A Coordination Model for Medical Diagnosis

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ABSTRACT

This article presents a coordination model based on agents for the medical collaborative diagnostic. Different agents have been proposed and implemented to be operative this model. Human and software agents work together to achieve a common solution to patient's problem. Different interactions between agents are defined. A web application to host the software agents has been implemented also. The design and development methodologies use a model-view-controller pattern and JSPs and Servlets technologies. The system was completly developed and tested. The usability and performance tests have be done.

Keywords: Cooperative systems; Medical diagnosis; Coordination model; Multi-agent systems.

1. INTRODUCTION

The medical activity is a complex task which involves a dense interconnection of organizational roles. Each individual care-provider strives to manage his workload, which consists of direct patient care work as well as communication and coordination with other members of the care team. There are many interactions between different members in the medical community. When patient care was limited to a primary physician with a thorough understanding of the patient's medical history, the coordination of patient care remained relatively simple. There are other less obvious cases for which it is not easy to establish a satisfactory diagnosis directly (complex cases).

There are many reasons for this: (1) a number of available judgment elements may not be enough, (2) the illness has not evolved enough for certain signs to appear; and/or (3) an incidental no schematized cause may appear. The diagnosis in these cases can then involve great difficulties and require a complex procedure. This procedure can implement several clinical maneuvers (exploration of various organs or systems, complementary tests, and sometimes, a further patient observation) which are repeated several times [1]. Most protocols have been designed in consideration of clinical patient contexts such as concurrent diseases, but have little ability to consider the dynamic impact of workflow context on protocol execution. It is for this reason that all efforts orientated in this direction are pertinent well.

The application of agent technology to health care domains is very vast. The interest for this domain is increasing more and more for these last years. Agents have the potential to assist in a wide range of activities in health care environments [2]. They can maintain the autonomy of the collaborating participants, integrate disparate operating environments, coordinate distributed data, such as patient records held in different departments within a hospital or in several hospitals, clinics and surgeries. The agents in a multi-agent system may be running in different locations, for example there may be an agent associated to each department of a medical centre [3] or an agent associated to each person that is included in a health care program in a certain community [4].The autonomy of each agent in a multi-agent system permits to maintain the independent views of each modelled actor, for example each agency involved in the provision of health care to a community, such as social workers, health care professionals or emergency services may have different private policies that determine their relationship with other agents and their individual decisions [4]. Agents can also handle the complexity of solutions through decomposition, modelling and organising the interrelationships between components; improve patient management through distributed patient scheduling using co-operating intelligent agents; provide remote care monitoring and information for such groups as the elderly and chronically ill; undertake hospital patient monitoring; supply diagnosis decision-support; improve medical training and education in distance-learning tutoring systems [5]; gather, compile and organise medical knowledge available on the Internet; and enable intelligent human computer interfaces to adapt to medical data and users requirements and to visualise medical data.

There are many examples of agent technologies to medical applications: patient appointment scheduling, medical information retrieval systems and medical ontologies, medical workflows, medical coordination systems, remote care monitoring and support, distributed decision-making systems, care management system by specialties, and more recently, systems directed towards the Web and Internet. The

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agent-based coordination of tissue or organ transplants across a hospital [6] [7] could provide significant improvements in the time required to pull together the resources required for a transplant operation [8]. An intelligent user interface to adapt to a clinician's requirements, characteristics of diabetic patients whose records are being accessed uses a multi-agent framework to coordinate these possibly conflicting requirements [9]. Patient scheduling coordination in hospitals to the management of medical processes is considered in [10]. A cooperative multi-agent framework can support the heterogeneous transaction workflow process among the people involved in patient care management. It is based essentially on the use of ontologies for the integration of the heterogeneous sources [7].

The aim of this work is to present a coordination model and its implementation in multi expert medical diagnostic framework. The approach is based on the concept of the agent, with the idea of modeling a group of experts via community of agents under interaction.

