Distributed Data Management
Supporting Healthcare Workflow from Patients’ Point of View

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Patient’s mobility throughout his lifetime leaves a trial of information scattered in laboratories, clinical institutes, primary care units, and other hospitals. Hence, the medical history of a patient is valuable when subjected to special healthcare units or undergoes home-care/personal-care in elderly stage cases. Despite the rhetoric about patient-centred care, few attempts were made to measure and improve in this arena. In this thesis, we will describe and implement a high-level view of a Patient Centric information management, deploying at a preliminary stage, the use of Agent Technologies and Grid Computing. Thus, developing and proposing an infrastructure that allows us to monitor and survey the patient, from the doctor’s point of view, and investigate a Persona, from the patients’ side, that functions and collaborates among different medical information structures. The Persona will attempt to interconnect all the major agents (human and software), and realize a distributed grid info-structure that directly affect the patient, therefore, revealing an adequate and cost-effective solution for most critical information needs.

The results comprehended in the literature survey, consolidating Healthcare Information Management with emerged intelligent Multi-Agent System Technologies (MAS) and Grid Computing; intends to provide a solid basis for further advancements and assessments in this field, by bridging and proposing a framework between the home-care sector and the flexible agent architecture throughout the healthcare domain.

**Keywords**— Body Area Network (BAN), Grid Computing, Home-care System, Medical Information Systems, Multi-Agent Systems (MAS), Persona
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INTRODUCTION

1.1 THESIS OVER VIEW

The increase in the life span of many elderly people means that there is more demand for support in their normal life. It is a fact that the general improvement in living conditions has increased the number of elderly persons, over 60 years old [53]. It is increasingly important to deploy technology in order to assist humans at home because of the forthcoming aging problem in societies. In addition, chronic problems (which contribute to most deaths and illnesses require continuous, long-term monitoring, rather than episodic assessments [54]. Continuous monitoring can also benefit rehabilitation patients or those recently released from the hospital. Detecting any disease symptoms as heart attacks for example would save a patient’s life. That is why an essential factor is to recognize any signs or symptoms and seek prompt medical attention.

Moreover, medical workers at nursing homes spend much time on communication to get the right information to the right person at the right time. This communication is a prerequisite for proper patient care [30]. Delays cause stress, discomfort, and dissatisfaction among caretakers and patients as well as possible detrimental health consequences for patients. Identifying the actual problems nurses face in everyday work, determines which could be solved within our research’s scope, and identifies which would bring the most gain. The patient charts contain the most important information, but they are only accessible from the nurses’ office computers. When nurses need additional informal information, they must be able to contact the person who previously cared for the patient. Systematic observation and empirical research supports the idea that major problems are summarized as:

i. Lack of communication,

ii. Information dissemination,

iii. Access to patient charts and old medical history, and

iv. Organizational issues.

As patients get into advance stages of age or illness, their medical/clinical data history contributes heavily to the decisions that doctors base their own diagnostics on. Thus, if doctors were missing some medical reports, which the
patient thought of insignificance to disclose of, the results would get higher towards risks and threats for the patient’s healthcare [1]. This also applies for old people who are in special care units or home-care, hence, a persistent need arises for efficiency around the clock, monitoring and supervising their status and healthcare situation.

Several technologies, throughout healthcare organizations, were introduced and adopted in the past couple of years, in order to provide a better outlook for the patient’s welfare; most of these technologies were hospital, medical, clinical, and laboratorial centric. The volume of distributed medical information routinely collected within numerous healthcare enterprises is extending and prohibited from being shared [2]. Several major factors effect this prohibition, cause of, patient’s discreet information of bad medical/surgical decisions, or even most of the time, miscommunication throughout the hospital’s departments that leads to medical errors [3]. These decisions were built on personal experiences or reference books, resulting in unexpected outcomes and sometimes not foreseeing deadly ends. This miscommunication or discontinuation with other institutions or laboratories would have helped in avoiding similar disastrous situations [4].

Prototyping this dilemma consensus was, that it should support easier communication among the personnel and also function as a documentation tool for informal notes from the Patient's point of view, thus, being mobile and be accessible from anywhere.

In this thesis, managing to leverage patient centric information would be our start-up point and case of study, since little concern has been done towards this approach. Data retrieval and its integration is one of the major problems that face either doctors or healthcare organizations, especially relevant, when patient’s information is produced in heterogeneous environments [5]. Furthermore, instead of investigating possible applications for a specific technical platform, we start from a more general view of agent technology when looking into everyday objects and activities to learn about possible applications.

Several technologies and approaches will be adopted in creating a Persona\(^1\), which helps in coordinating data from different information sources. This data would be in the form of Patient centric data treatment management, thus, establishing an interface for high quality treatment, continuous data flow management in the form of a multi-agent system that works on autonomous capabilities, and coordinating to achieve a Patient focused Agent. All these

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\(^1\) Is a Multi-Agent system that coordinates with other Agents to maintain a better knowledge management of the Patient’s historical and current medical data.
segments interconnect using several Grid computing services, in order to maintain an enhanced and advanced processing and distributed computing procedure [2, 10].

1.2 AIMS AND OBJECTIVES

A preliminary systematic review was conducted by adopting Barbara Kitchenham’s guidelines [62], for interpreting and evaluating the most up-to-date research relevant to multi-agent systems and grid computing architectures.

Several architectures have been proposed throughout the home-care domain and intelligent systems; but still, each architecture provided partial components for home-care monitoring. Implementing these components, would result in falsely accumulated integration. As a result, numerous points emerge:

First, different architectures do not perform well when the complexity and size of the environment increases [5]. However, recent researches throughout the multi-agent community, focused towards the development of more efficient agents, which conducts the coordination approaches based on various relations, and communications. The proposed architectures in [11, 12, 13, 29] considered a trade-off between efficiency and effectiveness of agent or any other architecture. On the other hand, several studies have been conducted throughout [30, 33, 42, 43] in utilizing the connectivity and coordination concepts between patient monitoring devices and several computing architectures. Consequently, none of these architectures provided any new methods for merging these technologies, and creating specific agent architecture for supporting and coordinating the Patients’ needs. Thus, our proposed solution would assist in creating an overall different prospective to Patient-Agent environment.

Throughout the thesis, we will evaluate and examine the proposed architecture by revising several grounded theorems, and comparing them to conclude with the utmost and preferable architecture. Throughout the multi-agent research community, few research studies have been conducted in the distributed data management, which supports healthcare workflow from the patients’ point of view. Where, most of the agent technology research was built on advancing specific architectures/components separately. Trying to implement a multi-agent
system associated with the grid computing architecture would utilize a better understanding of the current technology.

Second, several challenges in measuring the quality of home-care materializes, lacking the practical guidelines for improving and maintaining efficient results. Few proposals have been made for such an evaluation [3,4,5]. However, a sequential procedure was not addressed for evaluating the suitability of the proposed methodologies. Thus, a qualitative approach adapting the grounded theory process would be conducted, verifying and guaranteeing the optimal evaluation process for a better approach to home-care.

There is very little research towards evaluating the quality of both the tools and the outputs of the Agent technology in health-care. Several literature studies were addressed, but few articles have spoken about how to provide a better tool for conveying an efficient and smoother homecare process. Thus, this review will assist in building a structure for advancing the knowledge from this prospective and building a grounded theory for further analysis.

### 1.3 RESEARCH QUESTIONS

The Multi-Agent systems’ mission, throughout healthcare environment, is to integrate thousands and millions of instances and tasks; thus, smoothing the way for medical stuff, and boosting their knowledgebase and reasoning concepts by harvesting historical and live data. Several sequential procedures would be conducted, in order to demonstrate a better prospective of this research area, and address a better understanding of the prompted dilemmas.

