Critical assessment of the usefulness of multi-agent technology in health care projects

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Abstract—This work describes several projects focused on health care environments that have used a multi-agents approach to solve them. Descriptions have their focus on multi-agents part and makes an analysis of the agents used in each project and the reasons of selecting these methodology.

Keywords—agents, multi-agents, health care

INTRODUCTION

Multi-Agents systems tries to solve large problems in a distributed and fault-tolerance manner. It is because the nature of Agents allows them to be sufficiently proactive and autonomous to make decisions depending on their environment circumstances.

In this work, I will analyse some systems applied in health care environments that have used multi-agent approaches to solve the problems. We will see why these kind of problems are eligible to apply these methods, and which are their advantages on using them.

First of all we must know what is an agent. There are some discussions about what is exactly, and much of them converges in the next description. An agent is an autonomous software entity, that is driven by some personal and/or social goal, and it is able to make decisions given the changes of their environment. Some of the typical properties that agents have are:

- *Reactive* : Responds to changes that occur in its environment.
- *Pro-active* : Takes initiatives and recognises opportunities to achieve goals.
- *Social* : Interacts with other agents or entities.
- *Rational* : It makes rational decisions given their goals and knowledge.

Extending the description of a unique agent, we reach a multi-agent system where multiple of these agents uses their abilities to reach a global goal, dividing a big problem in several subproblems.

With these descriptions we have an idea on how these systems may help in solving big and distributed problems. We will see in the next sections an analysis of different health care projects and the usefulness of multi-agents in solving them.

The analysed projects are *CARREL* in section 1 that is a distributed system for tissue and organs transplants planning, *HealthAgents* in section 2 is a distributed system for brain tumour diagnosis and prognosis, *Health Care Services* in section 3 which is a system to facilitate the communication between medical personnel, *SHARE-it* in section 4 that is a platform to integrate several kind of e-tools to facilitate the mobility of people with disabilities and senior citizens, *i-Walker*in section 5 that is an intelligent walker that helps people with disabilities and uses the *SHARE-it* platform, *K4Care* in section 6 that facilitates the communication between home care medical services and finally *PalliaSys* in section 7 where the system wants to helping the people of the Palliative Care Unit (PCU) of a big hospital.

In each section there is a brief description of the system, then we will focus on the different agents involved and finally a discussion about the convenience of using multi-agents system approach to solve the problem.

1 CARREL

CARREL is a distributed system initially designed for planning tissue transplants. Once the specification was finished it was extended to human organs too. It tries to decrease the number of organs and tissues lost by the critical amount of time in their distribution. While some tissues can be out of a body from a week to one year, in the case of organs this decreases to hour or a day.

They decided to use multi-agent system for various reasons; its geographic distribution, because was a communication problem, to solve coordination issues and for the existence of a variety of regulations in each region or country.

Given that the negotiations are a critical phase, it is necessary to avoid potential conflicts in the decisionmaking. For that reason and what *Moses and Tennenholtz* stated (see [4]), they created a social structure where some of the agents may impose some order. In this structure they created the institution entity, its task is to control the agents behaviour, to be up to date in available pieces in the tissue banks and recipients in the waiting lists, to ensure the correctness of the commitments, to coordinate the deliveries and to record all incidents of the system.

The rest of the system is related to the agents and is explained in the next section.

1.1 Agents

This architecture is organized with different scenes where the transactions and negotiations are done. In each of this scenes there is a institutional agent that manages the scene. In the next list there is an explanation for each of the different agent roles:

1) *RR Agent*: Reception Room is the first scene where the external agents identify and acquire the roles that they can play with their context.
2) *CR Agent*: Consultation Room is the scene where the agents can update the institutions about waiting list and information on piece reception, transplant operations and the health of recipients.
3) *IM Agent*: Institution Manager which coordinates different scene managers.

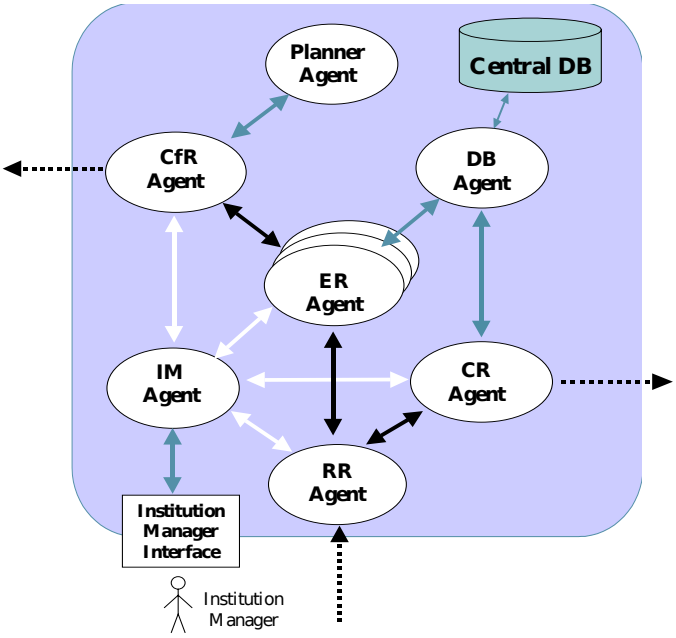

Fig. 1. The multi-agent architecture of a Carrel platform (adapted from [3])