2. MEDICAL COLLABORATIVE WORK

When medical group members interact at various stages of the diagnostic reasoning process, several collaborative medical decision-making features (Group cognition support, Individual decision-making styles, Medical task integration support, Multiple criteria decision-making, Knowledge-base interaction) are at play [11], due to the presence of several instances of the medical decision process. Specialist interconsultation, case conferences and morning rounds in hospital, include exchange and cognitive processes of the group type [12]. There are several models of information flow in medical practice, for example, communication between generalist and specialist in the same or different specialities (inter-consultations), communication among specialists (staff meeting). However we are interested in the multi expertise exchange.

These collaborative acts are important both for clinical decision-making concerning diagnosis and treatment, and for the training of student and novice physicians.

Currently information between medical group members necessitates synchronous or asynchronous time for the exchange, analysis and interpretation of clinical data. In this way, coordination tasks in this environment are really relevant. A clinical case illustrating this type of work is shown in figure 1 (A more detailed explanation is found in [13]). In this case, we can observe the interaction among a GP, a radiologist, a lung specialist and a pathologist [14].

3. THE COORDINATION MODEL

The coordination deals with management of the interactions between entities in the systems. Coordination is a central problem for numerous complex dynamic systems composed of interacting activities. This definition means that all participants in a coordination process have interdependencies. Thus the elaboration of coordination theory [15] has tried to identify which generic dependencies can exist and which sort of processes may be involved. An interesting general outlook on coordination can be found in [16], in which Ossowski gives an overview on formal and informal characterizations and models of coordination in human societies and its models in social science.

The cooperation between agents is an essential feature of the system, an intrinsic feature because it depends on the processes executed by a set of agents, in order to reach some goals. There is a collective intentionality to realize an objective. The most of multi-agent systems are not interested in the way an agent resolves a task but how a group of agents succeeds in resolving a complex problem. The specific feature of the collective activity results of the function of cooperation between these entities.

In classical multi-agent systems, the cooperation requires the use of explicit techniques of coordination (or negotiation) which are either distributed or centralized with the assistance of an organizational structure.

A coordination model is an abstract framework for the composition and interaction of active entities. A general coordination model can be defined by the following elements [17]:

- The *coordinate entities*, which are the active entities running concurrently. They are the direct subject of coordination, therefore the building blocks of coordination architecture.
- A *coordinating medium*, which allows the coordination of all participating entities. This medium also serves to assemble entities into a configuration. It is therefore the actual space where coordination takes place.
- The *coordination laws*, which specify the semantics framework of the model. They determine how the entities are coordinated using the coordinating media.

The most used classification distinguishes between data-driven and process-oriented coordination models [17]:

- In data-driven coordination models, the state of a program is defined in terms of both the values of the data being received or sent and the actual configuration of the coordinated components.
- With process-oriented (or control-driven) coordination models, the state of the computation at any moment in time is defined in terms of only the coordinated patterns that the processes involved in some computation adhere to coordination models and languages. Therefore an application is centered on the processing or flow of control. The attention is concentrated on processes and their organization. The data does not play a role in the coordination.

Clinical case

A 40 year-old male patient, non-smoker, without any obvious particular antecedents in his past medical history. He attended his GP with a non-productive cough of a three-month evolution . His physical tests normal. GP recommended him a palliative treatment and some laboratory and paraclinical tests (Postero-anterior chest x-ray).

x-ray result : circumscribed 2-3 cm nodule located in the right upper lobe of the lung with the presence of interior calcifications of non-specified type. Heart and rest of study without obvious modifications. Scanner recommended.

CAT Lung scanner: It indicates a 2 x 3 cm mass with non-epimaculated aspect located in the right upper lobe of the lung with non-specified calcifications. There is no affectation of Mediastinum lymphatic ganglia. There are no other masses in the thorax.
Pulmonary biopsy: macro and microscopic analysis of post-operative piece.

