INTCARE
Multi-agent Approach for Real-time Intelligent Decision Support in Intensive Medicine

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Abstract: For an Intelligent Decision Support System to work in real-time, it is of great value the use of intelligent agents that cooperate with each other to accomplish their tasks. In a critical environment like an Intensive Care Unit, doctors should have the right information, at the right time, to better assist their patients. In this paper we present an architecture for a Multi-Agents System that will support doctors' decision by in real-time, guaranteeing that all required clinical data is available and capable of predicting the patients' condition for the next hour.

1 INTRODUCTION

There is a need to develop an Intelligent Decision Support System (IDSS) for intensive care to help doctors decide about the best care to provide their patients. Such system is expected to reduce medical errors, to fasten clinical interventions and, overall, to provide better care by having the required information at the right place, at the right time. The INTCare system has this vision and its goals are towards an IDSS as a Multi-Agents System (MAS).

"Intelligent agents with their properties of autonomy, reactivity, and proactivity are well suited for dynamic, ill-structured, and complex environments (Gao and Xu 2009), such as an Intensive Care Unit (ICU). This paper presents the INTCare system as a MAS for intelligent decision support, an innovative agent-based architecture, and the prototype system.

Intelligent agent technology is at an appealing point in its advance. "Intelligence with Interaction" applications are progressively more being developed in domains such as meteorology, manufacturing, war gaming and capability assessment (Tweedale et al. 2007).

More useful than a system acting intelligently, is the ability for a system to cooperate in an environment with other intelligent agents, whether they are humans or machines (Guerlain et al. 2000). Furthermore, "it is necessary for a system to be able to communicate with others, detect and correct mistakes, and take advantage of others' abilities.". The key is to use distributed artificial intelligence for decision support (Cortes et al. 2000).

2 BACKGROUND

MAS are computational systems in which several artificial agents interact to perform predefined tasks to satisfy some set of goals (Lesser 2003).

INTCare is an IDSS for intensive medicine that makes use of intelligent agents based on a MAS. For supporting clinical decision, it makes predictions of organ failure and outcome and, according to the predictions, it suggest therapies, treatments and procedures, by means of DM (Data Mining) techniques. In order to accomplish its goals, the system is divided in four subsystems composed by intelligent agents that cooperate amongst the system's modules, as shown in Figure 1.

Subsystems:

- Data acquisition;
- Knowledge Management;
- Inference;
- Interface.

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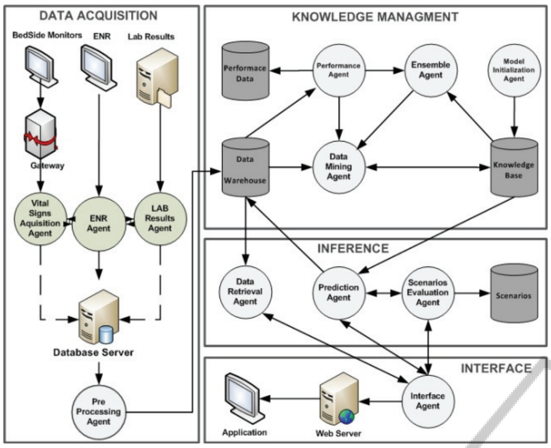

Figure 1: INTCare system and its four subsystems.

The data required for the DM models is gathered in the ICU and relates to the patients' clinical condition (monitored data, nursing records, lab results) and derived variables like Sequential Organ Failure Assessment (SOFA) scores, critical events (Silva et al. 2008), ratios (Vilas-Boas 2010) and Modified Early Warning Scores (MEWS) (Subbe et al. 2001). These data origins in distributed heterogeneous data sources and, to guarantee the system's viability in real-time, it relies on intelligent agents. In this paper, we focus on latest developments of the data acquisition subsystem in order to achieve INTCare's goals. They go beyond retrieving, collecting and integrating relevant information; they encompass discovering previously unknown, implicit and valuable knowledge (Klusch et al. 2003). Even though the previous system had a data acquisition subsystem, it lacked some important features and functionalities, mainly related to the information it was able to acquire. This subsystem was able to gather and store data from the vital signs monitoring. However, with our advances in the research related to the prediction of organ failure, there is the need for more data other than the previously gathered, mainly data from lab results and drugs systems. Also, previously, data was collected and post processed, which was not suited for a real-time system.