The main issues triggered throughout our research are:

- What are the effective tools that might help in formulating a better understanding of the Patient’s medical history, in the context of Agent Technology?
- What are the various agent technology mechanisms adopted, which might help in lowering the lack of standardization of concepts?
- To which degree can the automation of the multi-agent systems process be coordinated?
- What are the tradeoffs and barriers of grid computing services, agents’ security, and information agent collaboration?
• What are the main criteria needed for evaluating the suitability of agent technology, and improving the healthcare decisions, accuracy, and efficiency of results?
• What are the future expansions or visions that are going to be adopted in agent technologies throughout homecare environments?

1.4 RESEARCH METHODOLOGY

A qualitative approach would be adopted conducting a sequential procedure, hence, trying to derive knowledge based on pragmatic grounds, explanatory prospective, and action research. Our research will be built on various readings, experiments, and data collection processes, to eliminate any replication and keep-up with the data comparison procedure; thus, overcoming any redundancy and attacking the proposed challenges and barriers from a better prospective. Moreover, concluding the research with an assessment that would outline and highlight agent systems and grid computing in Home-care environments.

Our study for this specific topic is purely based on thorough investigation and assessment, hence, trying to develop and assist in building a solid basis for furthermore additional research in this area.

During our study, we will verify, validate, compare, and check against any valid criticism the proposed architectures and results. Thus, highlighting their advantages and disadvantages, and proposing a general analysis, this constructs a refined basis for future work.

1.5 BACKGROUND AND MOTIVATION

Intelligent Agents are being developed and researched in nearly every discipline. Since the conception of Artificial Intelligence (AI), a variety of
applications have used AI techniques, but only recently with the advent of data mining and other techniques has there been a surge in the community of developers and researches interested in advancing Agents technology. There is an endless horizon of possibilities for Intelligent Agents, where it is visible in nearly everything.

Already Intelligent Agents are making decisions for us. Although this technology is just beginning to emerge in our every-day lives in limited applications and environments, but still these agents are communicating with each other, using different terminologies and ontology structures.

In today’s IT applications, data knowledge systems, and all other related resources are inherently heterogeneous and complex, making decentralized solutions a necessity in order to assure flexibility and scalability [23]. Toward this aim, the introduction of new construction tools, demonstrate features such as autonomy, reasoning, knowledge encapsulation, and cooperation [6]. A powerful solution, according to this consideration, is agent-based systems, which represent an alternative way of analyzing, designing, and implementing complex software systems [8].

**Multi-Agent Systems**

An agent is a computer system that is capable of flexible autonomous action in dynamic, unpredictable domains. Multi-Agent systems interact in dynamic and heterogeneous environments, span organisational boundaries, and operate effectively within rapidly changing circumstances and with dramatically increasing quantities of available information [6].

Indeed, several observers feel that certain aspects of agents are being dangerously over-hyped, and that unless this stops soon, agents will suffer a similar backlash to that experienced by the Artificial Intelligence (AI) community in the 1980s [36].

On the other hand, the agent-based view offers a powerful repertoire of tools, techniques, and metaphors that have the potential to considerably improve the way in which people conceptualise, and implement many types of complex systems.

Agents equip software designers and developers with a way of structuring an application around autonomous, communicative components, and lead to the
construction of software tools and infrastructures [7]. These Agents offer a new and often more appropriate route to the development of complex computational systems, especially in open and dynamic environments. Agents learn from and about other agents in the environment, hence, eliciting and acting upon user preferences, finding ways to negotiate and cooperate with other agents, and developing appropriate means of forming and managing coalitions [8].

Although Multi-Agent Systems possess several strengths for managing data in a medical healthcare systems, but still, several weaknesses emerge in such a complex and heterogeneous environment. The increasing number of tasks creates an urge for autonomous agents, thus, becoming increasingly important for these agents to be able to discern which agents can be trusted and which cannot. This is especially true when interacting agents may have divergent goals.

**Grid Computing and Distributed Processing**

Grid computing is an emerging infrastructure, regarded as a software technology, fully using the spare computing resources. Grid Computing is an active research area, providing a flexible infrastructure for complex and dynamic resource sharing, largely focusing on issues of performance, scalability and standardisation [9].

The Grid architecture adopts a service-oriented perspective, in which distinct stakeholders represented as software agents; provide services to one another, under various service level agreements, in various forms of marketplace.

Multi-agent systems community is offering various new opportunities for Grid computing, thus, striving to enhance the parallel computing or distributed
processing structure, by tackling several dilemmas, which extent to cope with semantically enhanced service descriptions and specification of resources, autonomy, collaboration, self-organisation, intelligence, and adaptability.

The implementation of Grid computing in several major projects conducted by medical institutions, solve their huge computational processing models. However, the philosophy of grid computing in healthcare case plays an important role in hospital/clinical information system distributed monitoring, control, services, and distributed parallel computing; also by providing important pools of new data in the search for patient cures and treatments. Due to the highly complex broad spectrum of multidimensional heterogeneous environments, throughout hospitals and medical centres, task allocation, resource management, and load balancing is some of a challenge [10].

![Fig. 1. Networking using Grid Computing](image)

The strength of Grid computing is built-up on its flexible structure, where the overall computing infrastructure consists of three conceptual layers [32, 33].

1. Data/Computation: this layer deals with the way that computational resources are allocated, scheduled, and executed and the way in which data is shipped between the various processing resources. It is characterised as being able to deal with large volumes of data, providing fast networks and presenting diverse resources as a single meta-computer. The data/computation layer builds on the physical Grid fabric i.e. the underlying network and computer infrastructure.

2. Information: this layer deals with the way that information is represented, stored, accessed, shared and maintained; thus, data is equipped with meaning.

3. Knowledge: this layer is concerned with the way that knowledge is acquired, used, retrieved, published, and maintained. In this layer, knowledge is considered as information applied to achieve a goal, solve a problem or perform a decision.
The real and specific problem that underlies the Grid concept is coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations [34]. The sharing that we are concerned with is not primarily file exchange but rather direct access to computers, software, data, and other resources, as is required by a range of collaborative problem-solving and resource brokering strategies emerging in industry, science, and engineering.

Throughout this thesis, we will propose a framework based on the combination of the two technologies, which depends on grid computing for hardware support and agent technology for software support; integrating seamlessly the dispersed computing resources to implement, high-performance information management in home-care environments.

### 1.6 OWN CONTRIBUTION

This research expresses a pragmatic case study aiming to investigate the modelling and design constrains, as well as the analysis techniques throughout a high-level view. Moreover, proposing an architectural structure and architectural description, by constructing a patients’ centric information environment, and emphasising the home-care/personal-care process. This procedure emerges towards supporting the medical personnel, and providing an efficient information structure that would be a vital and valuable asset for the provision of 24-hour health services.

### 1.7 FURTHER GUIDELINES

In the next part of this thesis, we will scrutinize Homecare environments, studying the essential engineering processes needed to smooth this process; furthermore, evaluating the various frameworks that might benefit this environment and advance it. In Section 3, we will trigger the security issues that are required in the multi-agent system environments, throughout their coordination and communication processes. Summing up, in section 4 and 5, with a general discussion, conclusion, and future work for this thesis.
ARCHITECTURE

2.1 HIGH-LEVEL VIEW OF HOME-CARE SYSTEM

Health monitoring at homes can be quite effective as people spend most of their lifetime at home. People take rest at home when they are sick, as they feel more comfortable and are close to their friends and relatives. Our ongoing research is focused on monitoring patients at home, for early detection of symptoms.