Diagnosis: ENDOBRONCHIAL HAMARTHOMA.
The patient left the hospital and considering the benign origin of the pathology, the doctor recommended an annual check up with his general practitioner.

Fig.1: *A clinical case*

- Hybrid models. These integrate shared data space functionalities in a process- oriented view.

Following the component definition above mentioned, we define our agent coordination model figure 2.

The general structure that we used for the representation of the model is a version simplified of CommonKADS [18] and it follows the philosophy developed in [19]. Finally, we it is defined grammar for the model figure 3. The components of this model are:

- *The coordinate entities.* These entities are all the entities that take part in the medical resolution problem. They are constituted by the human agents (physicians) and the computer tools used, represented by the software agents.
- A *coordinating medium.* Our model is conceived as a hybrid coordination system, i.e. data-driven and process-oriented aspects are been considered [14]. This coordination is guided by agents with specific functions and tasks to be achieved; and the basic mechanism of communication is the medical history.
- The *coordination laws.* It is a set of rules for which the agents are directed. There are a social environment and the medical protocols to be respected. The events presented deal with different states to the patient's evolution and these are reflected in the medical history.

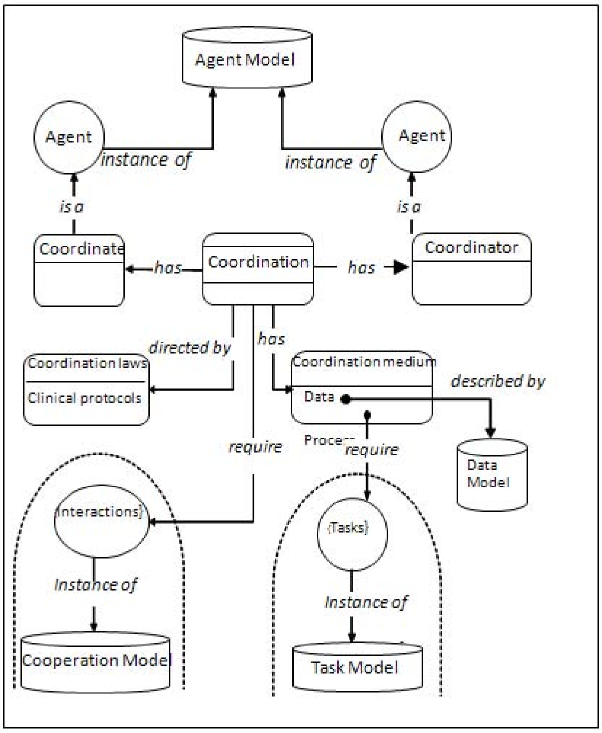

Fig.2: *Coordination agent model*

< Coordination model> ::= **coordination-model**
<relations-coordination>
<task global model >
< coordination-protocoles>
end- coordination-model

< relations-coordination > := {< coordinator -agent>, < agent-coordinate>, <medium>}+

< coordinator-agent>::= manager agent | planning agent | distributor agent
<medium> := data| processes
< coordination-protocoles> := {<rules>}*

Fig.3: *Grammar of formalization language to the coordination model*

4. IMPLEMENTATION OF THE COORDINATION

The operation of our coordination model includes the definition of all coordinators and coordinates entities, means to execute cooperation and the coordination laws that are governed by clinical protocols. The latter includes a detailed study of all restrictions considered in the medical work. These restrictions include: economic, cultural, ethnic, religious, moral, legal, geographical restrictions. The first two will be detailed in the following sections. The last, due to its extension, will be not treated in this article (for reference about this topic see [20] [21]).

4.1 Agent description

The development architecture follows a three-level structure (figure 4): the collaborator level or users (human agents), computer systems agents (software agents) and the data level (databases and knowledge bases). This architecture permits us to clarify the semantic definition of the problem under study. The agents enable us to identify and define all human and artificial individuals interacting and taking part in co-operative problem solving. Human agents represent physicians of different specialties and patients. The medical decision (diagnostic) can be reached only by extensive consultation with domain experts by human agents. Artificial (software) agents have been proposed to the coordination and communication tasks of medical work. Databases and knowledge bases represent the medical histories of patient and the factual knowledge in medicine (relationships between pathologies and signs and symptoms, pathologies and treatment, etc.).