The system is currently being tested in the ICU of Hospital Geral de Santo António (HGSA), Porto, Portugal.

3 DATA ACQUISITION SYSTEM - REDESIGN

With the new requirements of INTCare, i.e. data collected in real-time and available online, it was necessary to redesign the data acquisition system and its architecture. The new model allows all data to be collected and stored in electronic mode and the extinction of paper-based information throughout the ICU. The existing agents were preserved and added new tasks.

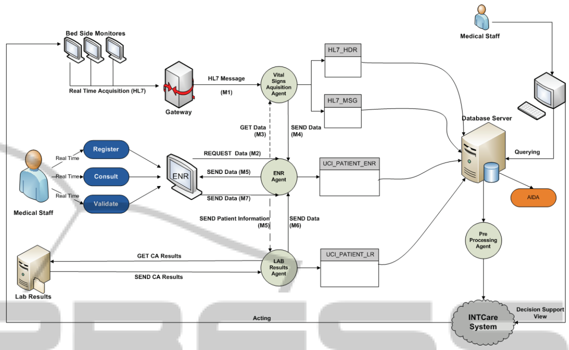

Figure 2: Data acquisition subsystem.

The tables contained in the database are defined in terms of their attributes, as follows:

HL7_HDR	$\subseteq$ {MSG DATA}
HL7_MSG	$\subseteq$ {Vital Signs)
UCI_PATIENT_FEE	$\subseteq$ {PaO_2, FiO_2, Glasgow, Urine Output, Amines, Patient Outcome, Drugs, …}
UCI_PATIENT_LR	$\subseteq$ {Creatinine, Billirubin, Blood Platelets, PaO_2, FiO_2, SOFA, …}
UCI_DATABAE	$\cup${HL7_MSG,UCI_PATIENT_FEE, UCI_PATIENT_LR}

Figure 2 presents the link to other subsystems, which is a consequence of the work of Data Acquisition System.

4 INTCARE SYSTEM'S AGENTS

The tasks of the intelligent agents support some system modules: Data Acquisition, Management of Knowledge, Inference and Interface. The flexibility and effectiveness of such systems depend on the agents and the interactions between them.

4.1 Data Acquisition Agents

These agents will be in charge of the tasks associated to the data acquisition.

Gateway (a_{gat}) is responsible for capturing the vital signs data from bedside monitors and operates in real-time. These data are packed into HL7 messages and sent to the Vital Signs Acquisition Agent. It collects information, in average, once per minute and restarts at each hour to ensure that no communications failures compromise the system;

Vital Signs Acquisition (a_{vsa}) was reformulated. It is an AIDA process that parses the HL7 messages in real-time, extracts information blocks, splits the information and stores them in the database tables.

The table HL7_Message contains the values and results from vital signs monitoring (id_category, value, patient_id, msg_date)**.**

ENR Agent (a_{enr}) is new and was created with the Electronic Nursing Record (ENR) (Portela et al. 2010, M.F. Santos et al. 2009b) and replaces the Clinical Data Entry Agent. It was developed to allow some information in electronic mode.

This agent works in two forms: automatic (can save the data in minutes) and manual, when it's the user who saves the information. It is responsible to capture the clinical data from the medical and nursing staff (Gago et al. 2006). When it receives the data, it splits the information, clears the information displayed in the table for that patient in that day and stores the new data.

LR (a_{lr}) is new and it's an evolution of Clinical Analysis Data Entry Agent that was responsible for capturing the clinical data from the lab results.

This agent works in association with the ENR because it only gets information from a certain patient when it is required by the ENR. The process is easy and smooth; The ENR agent requests to (a_{lr}), every five minutes, new results of lab results. This agent verifies if there are new results from a patient and, if so, it stores them in UCI_PATIENT_LR and sends the new information to ENR.

All information collected and stored by data is available by AIDA (Abelha et al. 2003).

AIDA (a_{ada}) is an agency to archive and to disseminate medical exams and results, implemented at the hospital. It supplies the lab results and nursing records through the clinical analysis data entry agent and clinical data entry agents (Abelha et al. 2004).

Pre-processing (a_{pp}) agent is responsible for the correct linking of all the values in order to create a valid medical record for the patient (Gago et al. 2006). It is in charge of solving some data acquisition problems (M.F. Santos et al. 2009a).