4) *DB Agent*: Data Base is the mediator between the database and the agents.
5) *ER Agent*: Exchange Room is the scene where is made the assignation process.
6) *CfR Agent*: Confirmation Room is the scene where the initiated exchange is confirmed.
7) *Planner Agent*: This agent needs to have into account the restrictions of the tissue or organs to allocate.
8) *HF Agent*: Hospital Finder Agent are sent by hospitals with tissue requests or organ offers.
9) *HC Agent*: Hospital Contact Agent are in charge of receiving notifications about organs or tissues that has appeared for a recipient that is in their waiting list.
10) *HI Agent*: Hospital Information Agent maintains the information about its hospital updated in Carrel system, they can query the Carrel database.
11) *TB Agent*: Tissue Bank notifier are sent to update Carrel about tissue availability.

1.2 Discussion

Carrel system copies the human approach of dealing with the organ allocation problem and creates an automatic platform that mimics this

system. The idea is to accelerate the process because human communication is slower than computers communication. The use of multi-agents systems seems appropriate because it solves the problems of distribution, negotiation, synchronisation and diversity in source format.

The same problems applicable to humans can be applied to agents, anyhow agents are much faster than humans in solving the conflicts.

It has also been demonstrated that this platform is easily extensible and scalable. Vázquez et al. [3] extended the tissue exchange with organs allocation in a easy way.

2 HealthAgents

HealthAgents was a EU-funded research project to create a Distributed Decision support System (DDS) for brain tumour diagnosis and prognosis. The principal idea is to implement some Pattern Recognition and Machine Learning Techniques in a distributed manner.

The problem of medical data in order to detect health issues in patients is the privacy of the data. There are also different laws in each country that makes this problem impossible to solve in a centralised form. For that reason, the agents in this system are able to travel from one location to another classifying new cases in all possible hospitals, without taking out confidential data, and returning only with the diagnosis. The final decision is taken by doctors that are able to compare different diagnostics and evaluate their relevance.

2.1 Agents

There are three kinds of agents in that system (see the architecture in fig. 2). When a doctor brings a new case, he starts interacting with the *GUI Agent*. This shows the different options and takes the new case data. Furthermore, in the final phase it will interact with the doctor a second time.

Once the *GUI Agent* have the new case, it contacts with the *Directory Facilitator Agent*. This agent is a yellow pages system that knows all hospitals and nodes that are able to diagnose the new case. With that information the *Gui Agent* contacts with all the *Classifier Agents* to ask for diagnosis.

Classifier Agents uses local knowledge to do diagnosis for the new case. This knowledge is extracted from local databases, local classifiers, doctors, etc.

Finally the result of all classifiers is returned to the initial *GUI Agent* that is able to present the results to the doctor. He is able to interpret the classification and to decide the final diagnosis.

2.2 Discussion

The idea behind the Agents in this systems is very interesting, but it is not huge enough to require multi-agent systems. It is obvious the need of a distributed approach to confront the privacy and law problems, but in this problem the goal of the agents is to know their situation and to start the diagnosis. With this little problem it must be enough to make the same system with known and old technologies.

On the other side, it gives a starting platform easily scalable to add new diseases and classifiers. The good side of multi-agents systems is this. With the basic scenario it is possible to add new classifiers, GUIs, directories, devices and a huge amount of systems able to contribute to do the diagnosis.

3 Health Care Services

Health Care Services (HeCaSe2) is a platform to facilitate the communication and information between doctors, patients, nurses and other people involved in medical issues. In this distributed system there are a lot of different agents, each one is autonomous and proactive. One of the utilities is to save an historic of a patient and send all this information to the doctors agent. With all this information, the doctor or his agent are able to decide new actions.