- The medical meeting agent: This is considered as a high level hierarchical agent. It is a set of agents defined to identify the group of physicians. The communication protocol between agents follows human communication procedures based on personal conversations; that is, somebody intervenes and the others remain silent and attentive. Once the person has finished, another one intervenes, and so on. The leadership position can be assumed by the medical doctor who sits down face-to-face to the patient (Physician in charge of the case).
- Medical speciality agents. They define a classification based on the different medical specialities, i.e., human agents such as radiologists, neurologists, pathologists and others. Agent knowledge is heterogeneous. The agents divide the tasks among themselves and share data about the patient. Each one of these specialists can observe only one part of the "outside" (i.e., the patient).
- The patient: A human agent who as an active role in his/her treatment. He/she requests medical appointments, takes part in his/her cure, and asks for information. He/she permits the clinical context to be established.
- The coordinator agent: This is considered as a high level hierarchical agent. It is a set of agents defined to identify the group of software agents.
- The planning agent: An artificial agent that manages everything related to time in the system: it assigns the tasks within a time context, checks the time of their activation, execution and ending. It returns the requests of task assignments if it has not received a timely response. It centralizes information about task executions and their different states of development.
- The distributor agent: An artificial agent that finds out those agents that will execute the tasks, according to their specialities and availability for executing them. To do so, it takes into account the urgency of tasks required. It centralizes information about group members.
- The manager agent: An artificial agent that controls the requests for tasks. It sends and receives results.
- Interface agent: An artificial agent that controls the security accesses to systems and data. It provides access to the expert systems agents. It adequately adapts the appropriate interface according to each user with his/her different levels. It centralizes general access information.
- The data agent: An artificial agent that manages data in the databases and knowledge bases. It manages metadata, user view definitions, and authorizations to data access. It also controls anything related to data integrity and recovery mechanisms.

4.2 Agents interactions

There are many types of agent interactions (figure 4), these ones depend on the evolution of medical case treated. We can mention :

Human Agents- Human Agents: Interactions established between physicians and patients.

Human Agents - Software Agents: The physicians make their functions and their tasks through system interfaces and software agents.

Human Agents - Applications: Physicians use application oriented by specialty to make their works. Patients use applications to querying, and others.

Software Agents - Software Agents: Software agents communication themselves to make cooperative tasks.

Software Agents - Applications: Software agents communicate with computer programs and interfaces.

Software Agents - Data: Software agents use data to make their functions.

4.3 Operation coordination practices

Normally, the medical diagnosis work imposes the execution circuits that are not fixed a priori and depend on the medical case tried. In the medical case (figure 1), only 4 physicians interact. The clinical protocol followed leads to a generalist to require the intervention of a lung specialist, a radiologist and pathologist. But this situation can change in other cases. Thus, the coordination means are based on: a) communications between different actors (according to different interventions described in the preceding section) and b) the medical history, in which lie all the actions taken by and on patients.

5. DESIGN AND IMPLEMENTATION OF SYSTEM

We defined two stages for the development of our project: in a first stage, implementation of a medical