Before data is consolidated in the data warehouse, the agent verifies the data in order to remove null values and correct the values that are out of range (M. F. Santos et al. 2009). It proceeds with the copy of the values received from the three data sources: bedside monitors, electronic nursing records and lab results that were stored in the tables.

At the moment, we are studying another method to optimize results using the MEWS.

4.2 Knowledge Management Agents

This subsystem is composed by three agents: Data Mining, Performance and Ensemble.

Data Mining (a_{dm}) agent is responsible for the retrieval of the relevant data in order to make possible the application of AI algorithms for the predictions and to train new models, whenever requested by the Performance Agent (*apf*). After the training, the models are stored in the the Knowledge Base, applying the Predictive Markup Model Language (PMML), which is a XML based model description language (Guazzelli et al. 2009) (Gago et al. 2006).

This agent converts the data stored in the data warehouse in Knowledge, creating models in real-time using online data.

Performance (a_{pf}) agent is responsible for continually consulting the data warehouse to collect statistics, as a base to calculate a set of assessment parameters maintained in the Performance Database (Gago et al. 2006). It analyzes the new data that was stored in data warehouse and verifies the performance of the prevision models through DM.

If the collected statistics show that the performance has fallen below a predefined parameter, a new model is requested to replace the poor performing one (Gago et al. 2006).

Ensemble (a_{ens}) agent was created to enhance predictive performance by combining several models in order to produce models with better results (Dietterich 2000); It is possible to combine techniques like decision trees and artificial neuronal networks.

4.3 Inference Agents

The inference subsystem didn't have any adjustments and its agents are the same presented with the INTCare System (Gago et al. 2006).

Prediction (*apd*) agent answers user questions by applying the adequate models contained in the

Knowledge Base to the data stored in the data warehouse (Gago et al. 2006);

Data Retrieval (*adr*) agent's task is to retrieve, from the data warehouse, the information requested by the interface agent (Gago et al. 2006);

Scenario Evaluation (*asc*) agent makes possible for doctors to create and evaluate what-if scenarios. After receiving the data from the interface agent, this agent requests a forecast from the prediction agent, the scenario is then stored in the Scenarios Database. and the result is sent back to the interface agent (Gago et al. 2006).

4.4 Interface Agents

The Interface subsystem only has one agent, the Interface Agent. This subsystem suffered some alterations due the changes presented before. At the moment we have the web-based ENR that collects data from various data sources. ENR is also a consulting platform for patients' clinical data and, furthermore, the prediction models created by DM can also be consulted.

Interface (*aint*) agent makes possible web-based interaction with the system by providing an easy way for doctors to request prognostics and evaluate scenarios (Gago et al. 2006). For the past days, the actual SOFA score is shown, together with the value predicted for the next day. It is also possible to consult the confidence levels associated with the prediction values (Gago et al. 2006). At the moment, we can predict the results for the next hour (Vilas-Boas 2010) and a holistic view of the patient to the next hour will be supported by presenting, in the same chart, the information regarding the organic systems. Also, the values predicted for the next hour are shown, providing information that may suggest the need for immediate action.

5 MULTI-AGENT SYSTEM

INTCare is a MAS because it uses a conjunction of several agents for preparation of data for prediction. MAS consists of a set of agents that communicate with each other and work together towards common goals, with a degree of reactivity and / or reasoning (Wooldridge, 1999).

5.1 First Multi-agent Process

All agents presented collect data in real-time and online mode. They communicate among themselves to obtain better results. The a_{gat} agent processes the monitored data. When the gateway receives the vital signs from the monitors, it sends a HL7 message (M1) to the vital signs acquisition agent and it parses the information. Next, there is an example of a HL7 message:

MSH|^~\&|*DHV* |***h2***|***h3***|***h4***|||*ORU^R01*|***h1***|*P*|*2.3.1*

PID|*1*||***d1***||***d2***

PV1|*1*|*U*|***v1***

OBR|*1*|||*DHV*|||***r1***|

OBX|***x2***|*NM*|***x3^x4^^^x5***||***x6***|***x7***|||||*R*||||***x1^ v1***||

Table 1 explains the variables in the exchange of messages between the agents a_{gat} and a_{vsa}.