3.1 Agents

There are ten different agents, each one with its functions and autonomous decisions (see fig. 3). Here is a list with a description of all these agents:

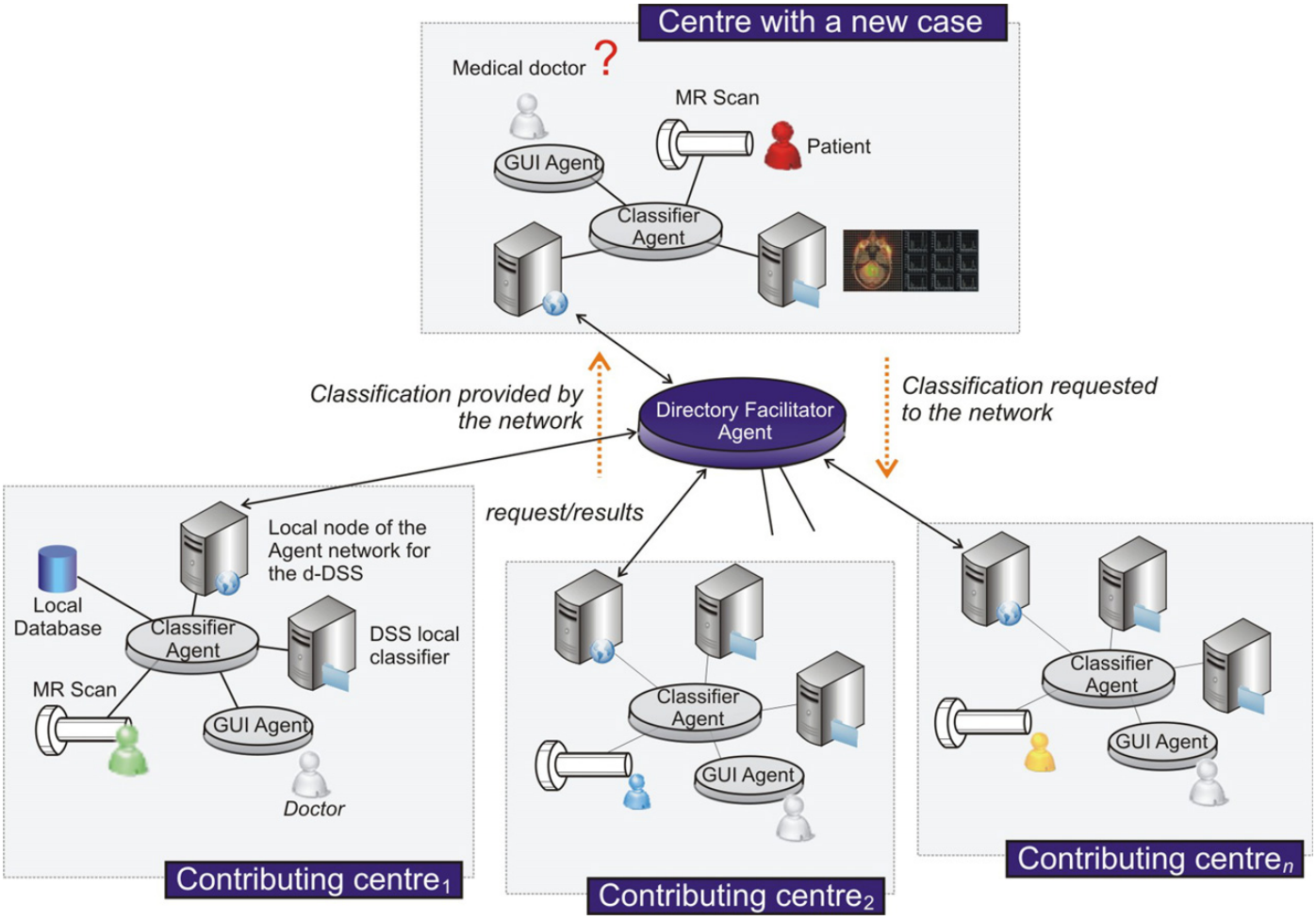

Fig. 2. Architecture of the clinical distributed-DSS for brain tumour diagnosis proposed in the HealthAgents system (from Ref. [1]).

1) *User Agent*: They have access to personal data like name, nationality, age, sex, etc. Also, they are able to get daily information like weight, timetable, walk, etc (all these enumerations are only examples of possible data they can acquire). They are also able to communicate with the *Broker Agent*.
2) *Broker Agent*: These are bridges between the medical centres and the patients. They can communicate with *Medical Centre Agents*.
3) *Medical Centre Agents*: There is usually one of this kinds of agent per medical centre. They knows all different departments (*Department Agent*) and their modifications. Also knows the general services (*Service Agents*).
4) *Department Agent*: Each department contains a set of doctors (*Doctor Agents*), specific services (*Service Agents*), a guideline (*Guideline Agent*) and a medical ontology (*Ontology Agent*).
5) *Doctor Agent*: This is the main agent in the system. It interacts with experts in order to know the possible actions and the appropiate patient.
6) *Service Agents*: These represents physical or human resources such as bedrooms, medical machines, stretcher-bearers, etc.
7) *Guideline Agent*: These are able to perform actions with the guidelines such as searching, storing, changing of clinical guidelines.
8) *Ontology Agent*: These gives access to the medical ontology of the department.
9) *Medical Record Agent*: This agent ensures the security of all records in the

databases. It is the only agent able to interact directly with the database and all his communication is secure.