Nowadays in healthcare systems, a great deal of efforts and resources are spent in producing standalone systems, to solve specific problems. In reality, these problems are the sub-problems in a larger distributed system. In order to achieve this goal, first, a patient framework, which provides assistance for cooperation and communication between hospital and medical schemes, is essential. In addition, the demand for distributed processing stems from the fact that the centralized decision-making (Persona) cannot guarantee the optimal data collection of historical medical records.

2.2 MEDICAL INSTITUTES PROVISIONS

The provision of healthcare typically involves individuals, located in different institutions. Thus, in order to achieve an efficient and effective care, their decisions and actions need to be coordinated. To facilitate the smoothness of decision-making and coordination process, software agents become an integral part throughout their daily practice.

The grid concept helps in addressing some of the concerns among the distribution of Medical Information. As we know, the healthcare medical information data is large in size and lack structure, therefore, searching and
extracting knowledge is difficult. Thus, using the Grid services in creating a clustered and data storage structure enables a seamless integration and sophisticated analysis. On the other hand, all the formulated discoveries within laboratories can be transparent to the medical teams, and revised. Medical teams would have a wider prospective and experience, hence staying up-to-date and not referring to old medical books.

The Grid’s services will act as a major link between several medical centres and hospitals, thus helping in creating a lower threshold of deadly mistakes; Moreover, providing a transparent environment that would be easier to learn from either on the medical, theoretical, or practical level.

Although, Grid computing, as standalone structure, offers a compelling vision; on the other hand, it raises various barriers, which sums up to:

- **Technology barriers**: Although Grid computing has the capability to join and map computational resources; but still, agent technologies capabilities are in need, to smooth the huge ocean of medical data and refine it by supporting the patient from his point of view.

- **Business Barriers**: If the standalone Grid Computing architecture was adopted, the medical and healthcare system would be intensely disrupted; since all mainstays of medical information structure would require significant adjustments.

- **Administrative Barriers**: The Grid Computing architecture will create a cumbersome process for information retrieval and will not preserve a secure administrative and patient medical data history.

Our approach touches on opportunities to impact care in the following ways:

- Preventative monitoring in the home for early detection of onset medical conditions.

- Proactive human-computer interfaces that use context-aware sensing, hence, motivating health-conscious behaviour change over long periods, including medication compliance.

- Data collection from sensors in the home (e.g. bio-monitors), which aid medical professionals in diagnosis and treatment.
• Providing a high abstraction level of care management strategies, by linking all relevant agencies into a single framework of accountability.

• Developing cooperative structures within the community structures, to change service provision and care policies through the use of automated agents involvement in planning, scheduling, organizing (both formal and informal) care and even directing care service programs.

• Devolving care management and responsibility to those providing the care, by providing shared supervision and teamwork, thus, developing a much more responsive and client centred environment that adapts rapidly to changing needs.

Some of these objectives have already been investigated in the medical domain using Multi-Agent Systems architectures. For example, the GUARDIAN system [Hayes-Roth & Larsson, 1996], considered patient monitoring in a Surgical Intensive Care Unit. Support is provided for collaboration among specialists. Each one is an expert in a specific domain, but fully committed to sharing information and knowledge among each other, and the nurses that continuously monitor the patient in the physicians’ care.

Another example is [Della Mea, 2001], who describes a more general agent-based telemedicine framework, which assists specialists in diagnosing difficult cases through information sharing, cooperation, and negotiation. In this case, each specialist has their own Telemedicine-Oriented Medical ASsistant (TOMAS) agent, which behaves as a medical assistant, and has two generic functions: an agenda for managing appointments, and methods for access to patient records. Telemedicine interact by remotely exchanging patients’ data, cooperative annotation of cases, and negotiation of appointments. These approaches have been greatly assisting to standardise patient’s records and medical information. [Dick et al, 1997; Department of Health, 2001].
As a result, our implementation of a Multi-Agent/Grid computing architecture (Persona), aims to take these mentioned architectures from the purely medical domain, and integrate them into the general community care environment, where the linkages are less formal and effective cooperation and negotiation is essential if appropriate care is to be delivered. The proposed Persona will be incorporated for home-care services, supporting both medical and administrative personnel. The proposed Persona consists of several agents, which percept about the environmental states, and act correspondingly. The ultimate goals are to effectively manage and interpret the large volume of medical data collected during the patient sessions with the system, to provide a mechanism for evaluation of the educational process, and to report to the practitioners. These aims are addressed by designing and applying a coordination strategy among a team of agents with distinct roles, each one with a particular expertise in terms of a reasoning scheme, and a knowledge sharing mechanism combined with message exchange; hence, coordinating and filtering data to ensure that appropriate and correct information is distributed to all concerned.
REQUIRED ENGINEERING

3.1 FEATURES AND IMPLEMENTATION

People are increasingly cooperating to share electronic information and techniques throughout various industries [48]. In healthcare applications, data (a single patient’s healthcare history), workflow (procedures carried out on that patient), and logs (a recording of meaningful procedural events) are often distributed among several heterogeneous and autonomous information systems. Different healthcare actors—including general practitioners, hospitals, and hospital departments—administer these information systems, forming disconnected islands of information. Communication and coordination between organizations and among medical team members permits information sharing and distributed decision making. Agent-based techniques often support this communication; modelling application components as somewhat autonomous agents easily reflects healthcare institutions’ decentralized networks. The agent approach also naturally extends the notion of encapsulation in systems owned and developed by different authorities.

Even with agent technologies, healthcare institutions’ distributed nature sometimes hinders patient treatment because a patient’s healthcare history and therapy documents are spread across independent institutions. To provide better, user-centred healthcare services, providers must view patient treatment processes and data as a whole. Although agent-based cooperation techniques and standardized electronic healthcare-record exchange techniques support healthcare providers’ semantic interoperability, they still must reunify the pieces of different therapies executed at different places. Currently, there are no widely accepted unification methods for patient healthcare records. It is common for doctors to depend on the patients themselves in order to include data from previous treatments and tests.

Deploying the Persona lets medical staff trace how actors reached particular results by identifying the individual and aggregated services that produced a particular output. We need such an integrated view of treatment process execution in homecare multi-agent systems to

✓ Analyze distributed healthcare services’ performance.
Audit systems to assess whether, for a given patient, providers made proper decisions and followed proper procedures.

To achieve this integrated view, we must trace the origins of decisions, process the information available at each step, and acknowledge where that information came from.

### 3.1.1 Persona-Scenario Home-Care Analysis

One of the promising and important concepts to identify the user is a Persona, proposed by Cooper [46]. Reflecting that a Persona is a mask used in ancient Greek play. It is defined as a social role of person in a specific context [45], which is an appropriate model in the context of requirements engineering. Although some key concepts to apply a Persona in software design are proposed in [45, 46], any specific methodology based on the Persona is not provided.

In this thesis, a Persona (MAS) is presented aiming to add value to the home-care services. A Persona will act as an agent or multi-agent handler, from the patient’s side, providing a smarter, more flexible, and adaptable approach for Grid and Clustering technologies [13]. Its goal is to utilize information and communication technologies, to improve performance of nursing homes/personal-care, to reduce overload of caregivers, and to increase care quality of patients.

![Fig.3. High-Level view of Patient Information Connectivity](image)

The Persona will act as a problem solving ontology (task) agent layer, defining the constructs related to problem solving agents mainly, pre-processing, decomposition, control, decision, and post processing. This layer systematizes and organizes practitioners, stakeholders, and patients; hence, assisting in modelling
practitioner’s problem solving approach and tasks in domains that are complex and data intensive.

In developing the Persona, certainly, the adaptation of more and more sophisticated technologies provides a very high quality of services. With computing resources shared globally and managed end to end, the data centre can be anywhere, in the hospital, clinical centres, home-care units, or even shared between the two. Any authorized user can reach this pool of resources from anywhere, on demand. On demand computing is the foundation of a structure that is far more efficient, far less complex, and extraordinary flexible [19].