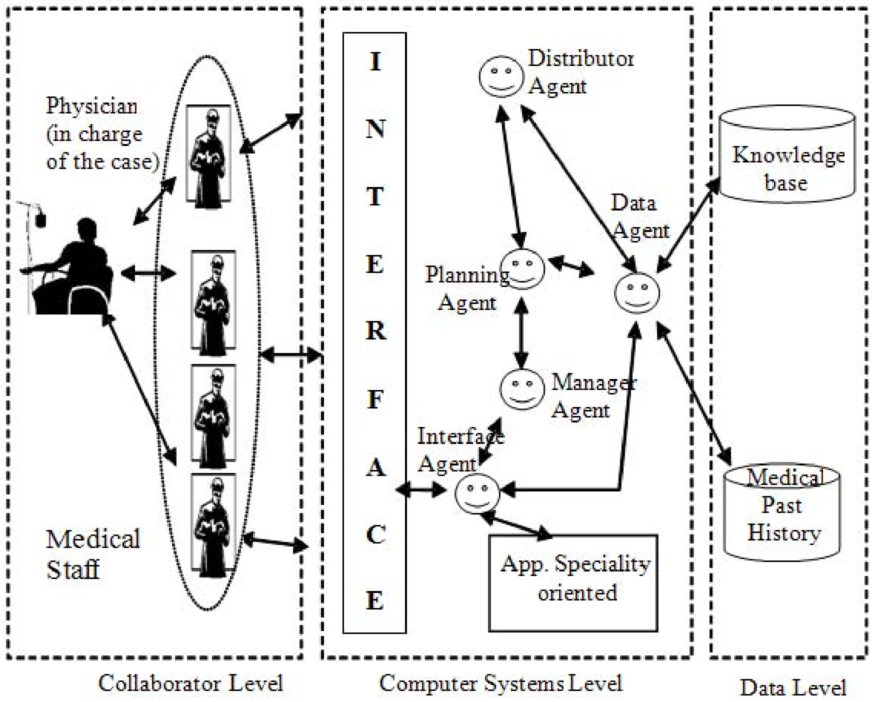

Fig.4: *Graph of the interactions between agents*

Web system for the data exchange between the doctors specialists in the medical solving problems (figure 5). This system offers to the specialists the adequate interfaces for storage and actualization of medical histories; and also be able the access to knowledge base. This data representation (figure 6) allows us to provide to different specialists a common place to share information about patients.

On the level construction, the system was conceived to allow an easy incorporation of the software agents. The development of these software agents constitutes the second stage of construction of our system and they have like principal functionality the coordination of medical work, the control of workload by doctors, the control of appointment, etc (figure 7). We conceived our system as a Web application which integrates interfaces and agents. The idea is to provide to the users a working tool easy to install, easy to integrate into other applications, and especially with capacities of portability.

Today, a large majority of the establishment of health care have computers with a connection Internet. We used a pattern architecture based in the Model-view-controller (MVC) for our Web application design (figure 8).

For the development of our application, we used a client-server communication model based on Sun Microsystems technology. This model is the base of the high level views of JAVA: servlets and JavaServer Pages (JSPs). In the context of our application, JSPs constitute the views of application according to model MVC, they allow the communication with the users; servlets constitute the models and one special servlets constitute the controller (figure 8). JSPs and servlets are coded in XHTML and java respectively, TOMCAT server is our web server and PostgreSQL is our database system.

For the development of the multi agent system, each agent has its own directory (following Tomcat structure), and each agent is also structured in directories according to WAF [21]. Each one of these directories (environment, behavior, resource and communication) contains the implementation of java classes. The communication between agents is made by pass messages thanks to javax.mail library (figure 9 and figure 10).

For the implementation of the agents, each agent constitutes a thread program by extending the Thread class of java. Each agent runs like an independent process on the server side (figure 11).

6. SYSTEM EVALUATION

Some usability and users tests have been done. Quality is reached by making sure that there is a convenient flow of medical information, that the tasks are assigned with the most adapted agents, and that the group of cooperation answers effectively to not planned events or to significant changes of the statute of its participants. The interfaces provide the man-machine communication and the use of certain services like the SMS and the electronic mails. The compatibility and the portability of our application function for several navigators Web (mozilla firefox,