3.2 Discussion

This system tries to reproduce and design a complex distributed platform. It makes necessary to use a system involving Multi-Agents systems. It is possible to solve this problem without agents, but the scalability of the project and the facility of the possible changes makes to be a good decision to use them.

4 SHARE-IT

SHARE-it (Supported Human Autonomy for Recovery and Enhancement of Cognitive and motor disabilities using Agent Technologies) is an assistive technology for people with disabilities and senior citizens. It creates a platform of multi-agent systems that delivers three main kind of services: monitoring, navigation support and cognitive support. Furthermore, this system learns the habits of the user and is able to adapt the behaviour of the different Agents to improve his comfort.

4.1 Agents

This system is composed by five different kind of Agents. In next list there is a brief description of each of these agents and its function.

1) *Patient Agent*: This can be embedded in a PDA, mobile, laptop or some device able to interact with the user. They can provide all the necessary information. Some of these useful information may be referring to collisions, paths, remainders, biometrics monitoring, etc. Other use of *Patient Agent* may be controlling the trajectory of the vehicle or basically asking for human help.
2) *Vehicle Agent*: This belongs to the vehicle hardware, therefore depending on the sensors it can detect objects in front or desired directions, monitor users biometrics, predict its localisation, move or brake the vehicle, etc. Also, it can communicate sending all desired information to other agents that may need it, or asking for navigation or configuration tasks.
3) *Caregiver Agent*: This agent must be in a device accessible by the caregivers. It can receive biometrics data from different users to detect any anomalies, or direct messages requesting for help.
4) *Environment Agent*: This agent can access to several sensors in its place. It will help for vehicle localisation, or giving instructions on how to get some place. In a more general view, it may send all accessible information to the interested Agent (controlling their grants).
5) *Home Agent*: It is placed in the user's home environment. It can create an historic with the user's activity with controlling purposes.

4.2 Discussion

This middle layer agent system allows a great integration between users, their caregivers and a variety of tools. It has been used in wheelchairs and a walker (see section 5) but a huge number of devices may use this interface.

The modularity of the project permits to integrate several kind of environments, sensors, and user interface devices. The election of multi-agents systems in this project is fundamental for the reuse of the same code. Furthermore, the capability of communication of Agents permits to implement different parts of the project in different programming languages. That is one reason that may speed up new projects based on this system.

5 I-WALKER

i-Walker is an intelligent walker that provides help to the user. It predicts the users intention and reacts according to the needed strength. It is also capable of guiding to predefined places like the kitchen, bedroom, living room, etc. Some of the services provided by i-walker are brake assistance to compensate lack of muscle force on descent and motor assistance to compensate lack of muscle force on climbs.

Furthermore, i-walker uses a Case-Based Reasoning to create an specific profile for new