In general, multi-agent systems are restricted to small numbers of agents, and often agents undertake similar tasks [8]. To support Grid computing, our Persona can offer different roles, by being organised into dynamic groups, and able to migrate between groups to support load balancing. In order to effectively manage and interpret the large volume of collected medical data, the Persona will act as an information gateway between the patient and the medical information structure [26]. The Persona will also interact as a local autonomous decision-making under minimal central authority, thus, providing a highly automatic mechanism for distributed autonomous task processing.

![Fig.4. High-Level view of the interconnected Agents](image)

From a functional point of view, the Persona provides a GUI through which users could make queries and receive answers. The Persona includes the Patients' medical information, thus, interacting and connecting with different medical
agents spread across healthcare centres, via various communication means, such as computer or mobile telephony, wireless technology, or worldwide web. Independently of the communication means used, all the data flowing to and from the Persona are stored in a Computerized Patient Record, specifically designed to meet the functional requirements of the Home-Care System [13].

The Persona also connects to various Department agents, hence assisting in the data clustering process and ease of search. These Department agents interconnect with Doctors’ agents to provide clinical information from previous visits and historical records. A specialized security agent would ensure the medical data’s privacy and confidentiality. A broker and coordinator agent provides an interface between the agents’ internal connectivity process, and assist in the negotiation, coordination, and corporation. The coordinator agent coordinates the ontology construction process by configuring, deploying, and finalizing the appropriate agents to explore the healthcare domain.

This coordination and partitioning approach, provides a seamless integration of distributed computing devices, and centralizes the ontology construction; hence decomposing the complicated operation and significantly reducing the overall workload in relation to the Agents’ negotiation.

The Persona may potentially be called upon to interact with any number of random agents in the system, to complete a single higher-level data request. The Persona has the ability to remember agents they have previously dealt with, and thus will be able to recognize agents that have cooperated or cheated it previously. The Persona will then be able to make future decisions on whether to cooperate with a given agent accordingly. As with Armstrong and Durfee [37], the behaviour of agents is governed by a set of parameters. For example, parameter “i” specifies the base probability for an agent cooperating with an agent it has never encountered. Hence, in addition to exchanging commodity, data agents can also share information about the trustworthiness or reputation of other agents. Agents can use this reputation information in conjunction with firsthand information (history) to form a primitive world model when dealing with other agents. In addition to using the stored history, the parameter “u” dictates how much weight is given to stored reputation information when calculating the probability of cooperating with a particular agent. Thus, an agent can learn about the reputation of another agent before having to deal with it for the first time. The Persona, will exchange reputation information immediately after exchanging data during a given interaction.
The actual delivery of routine care has to be fully monitored against the individual care plan. The objective is to provide the assistance necessary to make up for the disabilities of the individual, such as help with eating, washing, assistance with bodily functions and getting in and out of bed. The main problem with existing systems is the lack of responsiveness of the services providing it. In high quality residential setting, this kind of care is usually delivered whenever the client requires it. In a community setting, this care is usually provided on a very rigid schedule unless informal carers are willing to take on a very large burden. The proposed Persona will enhance the responsiveness of the service by:

- Allowing clients to request care directly from care providers and coordinators.
- Providing clients with better information about care schedules, such as when a care provider will arrive, and delays or changes to schedules at the earliest possible opportunity.
- Monitoring very disabled people, such as people with dementia\(^2\), in order to fit care interventions more closely to their patterns of daily activities.

In addition, in case of emergency interventions, the Persona will raise an alert when either some set of environmental conditions are considered out of range as defined within the individual care plan, or there has been some direct request for help, such as pressing a ‘panic button’. Thus, additional information can be collected, to indentify the problem by analysing the attached bio-medical sensors, and transfer it to the Care Plan administrator, which will decide upon these readings. The Care coordinator checks what the patient needs, which may simply be resolved with a telephone call, or more likely needs some more positive intervention that requires scheduling. Therefore, the appropriate Care provider can ensure that the patient is safe and secure.

Consequently, this lower level process assists in smoothing several higher level problem structures and trust issues, hence assisting in giving authorized medical personnel, access to patients’ records or up-to-date status/condition; moreover assisting nurses and doctors in lowering the overall error threshold, and reminding them which data to take into account before moving to the next step [9].

\(^2\) Loss of intellectual faculties, such as memory, concentration, and judgment, resulting from an organic disease or a disorder of the brain.
3.1.2 PERSONA’S-PATIENT CONNECTIVITY

Latest statistics have showed that Heart diseases are still the United States and United Kingdom's biggest killer. As a result, several conducted researches throughout the Bioengineering domain, embraced various equipments that can be easily integrated into the human body. Such a device is the mechanical pump known as the “Heart Pump”. It helps in maintaining and activating the blood circulation throughout the human body. In addition, another research conducted in Bioengineering, revealed a Bluetooth-enabled Electrocardiogram (ECG) Monitoring System [11], which would connect the heart pump using Bluetooth technology sending electrical signal to a computer.

These advancements in bioengineering and nanotechnology assist our Persona in reading/recording the daily health status, such as blood pressure, body temperature, heart-throb, and other vital signs. Thus, alerting the practitioners or the nurses in the home-care environment and creating a learning scheme for other Personas and medical people of what are the causes and effects that are implying these failures.

On the other hand, the Persona can act as a data-mining tool, scanning and collecting the historical data diagrams and clinical records of this patient, before undergoing into surgical or normal check up routines; thus, disclosing accurate historical trials of the patient, and equipping the doctor with precise data for any further analysis or diagnostics.

One of the most important and simple medical controller in a home-care environment is the insulin pump, which administers insulin in the treatment of diabetes. The device consists of several controls and processing modules that measure the insulin percentage in the human body; hence, when detecting any decrease in the overall percentage, it would pump the recommended or prescribed insulin quantity into the body.
Fig. 5. Mobile Persona connecting to Insulin Pump

Attaching the Persona to the insulin pump assists in determining and notifying any device failure, overdosed medical prescription, or any other causes that might affect the patient’s health. One of the major Persona’s challenges is its connectivity feature with several devices, components, and services that helps in highlighting any weak vitals and points out the cause of this act. This challenging combination or architecture, would perceive a limited human error threshold, thus, narrowing down the causes of the mistake to either a human agent (doctor or nurse), or a software agent. Therefore creating a better benchmark for pinpointing out what caused this disease/death and how to avoid it with other similar cases.

Fig. 6. Insulin Pump benchmarks and consumption scales for a Diabetic Patient

Moreover, an additional challenge for the Persona would characterise in preventing the patients’ medical information from any vulnerability and security flaws, the Persona would verify several security certificates with the specified doctor as pre-defined by the patient. This procedure maintains a secure data-mining and data-synchronizing process, and creates a flow of information that is anonymous for unauthorized personnel. The general anonymous browsing assists in statistics and furthermore deep research figures.
Monitoring is problematic in the community context, since direct supervision of care staff is almost impossible. The Persona facilitates effective monitoring in two ways:

- Care providers log their interventions directly into the system at each visit. These can then be compared directly with the contents of the Individual Care Plan. Any deviations can then be investigated hence, either the Individual Care Plan can be updated or other appropriate actions can be undertaken.

- Complaints procedures can be based on direct communication to the Care Coordinator; thus, improving monitoring and responsiveness. The logs can be used to compare actual interventions with those specified in the Individual Care Plan, which is then updated to take into account the new information.