Table 1: HL7 message variables (M. F. Santos, et al., 2009).

h1	Version ID	x1	Producer's ID
h2	Sending Facility	x2	Value Type
h3	Receiving Application	x3	Observation Identifier (cod)
h4	Receiving Facility	x4	Observation Identifier (cod2)
d1	Patient ID (Internal ID)	x5	Observation Identifier (descp)
d2	Patient Name	x6	Observation Value
v1	Assigned Patient Location	x7	Units
r1	Observation Date/Time	x1	

The information received by a_{gat} is split by a_{vsa} in the form:

HL7_HDR = {h1, h2, h3, h4, d1, v1, x1 }

HL7_MSG = {v1,r1,x2,x3,x4,x5,x6,x7,x1^v1}

5.2 Second Multi-agent Process

The ENR agent communicates with two other agents (a_{vsa} and a_{lr}) and all tasks are triggered by the ENR.

The ENR comprises of two forms to register data - manual and automatic. When the ENR requires information to fill its fields, it sends requests to the ENR Agent with the alert that data it required.

The a_{enr} analyzes the request and, according the needs, (*M2*) sends information to the other agents (*M3, M5*).

The Vital Sign Agent works in real-time and has new data all the time. In this case, it sends the new data (*M4*) to a_{enr} and it is sent to the ENR. If the ENR need lab results, the ENR Agent sends the Patient ID (PID) (*M5*) to Lab Results Agent and it will verify if some new results are available in Lab Results Server.

Finally, the a_{lr} stores data in the DB table and sends the newest data to the ENR Agent (*M6*) which, in turn, sends to the ENR application.

5.3 Other Multi-agent Process

The knowledge management, inference and interface subsystems needn't modifications at the moment, for they are working correctly and in accordance to the MAS and INTCare's goals. Their communication is visible in the arrows presented in the agents of each subsystem in figure 1.

- Performance agents perform some actions to Data Mining Agent and Ensemble Agent;
- Assemble Agents perform some actions to data Mining Agents;
- Scenario Evaluation Agent works together with Prediction Agent and Interface Agent;
- Prediction Agent works with interface agent and Scenario Evaluation Agent;
- Data Retrieval Agent works with Interface Agent and vice-versa;
- Interface Agent works with Scenario Evaluation, Prediction Agent and Data Retrieval Agent;

6 DISCUSSION

Table 2: Impact of the MAS system in intensive care.

Characteristics	Impact
Robustness	The medical staff can work with the guarantee that the information will never lost.
Fault Tolerance	Lack of system failures in critical environments and reduction of medical error.
Scalability	Possibility to work with large quantities of clinical information.
Speed up a system's operation	less time spent with informatics issues.
Efficiency	Systems always running in real-time and efficiently doing what users require.
Interconnection and interoperation of multiple existing legacy systems	Medical Staff can have information about patients when required, independently of the systems in which they that are stored.

Table 2 summarizes a set of characteristics of the MAS and their impact on a critical environment like ICU, comparing to a single agent or centralized approach.

By distributing computational resources and capabilities across a network of interconnected agents, performance bottlenecks or critical failures, are not a problem (Gruer and Hilaire 2003).

Overall, with the MAS there is great gain in system's performance, efficiency, reliability, scalability, robustness, maintainability, responsiveness, flexibility, and reuse (Chira 2007).

These are a critical aspects in intensive care where, most of the time, patients' lives are at risk and all valuable information should be available and its correctness and ease of interpretation must be guaranteed. Moreover, the MAS will also provide the means for prediction and decision models in real-time, with an hourly granularity.

In our approach, each of the intelligent agents is able to deal with specific tasks that can be grouped in data acquisition, knowledge management, inference and interface in an independent way, so that the system has a transparent behaviour for the applications, as well as for the users. For a real-time system like INTCare, a MAS presents advantages in processing speed-up, automatic data validation, access to data and availability of information electronically.

All modifications were tested in the real environment of the ICU, guaranteeing that they will suit correctly the requirements and identifying possible new requirements and/or refinements.

7 CONCLUSIONS AND FURTHER WORK

For accomplishing INTCare's goals, some redesign regarding the agents was presented. Data acquisition subsystems and its agents were reformulated and new agents were created.

Agents can perform some previously manual action in automatic mode, without human intervention. This feature is of great importance in a real-time IDSS. To achieve so, the Data Acquisition Architecture was redesigned to allow data acquisition in real time and online mode.

Regarding the interface, we are studying two solutions for presenting the information originated by the DM models – partially in the ENR and wholly it INTCare platform.

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