient or to all his/her patients, deassign alarms, and look up which alarms have been raised and require some attention.

- *Storage*

  Once an alarm has been defined and assigned, the DA sends a message with the definition of the alarm to the corresponding *Patient Agent(s)* (PAs, which may be one or several, depending on whether the alarm has been assigned individually or to all the patients of the doctor). The PA stores internally the alarm for future use. General alarms are stored in all PAs, as they have to be applied on all patients.

- *Check*

  When a patient sends an auto-evaluation, it is stored in the centralised database, and the PA associated to that person receives a signal. Then, this agent requests the data of the evaluation from the *DB wrapper*, and it checks all the general and doctor-specific alarms that it stores. If there are temporal evolution alarms, it also has to request the data of the previous auto-evaluations needed to check the evolution of the patient (PAs do not keep the evaluations, they are only stored in the PCU database).

- *Raise*

  If a PA detects that an alarm situation has occurred, it sends a message to the DA that defined that alarm with an explanation of the data that has caused the activation of the alarm. The DA presents to the doctor a list with all activated alarms, and then the doctor may study all this information and decide the best course of action to follow (e.g. to phone the patient, to send a home care team to examine the patient, or to send a message to the patient requesting him/her to be visited in the PCU of the hospital as soon as possible).

It may be noticed that all the alarm management process is made in an autonomous way, without doctors having to worry about checking continuously if patients have sent their reports. PAs send the detected alarms to DAs proactively, without waiting for explicit requests from doctors. In any case, doctors can always check all the data of all auto-evaluations sent by their patients, requesting it from the *DB wrapper*, regardless of the definition and activation of alarms.

## 4 Discussion and future work

The *PalliaSys* project will finish in November 2005, when we will deliver an agent-based system that will be deployed for testing at the Palliative Care Unit of the Hospital de la Santa Creu i Sant Pau of Barcelona, Spain. At that point it will be possible to evaluate the use of this personalisable alarm system.

Nowadays, the available Information and Communication Technologies introduce new modes of assessing the health status of chronic patients to improve the quality of their care ([Celler *et al.*, 2003]). Many papers argue that monitoring the functional status of patients can help to predict health risks and take the appropriate action at an earlier stage, avoiding hospital admission or reducing the length of hospital stay.

In this sense, the term *Telecare* ([Celler *et al.*, 2003]) has appeared, in contrast to Telemedicine. Telecare incorporates a broader range of healthcare activities related to taking care of patients remotely. The Home Telecare System (commercialised by MedCare Systems Pty Ltd) [Celler *et al.*, 2003] collects data from patient's general practitioners on the basis of the severity of symptoms. The collected data can be viewed by the doctor from any web browser; moreover, one of the most important features of the system is the possibility of analysing the temporal evolution of the data. For a particular patient, the system represents graphically the values of each symptom, in order to help the doctor to evaluate the status of this patient and take the appropriate action.

The introduction of multi-agent systems in telecare has proved to be highly effective. Projects and computer systems such as INCA [Beer *et al.*, 2003] and ILSA [Haigh *et al.*, 2002] conclude about the advantages of using multi-agent systems for supporting heathcare activities between patients and doctors, with particular relevance in areas such as the assistance to elder, chronic or palliative patients. Some of these benefits are:

- The patient-doctor relationship is extended.
- There is a proactive healthcare that emphasises prevention.
- Information is closer to the patients.
- Patients are free to be monitorised at home or elsewhere.
- Technology can suggest patients to visit the doctor, in case of doubt.
- A more complete treatment is achieved.
- Some healthcare processes are speeded up or made more automatic.
- Treatments become more continuous in time, and the patient feels he/she is being better assisted.

Combining multi-agent systems with the Internet is addressed by many previous works [Mazzi *et al.*, 2001; Celler *et al.*, 2003; Cortés *et al.*, 2003] as a way of making the patient participant in the healthcare activities, and also as a way of achieving a more flexible healthcare. One of the examples of this flexibility is in the area of healthcare alarm handling. [Rialle *et al.*, 2003] presents a telemonitoring multi-agent system that uses a set of sensors in a ”smart” house to recognise some predefined problematic scenarios, in which case it triggers an alarm in the corresponding emergency centre. This system has been tested at the Hospital Centre of Grenoble, which has been actively participating in Health ”Smart” Homes research in the last years. The PalmCIS application is intended to provide timely palm-based notification of real-time alerts. An intelligent agent checks the incoming patients' clinical data in order to detect potential problems and transmit a message to the physician and nurses responsible of that patient [Mendonca *et al.*, 2004].

Our future work in the *PalliaSys* project includes the following tasks:

- The definition of machine learning and data mining techniques that may be applied by the *Data Analyser* to uncover interesting information about the evolution of palliative patients or the general management of the PCU.
- The improvement of the security measures, so that only authorised agents may access the information of the PCU.
- Complete the implementation of the alarm management part of the multi-agent system using the *JADE* development environment, that provides a set of Java libraries that ease the implementation of FIPA-compliant MAS, [Bellifemine *et al.*, 2001].
- The deployment of the multi-agent system in the PCU of the Hospital de la Santa Creu i Sant Pau, and its trial with the real palliative patients and doctors.

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