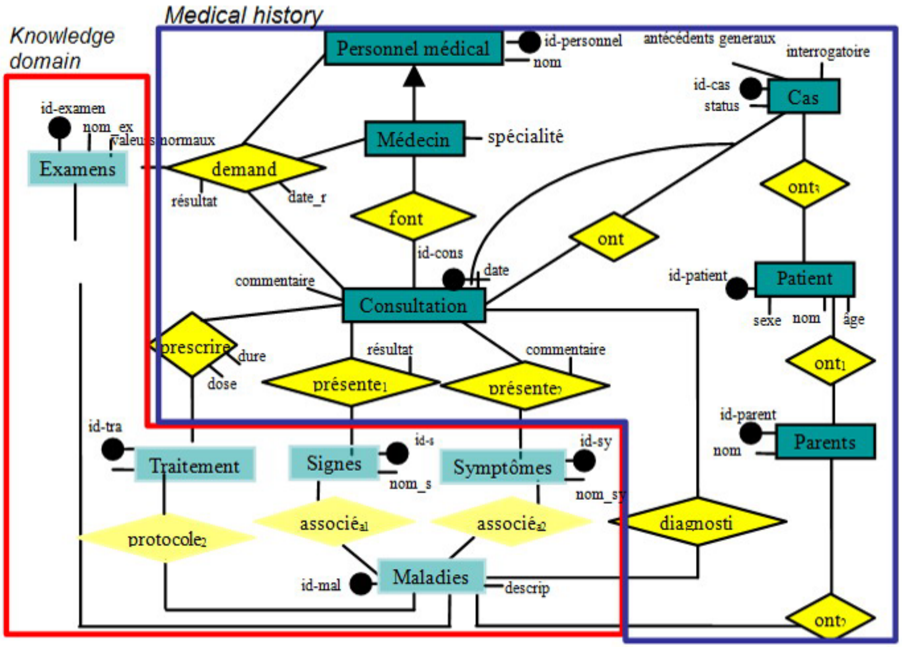

Fig.6: *Knowledge base (left) and medical history (rigth) representation*

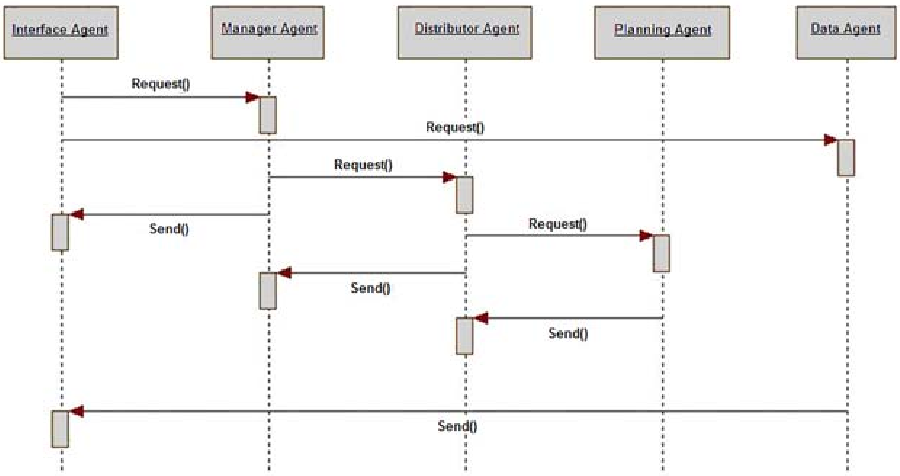

Fig.10: *Interactions for the communication between software agents*

Netscape navigator or Internet explore). It is supported by several systems of operations (linux or Windows). Under JDBC standard, it offers a support for traditional databases like PostgreSQL. The security of our application offers an identification user to guarantee the access to the authorized users. In the same way, each time that objects are modified in the database, the user trace is recorded. At the level of the user tests, our application was evaluated for five doctors; they agreed with the interface in the majority of the cases, like a general interface, but they suggested us the recording of the other data as well as not structured data (digital reports, digital images for the scanner and others).