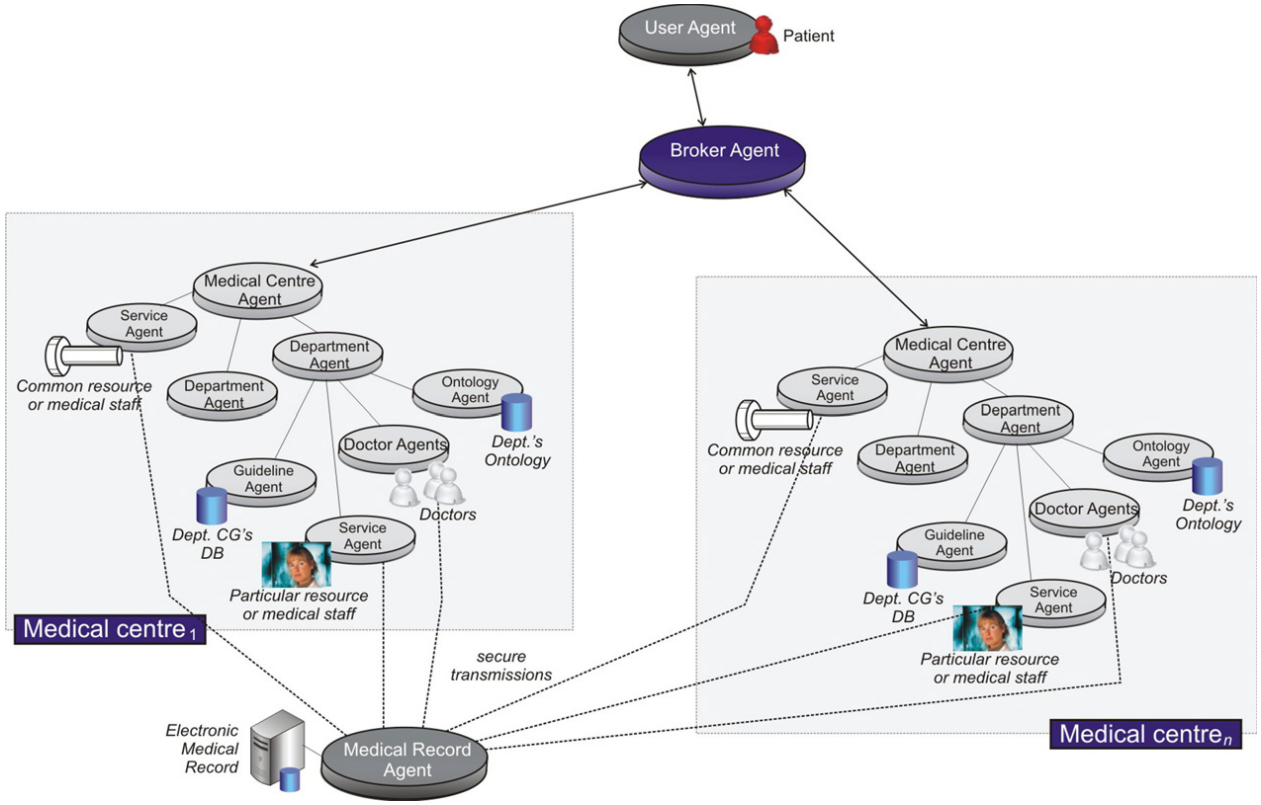

Fig. 3. - HeCaSe2 scheme architecture (from [1]).

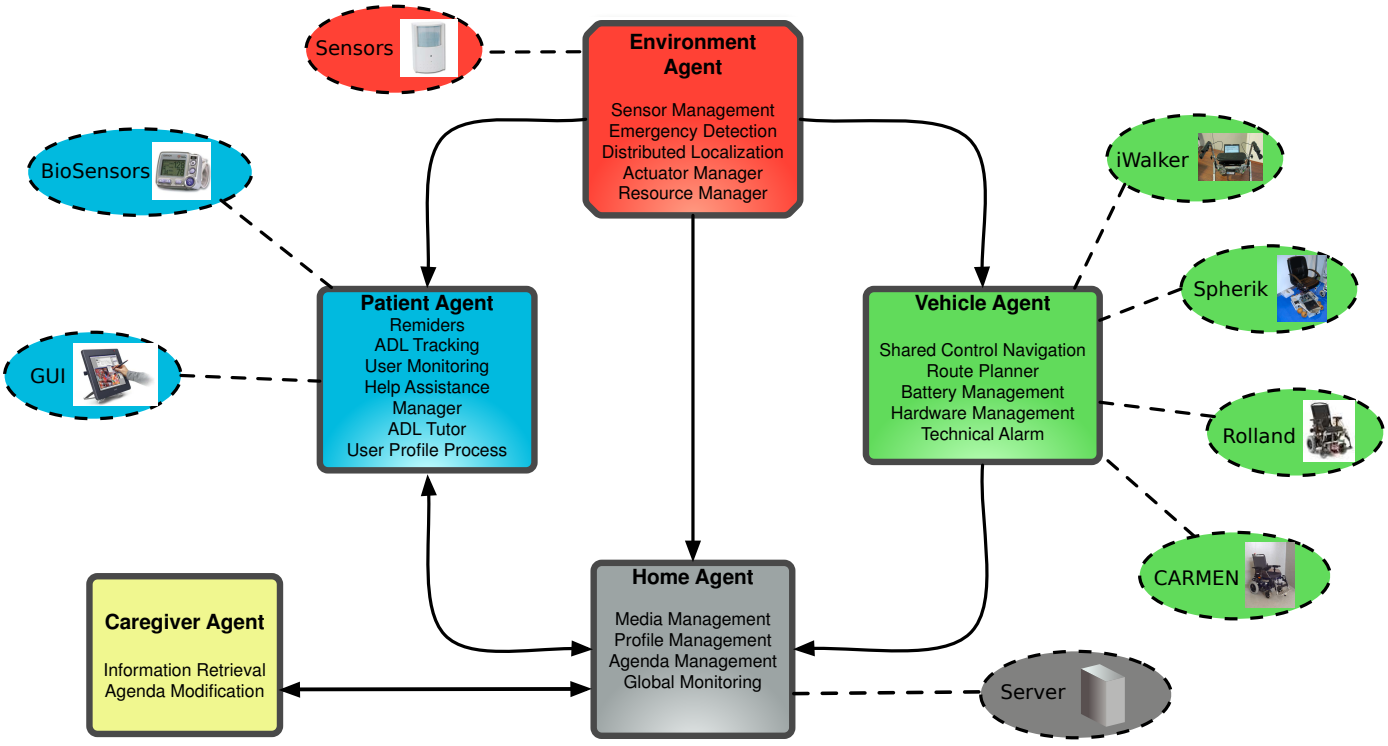

Fig. 4. SHARE-it Agent architecture

users. The medical expert can interact with the system to reach a good configuration of the walker for a specific user.