During normal home-care situations, the Persona will collaborate with several Personas and Multi-Agent systems spreading across the Grid services, to extract and monitor these mechanisms [20]. In order to effectively manage and automatically interpret the large volume of medical data collected during the patient’s sessions with the system. Hence, highlighting cases where urgent attention is potentially required [12]. The key goal of the Persona is to enrich and simplify the expansion of such an integrated collaborative environment, providing customized and secure access to all necessary applications, appropriate data, and resources available across the network.

### 3.2 THE PERSONA’S DESIGN

The proposed Persona is designed according to a coordination strategy based on task decomposition and distribution [21]. Task decomposition was based on the layout of the information resources and physical actors, as well as the expertise of available agents, while task distribution was based on an organizational structure, where agents have fixed responsibilities for particular tasks. Thus, each agent was delegated a specific and simple task to accomplish, avoiding the assignment of extreme computational burdens. Accordingly, emphasis was given in a task-oriented coordination among the agents of the MAS, where agents work in parallel, contributing to a common goal, and cooperate
sharing their experience [22]. Delegating simple tasks to each agent and coordinating the agent activities results in a MAS that can perform advanced functionality.

Throughout the design of the Persona, we can notice that a wide range of activities can be supported effectively. Thus, traditional database design techniques have difficulties with this richness, as each scenario contains actors with the same roles performing differently depending on their beliefs and actions within that scenario. Agents approach is specifically intended to address these issues and to smooth the data harvesting process.

![Fig. 7. Task & Problem decomposition for achieving system maturity.](image)

Historically, the success of most technologies has depended on the availability of a small number of commonly agreed-upon standards. The prototyping method used to design our system starts from studying the user (patient) requirements. Analyzing existing systems and revising their functionality and coordination relative to other factors; decomposing the whole system into patient’s records, care plan suggestions, health status, and administration/clinical systems. In addition, the large-scale interconnected and inherently distributed healthcare system information raises higher requirements in communication infrastructure, control technology, operation strategy, and the capability to prevent catastrophic failure regarding patients’ operations decision [20].


3.2.1 PERSONA’S VARIOUS FRAMEWORKS

For designing our proposed Persona, several studies were conducted to choose the availability, merits, and demerits of Multi-agent toolkits, which include FIPA, Zeus [38], and JADE.

The analysis was based on the following requirements,

i. Availability of the source code,

ii. possibility of standard agent functions and features extension,

iii. possibility of external function call (objects, DLLs, etc…),

iv. possibility of configuration recovering after system faults,

v. availability of name server storing information about registered agents,

vi. availability of message exchange mechanisms,

vii. availability of agent’s knowledge repository creation and modification for storage of agent’s knowledge, operation scenarios, and behaviour rules,

viii. and finally, the availability of agent’s “pro-activity” function.

A brief description of the several important Agent technologies includes:

**Zeus:** developed by the British Telecom Laboratories by Collis et al., is an advanced toolkit for engineering distributed multi-agent systems. Zeus specifies a design approach utilizing a three-layer model of an agent, the definition layer, the organization layer, and the coordination layer. It provides a set of graphical interfaces to allow a designer to create the multi-agent system. In addition, the agent is comprised of libraries that include communication tools (using KQML), social interaction, multi-agent coordination, and planning and scheduling. This tool generates source code for the agent-based system in Java [38].

**AgentBuilder:** AgentBuilder is a commercial product produced by Reticular Systems, Inc. It provides an integrated toolkit for the construction of intelligent agents and provides various graphical tools including project management, ontology management, agent management, protocol management, and run time engines. Agent Builder is Java-based and its communication language is KQML.
The Agent Builder agent model consists of agents that have beliefs, capabilities, commitments, intentions, and behavioural rules [58].

**JADE**: Jade (Java Agent Development Framework) is a software framework for developing FIPA-compliant multi-Agent systems. JADE provides a set of interfaces for the design of agents, implemented in Java. JADE uses the FIPA-ACL, utilizing a combination of socket, RMI, and CORBA [14].

NZDIS: the New Zealand Distributed Information Systems (NZDIS) project at University of Otago is a tool to develop new agent-based technology and techniques that can be used to provide integrated access to disparate information sources distributed across the Internet. The goal is to take advantage of existing, standard object-oriented approaches, wherever possible, and combine them with newly developed agent-oriented techniques [59].

The above-mentioned design tools use various approaches to facilitate the design of multi-agent systems. Among these, some aspects are notably similar to JADE and other areas such as agent conversation, actions and knowledge representations, planning of agents and maintain current state of agents, where JADE improves on the current collection of work. In the below table, we present a comparison of the major multi-agent systems developments’ toolkits.
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>FIPA</th>
<th>Zeus</th>
<th>JADE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developer</td>
<td>Nortel Networks</td>
<td>British Telecommunications Lab</td>
<td>S.p.a., University of Parma</td>
</tr>
<tr>
<td>Development Environment</td>
<td>Java</td>
<td>Java</td>
<td>Java</td>
</tr>
<tr>
<td>Agents ACL</td>
<td>FIPA-ACL</td>
<td>KQML, FIPA ACL</td>
<td>FIPA-ACL</td>
</tr>
<tr>
<td>External Application calls</td>
<td>API</td>
<td>Java applications</td>
<td>Java applications</td>
</tr>
<tr>
<td>Agents Hierarchy</td>
<td>Peer</td>
<td>Superior, subordinate, co-worker and peer</td>
<td>Peer</td>
</tr>
<tr>
<td>Fault Tolerance</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Library of predefined negotiation protocols</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Operating Systems</td>
<td>Windows, Unix</td>
<td>Windows, Solaris</td>
<td>Any OS with Java support</td>
</tr>
</tbody>
</table>

*Table 2. Comparison between different multi-agent systems frameworks.*
3.2.2 **Java Agent Development Framework (JADE)**

From the previous mentioned comparison (*Table 2*), several pros and cons appear throughout the different frameworks. JADE’s framework shows several merits compared to the others. Some of these features are:

- **Interoperability**: JADE is compliant with the FIPA specifications. Therefore, JADE agents can interoperate with other agents, if they comply with the same standard.

- **Uniformity and portability**: JADE provides a homogeneous set of API’s that are independent from the underlying network and Java version. More in details, the JADE run-time provides the same APIs both for the J2EE, J2SE, and J2ME environment. In theory, application developers could decide the Java run-time environment at deploy-time.

- **Easy to use**: The complexity of the middleware is hidden behind a simple and intuitive set of APIs.

- **Pay-as-you-go philosophy**: Programmers do not need to use all the features provided by the middleware. Features that are not used, do not require programmer to know anything about them, neither adds any computational overhead.

The goal of JADE is to simplify development while ensuring standard compliance through a comprehensive set of system services and agents. To achieve such a goal, JADE offers the following list of features to the agent programmer.

i. **FIPA compliant Agent Platform**: it includes the AMS (Agent Management System), the DF (Directory Facilitator), and the ACC (Agent Communication Channel).

ii. **JADE is distributed agent platform**: The agent platform can be split on several hosts. Only one Java application is executed on each host. Agents are implemented as one Java thread, and Java events are used for effective and lightweight communication between agents on the same host. One agent can execute parallel tasks, and JADE schedules these tasks in a more efficient way than Java Virtual Machine does for threads.

iii. **Programmable interface**, to simplify the registration of agent services with one or more domains.

iv. **Transport mechanism and interface** to send/receive messages to/from other agents.
v. Library of FIPA interaction protocols ready to be used.

vi. Automatic registration of agents with the AMS: AMS provides white page service and DF provides yellow page service in a MAS. Both AMS and DF reside in the runtime environment as agents.

Furthermore, JADE contains variable graphical tools to help monitoring and debugging processes, and a persistent and platform independent runtime environment. As JADE was developed under Java, we do not have to consider which platform will use this, and there will be no additional communication interface for runtime environment of other platforms.