6.1 Performance test

To verify the system performance, the users make random requests which were processed and observed their behavior in the system. The system performance will be significantly affected according to the platform specifications where the system will be deployed, ie if the software is installed in devices with higher processing capabilities, the system behavior will be better.

There are tools able to observe the average response time for a website, an example is WEBWAIT [23]. In this tool is only necessary provide the website address, the number of requests that will be executed and the waiting time between each request.

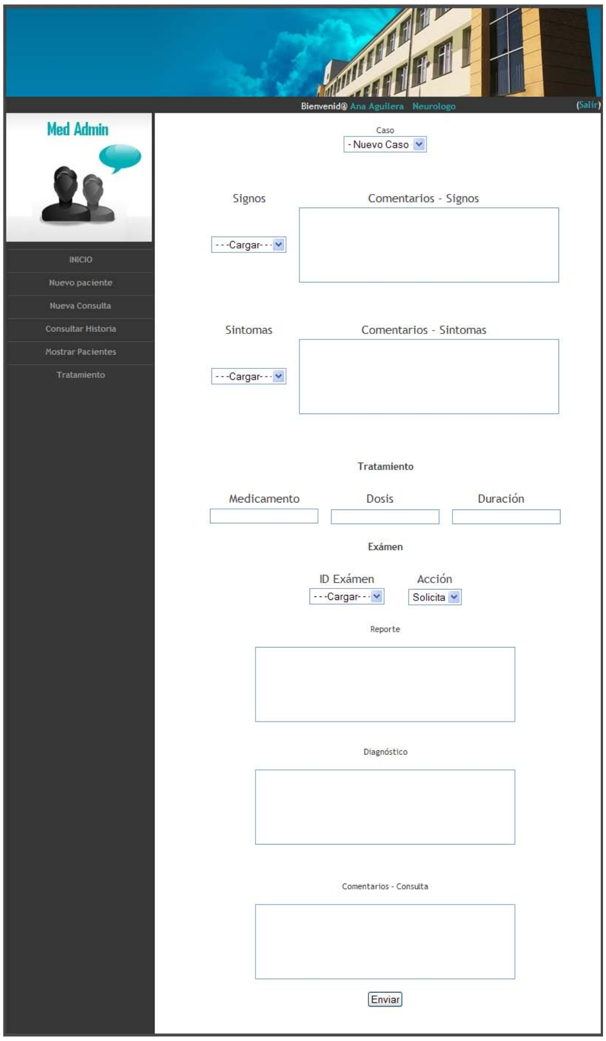

Fig.5: *Interface of patient's consultation*

Fig.7: *Model View Controller Model using JSP and Servlets technologies*

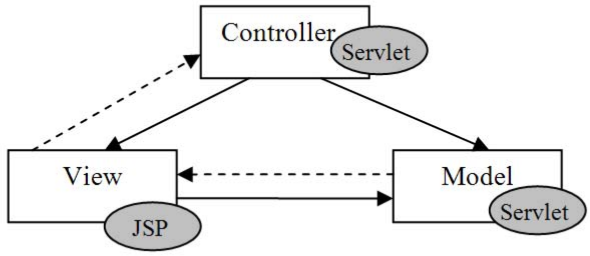

Fig.8: *Model View Controller Model using JSP and Servlets technologies*

The average system response with the configuration defined in the platform model (figure 12), with 100 requests and a waiting time of 10 second was quite acceptable (4.52 sec.). In spire that, the servers used in this test are used for multiple tasks.

7. CONCLUSIONS

Numerous techniques and systems have been developed in the medical informatics community for tackling isolated aspects of medical decision making. However, despite a well-documented need for supporting an integrated range of different functions (including knowledge acquisition, uncertainty management, task management and coordination), there has been very little prior work which attempts to provide comprehensive procedures for these different aspects of health care. We have seen that the medical work with complex cases is not an easy task. Many elements must be considered. We present in this work a mechanism to medical work coordination based on agents. A Web application has been developed for distributed management of patients with critical disorders. Preliminary evaluation of this application indicates that in real clinical application settings the procedure to built dynamically knowledge bases is effective. Internet is a technology that makes applications highly portable and accessible. The method followed in this development is easily integrated with other existing applications.