Fig. 5. Prototype of i-Walker (from [7])

5.1 Agents

This system integrates an Agent layer to improve the user experience. Concretely, it uses the SHARE-IT middle layer (see section 4).

5.2 Discussion

Since agents in this project are given by the agent layer of *SHARE-it*, this is an example of its use. In that example, the medical staff is able to adjust the parameters of the walker, depending on the patients information. At the same time the walker can give information about its usage, being able to compensate large efforts in one hand or another.

There is the possibility to improve the performance of several walkers by aggregating the information given by individual walkers and using data mining techniques to adjust general parameters.

6 K4CARE

Knowledge-Based HomeCare eServices for an Ageing Europe (K4care) is a project to integrate the communication between a variety of people involved in home care services. In these environments there is usually an elderly patient with some physical or psychological impairment. This facilitates the interaction of the system with people not trained to use new technologies. In the other side, a lot of different professionals need to coordinate and communicate efficiently. On that side, people is able to deal with a more complex interaction and device interfaces.

The system is able to learn from decisions taken by professionals in certain circumstances, and then make new recommendations in similar situations. Furthermore, some actions can be initiated by the agents to accelerate some processes

The agents part can accelerate some procedures dealing it automatically like patient's intervention plans, assignment of a professional when the patient needs an specific treatment, updating the composition of the Electronic Health Record of the patient, etc.

It also has several ontologies designed in order to model the medical knowledge and workflow. This allows the agents to take decisions based on procedures and knowledge it contains.

6.1 Agents

Thanks to the agents approach, instead of giving a general plan for the patients, the system can design specific plans for individual patients.

All the agents are based in the same concept basis (see fig. 6). For behaviour modelling, agents use *GAIA* ontology, that specifies concepts such as role, responsibility and permission. GAIA gives a layer of abstraction where the multi-agents can be seen as a computational organisation (see more information about GAIA in [9]).

For communication purposes, agents use *FIPA* ontology, that specifies different kind of messages and interaction protocols.

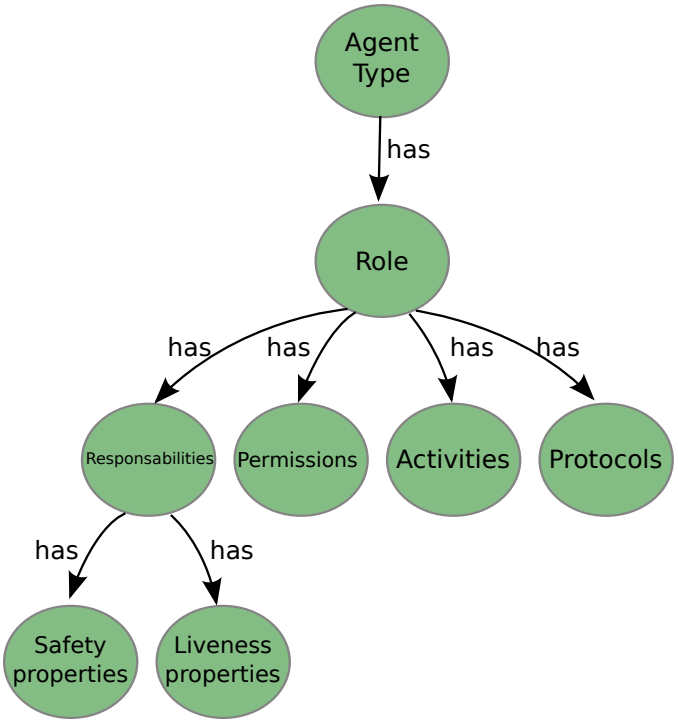

Fig. 6. GAIA agent model for k4care project

In this project there are two kind of Agents, first one are permanent agents for medical people (*Actor Agents*). The second one are dynamically created and removed when patients enters to the system or finishes his treatment (*SDA-E Agents*).

Despite of that difference there is not a variety of agents, instead of that each agent has some of the features specified in the *GAIA* structure, such as *Role, Responsibilities, Permissions, Activities, etc.*. When an agent needs information or an action not in its ontology, it can retrieve from the K4Care knowledge bases, who is able to do the required action; or send the information.