An important component or add-on that facilitates the moreover implementation of JADE among most platforms, is “LEAP”, which stands for “Lightweight Extensible Agent Platform”. LEAP is an agent platform to allow the seamless deployment of agents on all Java enabled connected devices, ranging from cellular phones to enterprise servers. LEAP provides the same functionality as the original kernel of JADE, additionally, enabling it to run on wireless devices and PDA’s; thus consuming lower resources and complying with the FIPA profiles [39].

**Leap** (Leap Light Extensible Agent Platform) is an integrated agent platform, which is capable of generating and executing agent applications. LEAP is lightweight enough to be deployed on mobile devices using Java 2 Micro Edition / Connected, Limited Device Configuration (J2ME/CLDC), instead of standard Java. It thus supports running of agent applications implemented over a large family of mobile devices, for example laptops, PDAs, mobile phones, etc., and communication mechanisms, such as TCP/IP, WAP, etc. It is transport layer independent. In particular, it supports transport protocols suitable for both wire-line and wireless communication. Finally, it is easily extensible such that, when deployed on a PC, it can provide additional functionality such as agent mobility support, user-defined ontology, and platform management tools.

The design and methodology of our proposed framework is based on most advanced and widely accepted Multi-Agent and Grid framework, specifically on “JADE” and “Globus” respectively. These open source components that have emerged as the de facto standard for several important connectivity, resource, and collective protocols. Thus, offering interoperability and useful test-beds for investigating Agent services and formulating a flexible, shared, and open infrastructure. Enabling enhanced federation functionality, supporting knowledge integration and dissemination at the higher semantic levels; hence, capitalizing on security and low-cost use of resources [14, 15]. Our main goal is to create the illusion of a simple yet large and powerful self-managing virtual computer out of
a large collection of connected heterogeneous systems sharing various combinations of resources.

### 3.2.3 Collaboration Information Agents (CIA)

Our choice of JADE for developing our Multi-Agent systems and Persona, showed a flexibility and efficiency in our framework. The different Agents structures in our framework are defined but not limited to [15]:

- **Information Agents, Services, and the Semantic Web**
  - Agent-based service discovery and composition
  - Agent-based service matchmaking and brokering
  - Agent-based distributed ontology mapping and learning.
  - Agent-based information search in the semantic Web

- **Advanced Means of Collaboration and Coordination**
  - Social filtering, cooperative search, group forming, negotiating
  - Cooperation in real-time and open environments
  - Self-organising information agent systems
  - Capability-based mediation between information agents
  - Collaboration in peer-to-peer networks

- **Agent-Based Knowledge Discovery**
  - Agent-based distributed data mining
  - Distributed information retrieval, text, and Web mining
  - Agent based privacy preserving data mining

- **Mobile Information Agents for Distributed/Pervasive Computing Environments**

- **Rational Information Agents**
  - Surveys, collaborative cases
  - Trust and Reputation
  - Issues of privacy of communication, data security, and jurisdiction

- **Adaptive Information Agents**
  - Multi-strategy and meta-learning for cooperative information agents

Our implemented Persona, tackles most of the Corporative Information Agents (CIA) by starting from the users, and employing agents to get the right information back for the user. In this perspective, usually, one finds a number of different types of agents (or agents with different roles). There are user-interface agents that learn about the needs of the user and present the information in a
personalized way. There are information fusion agents that integrate the data from heterogeneous sources. In addition, there are information gathering agents that try to find the most relevant data for the user and sometimes play a role in maintaining that data [16, 24].

In all of the above-mentioned information, we can notice that Agents’ coordination with other agents is an important element that determines largely the effectiveness of the system. Agents rely on asynchronous message delivery, which should be efficient and reliable. Since agents generally communicate by sending and receiving messages, it is reasonable to expect that the agent execution environment should minimize communication latency both within a terminal and between network hosts. Message-based communication is well suited to ubiquitous environments, because it is asynchronous in nature and message queuing makes it easier to support disconnected operations.

One way to facilitate the coordination between the agents is the use of Agent Communication Languages (ACL) [14]. Furthermore, it is important that the syntax, semantics, and pragmatics of the ACL be as precise and explicit as possible, so that the resultant agent systems can be as open and accessible to the various heterogeneous environments.

Comparing the pros and cons of various Agent Communication Languages, FIPA-ACL is heavily based on a multi-modal logical semantics for communication [7]. The advantage is that, it facilitates a precise formal description of the communication and its effects. Whereas, the disadvantage, agents are usually not equipped with the logical abilities needed to act according to this multi-modal logic [25]. One of the main points is that, the semantics are based on believes of agents, which is in one hand unknown for other agents and in the other hand changes quickly and easily. This makes many of the preconditions on communication either difficult to check or easy to fulfil, which was not the intended purpose of these pre-conditions. One famous example is the sincerity condition, which states that agents only tell what they believe in themselves. Of course, it is usually impossible for another agent to check what an agent believes in. It is worthwhile to point out that to successfully use ACL communication model between two agents, it all sums up to the message ordering and delivery, formatting and addressing, and other standard distributed communication issues [25].
3.2.4 **GLOBUS**

On the other hand, Globus Grid Components assisted in establishing a firm resource management, data management, and information services; thus, deploying three main types of agents. To realize these three components, the technologies used by these agents include Grid Resource Allocation Management (GRAM), Monitoring and Discovery Service (MDS), and Grid File Transfer Protocol (GridFTP). All of these components utilize the Grid Security Infrastructure (GSI) protocol for security at the connection layer by providing single sign-on, authorization and authentication, job submission, resource monitoring, searching and allocation, data movement, and a set of tools for application programming interfaces (APIs) [15].

The Open Grid Services Architecture (OGSA), under Globus framework [31], conducts efforts toward the standardization of grid architecture. It proposes a standard bases for web services concepts and technologies. The founding concept is the *grid service*, which is a web service exposing a well-defined set of interfaces and behaviours.

For application and functional development, Jade and Globus provide both appropriate programming models and a range of services. At the application level, the agent grid is defined as an enabling technology needed for command and control. From a functional point of view, the grid application-level characteristics suggest that the agent grid knows not only about agents, but also about their computational requirements (e.g., internal behaviours). Hence, the Grid provides a unified heterogeneous distributed computing environment in which computing resources are seamlessly linked [14, 15].

All these applications reveal the agent technology potentials in solving healthcare problems [29]. They highlight the close fit between intelligent agent properties and healthcare problems; matching agent reactivity, flexibility, pro-activity, mobility, autonomy, coordination, and communication with healthcare’s autonomous entities, coordinating activity in a distributed environment to solve complex problems. This grid and agent concept indicates to a new generation of grid systems where agents serve as both enablers and customers of the grid capabilities.
3.3 **Functionality**

The rising cost of medical procedure, puts enormous strains on health care industry and on individuals who are bearing the cost of the medical expenses. Usually, a Patient visits the hospital when he/she is sick or in critical condition; hence, resulting in huge medical expenses and risk. An early detection of the symptoms could save a lot of medical expenses and even save the patient’s life.

In a home care service for elderly people, the Nurse or Doctor investigates the mental and physical conditions of the Patient, thus initializing a long-term care plan, and attaching the Persona to the Patient.

The Persona’s role is to sense the environment of the patient, providing information regarding medical values submitted in concurrent sessions, and specific medical interventions for the patient. These medical data interpretation about the environmental states help in taking immediate actions and act accordingly.

The implementation of the Persona in several equipments smooth and ease the Patients inputting enquiry process. For example, a personal digital assistant (PDA) can act as an interface for the Persona. The PDA enables the elders to confirm any criteria or questioner, because a PDA can be handled by tapping its screen with a stylus or even a fingertip; in addition, creating the advantage of mobility and scalability.