8. ACKNOWLEDGMENT

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```
package Interfaz.Comunicacion;

import java.io.IOException;
import java.util.Properties;
import java.lang.Exception;
import javax.mail.internet.InternetAddress;
import javax.mail.internet.MimeMessage;
import javax.mail.*;
import javax.activity.*;

public class ACC {
    private String emisor,receptor;
    private String host = "smtp.gmail.com";
    public ACC() {
        emisor="agenteinterfaz@gmail.com";
        receptor="agentedirector@gmail.com";
        }

public void enviar_mail(String txt,String
asunto) {
    try {
      Properties prop2 = new Properties();
      prop2.setProperty("mail.smtp.host",
      "smtp.gmail.com");
      prop2.setProperty("mail.smtp.starttl.
      enable", "true");
      prop2.setProperty("mail.smtp.port","5
      87");
      prop2.setProperty("mail.smtp.user",
      emisor);
      prop2.setProperty("mail.smtp.auth",
      "true");
      Session     session     =     Session.
      getDefaultInstance(prop2);
      session.setDebug(true);
      MimeMessage     message     =     new
      MimeMessage(session);
      message.setFrom(new
      InternetAddress(emisor));
      message.addRecipient(Message.Recipien
      tType.TO,new
      InternetAddress(receptor));
      message.setSubject(asunto);
      message.setText(txt);
      Transport     t     =     session.
      GetTransport("smtp");
      t.connect(emisor,"interfaz");
      t.sendMessage(message,message.getAllR
      ecipients());
      t.close();
        }
    catch (MessagingException e) {
        System.out.println("Error  al  enviar
el email: "+e);
        }
    }
}
```

Fig.9: *Class for the communication between interface and manager agents*

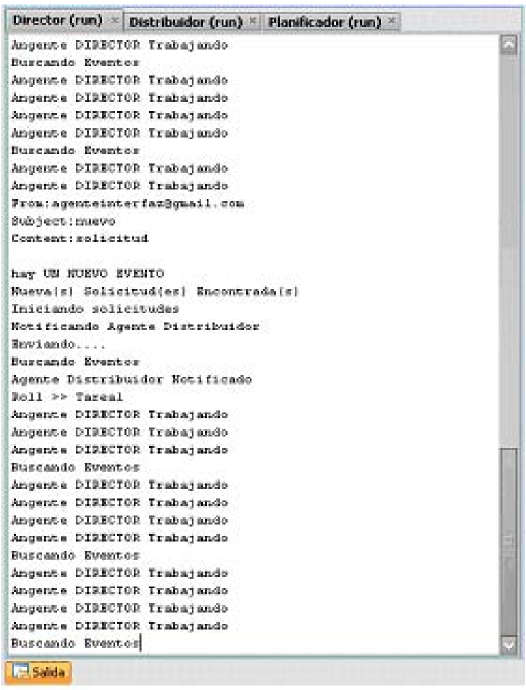

Fig.11: *Running Software Agents*

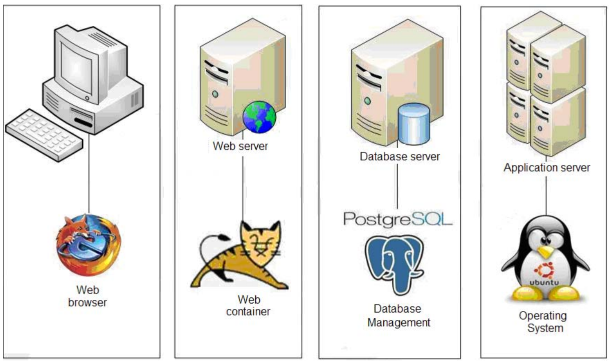

Fig.12: *Platform Model*

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