At the same time professional's agents that receive some requests can interact with human to help in the decision taking.

Finally when a designed plan is completed *SDA-E Agent* is notified about completion and if there are more tasks, it can send the next one to be performed.

6.2 Discussion

The use of ontologies to create the different roles and behaviours of Agents gives to this system a variety of uses. It seems to replicate the human behaviour in a medical environment, where the doctors, nurses and medical personal is static but increasing their knowledge. And the patients are dynamic in the sense that they starts a new case when they comes to the hospital.

The use of multi-agents seems appropriate for that approach, and it lets the system growth with the number of medical staff and patients in time.

Moreover, it will be better to do as a static the patients agents. Because there will be an improvement of the system if it learn from historic individually for each patient. This modification can be added without many changes due to its scalability.

7 PalliaSys

PalliaSys addresses the problem of helping the personnel of the Palliative Care Unit (PCU) of a big hospital. When new patients goes to these units, depending on their initial medical diagnoses they are addressed to different places. They can be assigned to beds on the PCU, another hospital unit, in socio-sanitary hospices and in some cases at home. PalliaSys is focused in the last case, where the patients can access to some services from their homes.

This system offers different functionalities or services depending on the type of user. Riaño et al. [10] divided the user services for patients, doctors, PCU manager and PADES teams.

The patients that lives at home are expected to fill some forms periodically and give them to the PCU staff. With PalliaSys, they can fill these on-line forms in a Web page, and send them to the *Communication Manager*. These patients also can modify their personal data such as his contact details, his family situation, his personal carers at home, etc. Finally, the patients can send or receive important alerts to the *Doctor Agents* indicating some issue or critical information. In the case of hospitalised patients his *Patient Monitor Agent* can monitors the information from sensors attached at its user and in case of anomaly it can send the information to the *Doctor Agent*.

The doctors can consult a report generated for each patient with aggregated information from all the auto-evaluations. They can also consult information introduced by the patients such as contact details, family situation, etc. Other functionalities like sending messages to certain patients, receiving alerts sent by patient agents, or add or delete patients from the system.

The PCU manager can access to the results of *Data Analyser Agent*. It can create useful statistics, figures, comparisons with previous years and more helpful information to facilitate the writing of an annual report. He also can retrieve some hidden information extracted with Data Mining techniques such as clustering the patients to improve their care services, or analyse individual patients to give better services.

The PADES teams performs examinations at the patient's home. For facilitate and accelerate the intervention, they can access to the patient's information in advance. After the visit, they should update the medical record with the result of the intervention.

7.1 Agents

Multia-gent system used in this project is composed of several agents. They are exposed and explained in the next list:

1) *Communication Manager*: is a middleware to communicate the multi-agent system with information technologies directly accesible by patients or doctors.
2) *Data Base Wrapper*: it controls the input and output information from PCU database. Agents needs to have grants for consulting or modifying the database.
3) *Doctor Agent*: Each doctor has assigned one of these agents. It gives all necessary information about their patients and any alert that may occur.
4) *CPU Coordinator*: It associates the different patients to their corresponding doctors, sending all the patients information to their corresponding *Doctor Agents*.
5) *Patient Agent*: Each patient has assigned one of these agents. They are continuously monitoring their patients and controls their health. They can send an alert if something goes wrong and send reminders to ensure the patient sends the periodic auto-evaluation.
6) *Data Analyser*: This agent will analyse with Machine Learning and Data Mining techniques all available information. It is intended to learn from this information and uncover interesting and useful medical knowledge.
7) *Mobile Doctor Agent*: These agents are embedded in PDAs that medical personnel will carry when visiting a patient's home. They can show information about the patient, also the results of the examination after the visit.

7.2 Discussion

We have seen an approach to improve the health care assistance of people with terminal illnesses. This system exploits the distributed problem to create a platform of multi-agents systems to communicate all the parts in the problem. Furthermore there are a lot of properties that make this problem affordable with multi-agents systems.

The communication of the different people in the PCU is huge enough to create a system based on this issue. Furthermore the organisation and cooperation of the elements improves the decisions velocity and the amount of time spend by medical staff. That is because nowadays people must spend a lot of time at phone, reading e-mails or paper information to be alert of last changes. In this system, the agents can spend this time exchanging the information and giving it to the appropriate person, all in the same PDA or PC application.

The agents also are proactive because they are able to throw alarms in situations where the patient can need help.

These reasons are enough to think about this to be a good solution, instead of performing a more complex system that fulfill all these requisites.