As soon as the patient connects to the Persona, a session is initialized, recording in a log file, his daily measurements and vital parameters. The Patient can choose either to send these measurements or not. In addition, the Patient can browse educational contents and reminders of healthy food, and his medication subscriptions, as advised/recorded by the doctor, which are in the form of text or voice messages. Furthermore, depending on the communication media, text or voice, the Patient can exchange messages with the nurse or the practitioner, who is supervising his/her home-care process, related to any lifestyle and possible symptoms/signs.

The Persona has several built-in bilateral multi-issue negotiation capabilities that help in the negotiation process and information among other self-interested Agents. The Agents would apply either Issue-by-issue negotiation or multiple issues at the same time, thus determining the optimal agenda and procedure [17,18]. Moreover, the Agents are capable of negotiating transactions.
in the absence of complete information about each other, hence creating a better data retrieval or data-mining tool.

Furthermore, the Persona significantly monitors the parameters of the patient and his vital signals; hence, as pre-defined by the clinicians, the Persona would be capable of distinguishing if the patient has any “dyspnea” symptoms or the patient has reported he is just exercising.

The integration of the Persona provides researchers with a powerful new arsenal to investigate previously intractable problems. Therefore, based on the quantitative and qualitative description of the overall patient’s characterization, different weights could be introduced for each parameter. For example, researchers can cross-correlate functional and structural medical data, to develop a more complete understanding of a certain disease. This Multi-Agent Grid infrastructure facilitates and enables information and knowledge sharing at the semantic level in order to support knowledge integration and services composition.

Although, most of the healthcare information involves medical processes with relatively modest computational needs, it contains significant semantic and data complexity. Consequently, the Persona will be built upon a high-level service for integrating agents and data resources, concentrating on dynamic resource discovery, dynamic performance, and distributed query processing. Thus, our main aim would be in developing services for data-intensive integration, rather than computationally intensive problems.

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3 Difficulty in breathing, often associated with lung or heart disease and resulting in shortness of breath, also called “air hunger”.

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SECURITY AND INTERACTION

4.1 SECURITY LAYER

The privacy a user demands and expects is context dependent [47], based on the environment’s requirements, persisting as a fundamental feature of the substrate into which pervasive computing is threaded. By using the capabilities of autonomous agents, designers can create privacy-aware applications in a scalable, context-reactive, and flexible manner. Scalability here means supporting the incorporation of new agents with their own privacy policies into the system. Context reactivity means allowing the adaptation of a pervasive application on the basis of dynamic context changes. Flexibility means allowing the specification and management of different types of contextual information depending on the environment’s requirements.

Autonomous agents’ capabilities can thus provide healthcare environments with the means to adapt pervasive applications’ behaviour to the user’s particular privacy conditions and demands, resulting in an agent-based privacy-aware system.

In the transmission of private and critical information, it is necessary to define the concepts that determine the diverse security levels [60]:

- **Confidentiality**: is the property that ensures that only those that are properly authorised may access the information.

- **Integrity**: is the property that ensures that information cannot be altered. This modification could be an insertion, deletion or replacement of data.

- **Authentication**: is the property that refers to identification. It is the link between the information and its sender.

- **Non-repudiation**: is the property that prevents some of the parts to negate a previous commitment or action.
4.1.1 JADE–SECURITY (JADE-S)

**JADE-S** [61] is a plug-in of JADE that allows the addition of some security characteristics in the development of MAS. It is based on the Java security model [62], and it provides the advantages of the following technologies:

- **JAAS (Java Authentication and Authorization Service)** [12]: it allows to establish access permissions to perform certain operations on a set of predetermined classes, libraries or objects.
- **JCE (Java Cryptography Extension)** [15]: it implements a set of cryptographic functions that allow the developer to deal with the creation and management of keys and to use encryption algorithms.
- **JSSE (Java Secure Socket Extension)** [14]: it allows to exchange critical information through a network using a secure data transmission (SSL).

Because of the sensitivity of the Patient’s medical history, security and confidentiality are essential and important aspects of our proposed system. One of the important cases that was triggered in Sweden couple of years ago known as “Confidentiality vs. Public Access Controversy” [35]. Where, Professor Lars-Christopher Gillberg, of Child and Adolescent Psychiatry at Gothenburg University in Sweden, and at the medical college of St George's, University of London in Tooting in south London, was always under attack regarding his concerns about the confidentiality of medical records and his role in a related controversy.

From 1996 until 2002, several paediatricians crossed the line from scientific criticism by criticizing Gillberg's research, hence accusing him alleging that the numbers reported by Gillberg were made up; however, Gillberg’s research was build-up on confidentiality agreements with his patients. After several court sessions and prosecutions, Gillberg was obliged to publish his research results, patients’ names, and their medical history. Causing two of Gillberg’s fellow researchers to destroy all the study cases collected over the past 10-15 years, thus, helping in keeping their promise and confidentiality agreement towards their patients.

This real case triggers the need to produce a security level agent in our proposed system, so that patients’ medical history will not be a public access controversy for anonymous use.
Adopting “JADE” in implementing the Persona, helps in providing several integral security tools for the whole system, such as, defining multiple levels of security, ranging from no restriction to tight security as it goes up in the hierarchy of privacy levels, is an essential aspect. In addition, since the main users would be patients, developing software service layers will improve node operations through simplified user interfaces, automated node configuration, and node management functions.

The Persona security architecture is a major and important aspect, which needs to be revised and researched for finding the best and optimal solution, thus, providing a roadmap for the mobility of security rules among various agents. The approaches to mobile security are different depending on the particular threats that are faced. Regarding our application, we decided to leave out the problem of threats of hosting environments against malicious behaviours. These threats are harder to face, and solutions often rely on detection means, more than prevention ones.

Mainly, we are focusing on the problem of dealing with potentially malicious security leashes, which could harvest data from the Persona for unauthorised use. Therefore, the security framework that is already available for JADE [40] assists in providing the different layers of protection.

### 4.2 **Persona’s Interaction Architecture**

When the Persona is requested to accept any new task from another agent, a first access protection involves authenticating the requester and checking the authorization to perform this action. Therefore, only authenticated and authorized agents can successfully ask to accept new tasks. However, the security measures do not go further what other technologies such as ActiveX already offers. In fact, once the request to perform a given task is accepted, hence, no more control on the access of protected resources can be enforced. The Persona can choose whom to trust, but, if the request is accepted, then the power of the received task cannot be limited in anyway [40].

As a result, the requester agent should provide not only tasks, but also access rights needed to perform those tasks. This is what is implemented throughout the security package of JADE, where the distributed security policies can be checked and enforced based on signed authorization certificates [14].
Our developed Persona will conduct on every requested action, a certificate that is signed by a known and trusted authority, listing the permissions granted to the requester Agent. Permissions can be obtained directly from the platform policy, or through a delegation process. Through this process, an agent can further delegate a set of permissions to another agent, given the fact that it can prove the very possession of those permissions. The final set of permissions received through the request message, can finally be used by the Persona to create a new protection domain, thus, limiting access to the resources of the system, as well as those of the application.

4.3 Persona’s Context

Medical environments produce large volumes of patient datasets, which might be categorized as static data (such as patient records in databases), and dynamic data (including patient vital sign readings). The Persona middleware is employed to manage and correlate multiple input/output streams of static and dynamic patient datasets, because of the inherent autonomy and mobility of agents.

The internal operations of the agents are based on a goal-orientated principle, which has its foundation in the BDI-model (Belief-Desire-Intention, [44]). A configurable manager module that uses a changing combination of individual information processing modules to build up needed functionality controls the functionality of an agent.