8 Conclusion

We have seen several health care environments where multi-agents systems seems to be a good

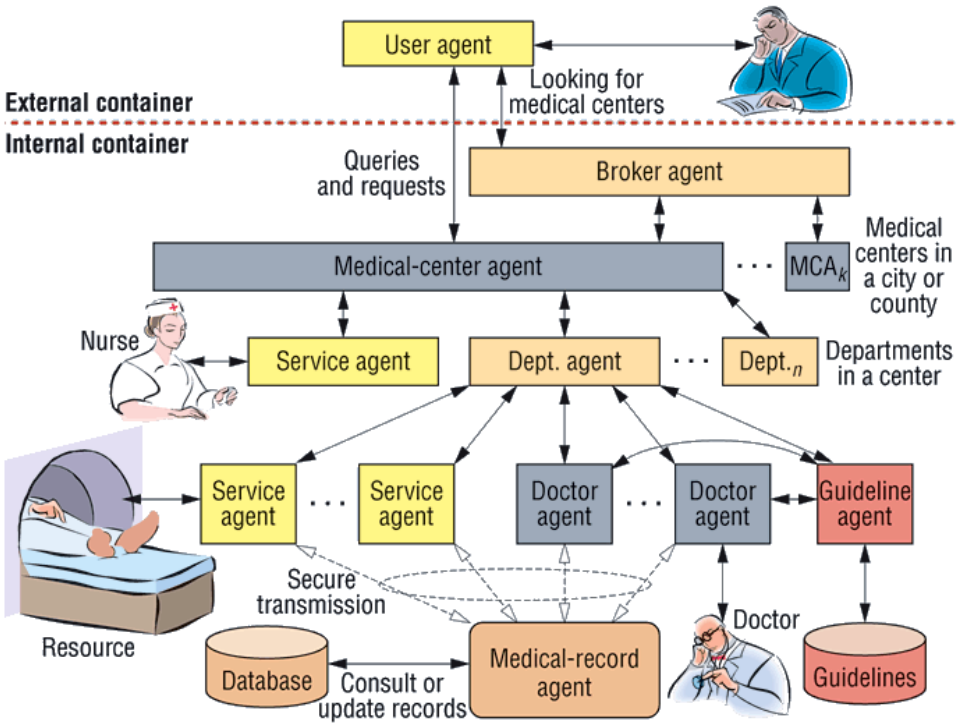

Fig. 7. - Pallyasis architecture (from project slides)

approach to solve them. The properties that these kind of projects have shown seems appropriates to decide these systems. But is it really a difference with using any other approach like servlets or daemons in each device? The answer is that it is always possible to solve all these problems without agents, but they are only an abstraction of the real programming code.

This abstraction give us a more useful vision about how the problem must be tackled, and from this point, the use of platforms like Jade or others is a personal decision that can make the system easier or faster to implement.

Then it is a personal decision to use the facilities that multi-agent architectures offers to us. For problems that have similar issues of integration, communication, decision making, etc. Or to use other kind of specification where the main problems are other kind of relations than the most human-like problems.

REFERENCES

[1] Isern, David, David Sánchez, and Antonio Moreno. "Agents applied in health care: A review." International Journal of Medical Informatics 79.3 (2010): 145-166.

[2] Cortés, U., et al. "Carrel: An agent mediated institution for the exchange of human tissues among hospitals for transplantation." (2000).

[3] Vázquez-Salceda, Javier, et al. "The organ allocation process: a natural extension of the Carrel Agent-Mediated Electronic Institution." AI Communications 16.3 (2003): 153-165.

[4] Moses, Yoram, and Moshe Tennenholtz. "Artificial social systems." Computers and Artificial Intelligence 14 (1995): 533-562.

[5] Arús, Carles, et al. "On the design of a web-based decision support system for brain tumour diagnosis using distributed agents." Proceedings of the 2006 IEEE/WIC/ACM international conference on Web Intelligence and Intelligent Agent Technology. IEEE Computer Society, 2006.

[6] Isern Alarcón, David. Agent-based management of clinical guidelines. Universitat Politècnica de Catalunya, 2009.

[7] Annicchiarico, R., et al. "The i-Walker: an intelligent pedestrian mobility aid." Proceedings of the 2005 IEEE International Conference on Robotics and Automation. 2008.

[8] Cortés, Ulises, et al. "AI Based Fall Management Services–The Role of the i-Walker in I-DONTFALL." Advances in Artificial Intelligence. Springer Berlin Heidelberg, 2013. 395-406.

[9] Zambonelli, Franco, Nicholas R. Jennings, and Michael Wooldridge. "Developing multiagent systems: The Gaia methodology." ACM Transactions on Software Engineering and Methodology (TOSEM) 12.3 (2003): 317-370.

[10] Riano, David, Antonio Moreno, and Aıda Valls. "PalliaSys: Agent-Based Palliative Care." IEEE 4th Conf. on

Intelligent Systems Design and Applications (ISDA'04). 2004.