The proposed Persona connects to several sensor platforms, as described previously, to software or physical sensors; thus, interacting with the Patient’s environment to check their vital signals and coordinate accordingly. Thus, the Persona consists of a context-aware framework, which inputs these raw data and an intelligent agent, inferring and triggering intelligent and automatic services according to the contexts from context-aware framework.
Through context awareness, a Persona can tailor itself to user preferences and perform tasks according to the physical space’s nature. Moreover, the more knowledge a Persona has of each user and his or her context, the better it can adapt itself to assist that user. Paradoxically, the more an application knows the user, the greater the threat to that user’s privacy.

In table 2, we identify the most important agents that interact within the Persona to assist in facilitating the overall monitoring, scheduling, coordination, and cooperation with the home-care/healthcare system and personals.
<table>
<thead>
<tr>
<th>Agent Name</th>
<th>Agent Type</th>
<th>Role</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contacts Agent</td>
<td>Monitoring/Mediator</td>
<td>Identification of new contacts, initiation of agent interaction protocol for contact assessment, and information gathering</td>
<td>Reactive/Communicative</td>
</tr>
<tr>
<td>Problem Indication Agent</td>
<td>Monitoring</td>
<td>Identification of out-of-range medical values or symptoms, vital signals in a specific patient content</td>
<td>Reactive/Communicative</td>
</tr>
<tr>
<td>Improvement Indication Agent</td>
<td>Monitoring</td>
<td>Identification of medical value transactions from out-to-in range, or positive signals in specific patient content</td>
<td>Reactive/Cognitive/Communicative</td>
</tr>
<tr>
<td>Overall Assessment Agent</td>
<td>Monitoring</td>
<td>Assessment of Patient status based on his/her previous conditions, as well as his/her current one (provided by the Problem Indication Agent and the Improvement Indication Agent) and compilation of an overall patient status characterization</td>
<td>Reactive/Cognitive/Communicative</td>
</tr>
<tr>
<td>Educational Agent</td>
<td>Monitoring</td>
<td>Generation of recommendations regarding adaptations in patient educational plan and impact assessment in case of an educational plan adaptation</td>
<td>Reactive/Proactive/Cognitive/Communicative</td>
</tr>
<tr>
<td>Scheduler Agent</td>
<td>Monitoring</td>
<td>Check schedule compliance in patient Contacts</td>
<td>Reactive/Communicative</td>
</tr>
<tr>
<td>Administrator Agent</td>
<td>Monitoring</td>
<td>Report generation for the Persona’s functional issues (i.e. Logging processes, statistics, etc…)</td>
<td>Reactive/Cognitive/Communicative</td>
</tr>
<tr>
<td>Administrator GUI Agent</td>
<td>Information/Visualization</td>
<td>Administrative information gathering and its visualization for the administrator of the Persona</td>
<td>Reactive/Communicative</td>
</tr>
<tr>
<td>Disease category Agent</td>
<td>Information</td>
<td>Information gathering of a specific disease related monitoring agents outcome</td>
<td>Reactive/Communicative</td>
</tr>
<tr>
<td>Disease category GUI Agent</td>
<td>Visualization</td>
<td>Information visualization for the medical staff</td>
<td>Reactive/Communicative</td>
</tr>
</tbody>
</table>

**Table 3. Description of the Agents that interact within the Persona**

Based on their role, there are different types of agents participating in the Persona’s context-aware framework, namely, mediator, monitoring, information, and visualization agents. In Table II, the agents are described in terms of their type, their role, their contribution to the abstract functional model described, and their features.

From a microscopic viewpoint, agents of the framework incorporate the following attributes (besides autonomy, which constitutes the fundamental agent attribute), according to their role.

- **Reactivity:** Agents sense their environment and act under specific conditions [23].

- **Cognition:** Agents perform information processing and reasoning, based on their internal knowledge base, in terms of rules. Specifically, rules apply to medical values and their evolution in
concurrent patient contacts with the Persona, taking into account previous medical interventions and agent actions.

✓ **Communication**: Agents participate in communication acts, interacting and sharing knowledge with other agents of the MAS [50].

✓ **Pro-activeness**: Agents are capable of “taking the initiative,” which is applied in the specific system as recommendations generated regarding educational plan adaptation [23].

The built-in context-aware framework receives users’ and environments’ raw data from sensor platforms, which are in the form of either software or hardware sensors; thus, analyzing this raw data using the context information interpreter and the context manager to prioritize and weight this data. The analysed data will be transformed to the information directory, where it would be classified and modified; afterwards, processed throughout an intelligent agent to create scales, benchmarks, and connect to the other medical agents to advice or alert medical personnel.

Latest statistics shows that Heart attacks are the leading cause of death in every part of the world. More than 60% of heart attack victims experience symptoms before the heart attack occurs. About half of all heart attack victims wait at least two hours before seeking help [41]. This increases their chance of sudden death or being disabled. The Persona would analyse these early symptoms using the context-aware framework, and alert the Patient/medical personnel about his/her medical condition.
4.4.1 PERSONA-TO-HARDWARE

On the other hand, according to the medical parameters that the Persona will monitor, the following agent-types may be distinguished:

- Agents monitoring a discrete value parameter, e.g. blood pressure
- Agents monitoring a continuous-time parameter, such as ECG (Electrocardiogram) signals, etc…

Appropriate processing techniques are applied, based on the medical parameters monitored. More specifically, medical rules and statistics are applied for the interpretation of discrete value and lifestyle-related parameters (based on thresholds, expected answers, and consecutive sessions). Signal processing techniques are adopted for the analysis of continuous-time parameters (e.g. ECG), in order to identify possible abnormalities. Moreover, the Persona takes into account the medical history of the patients, as well as the interventions applied by the corresponding medical staff, in the processing procedure. Thus, a more advanced outcome towards the characterization of patient status may be accomplished.

The Proposed Persona will act as a high-level framework for all of the sensors and the BAN (Body Area Network) [42] devices, which interact with the Patient’s body. The Persona will formulate a middleware; hence, collaborating with these BAN devices and collecting the Patients vital signals.

4.4.2 PERSONA’S COMMUNICATION ADAPTOR

Multiple wireless communication standards exist [55], each suited to certain applications. Bluetooth operates at 2.4 GHz and uses frequency-hopping spread-spectrum technology to prevent eavesdropping and to improve interference immunity. The Bluetooth specification supports 1, 10, and 100m transmission ranges. It features low complexity, low power consumption, and a reasonable
price. Bluetooth offers a point-to-point serial mode as well as a Host Controller Interface mode. Bluetooth also supports plug-and-play operations such as inquiry, connection, disconnection, and *ad-hoc* networking [57]. Its specifications make it suitable for wearable monitoring devices, and it is found in all of the mobile devices. Table III lists the characteristics of alternative wireless standards that prompted the selection of Bluetooth for this effort [56].

<table>
<thead>
<tr>
<th>Standard</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>IrDA</td>
<td>Short distance, Only point-to-point communication; Requires line of sight.</td>
</tr>
<tr>
<td>IEEE 802.11b</td>
<td>Complex protocols; High price; Higher power consumption</td>
</tr>
<tr>
<td>HomeRF</td>
<td>Disbanded in 2003.</td>
</tr>
<tr>
<td>ZigBee</td>
<td>Limited data rate; Only recent product availability</td>
</tr>
</tbody>
</table>

*Table 4. Wireless Standards compared to Bluetooth*

### 4.4.3 PERSONA-TO-AGENT

JADE provides lifecycle services, communication and ontology support, security and intra-platform mobility support, persistence facilities, and system management. In addition, JADE’s framework has been enriched with two types of agents that, on one hand simplifies the distribution of tasks inside a grid of agent platforms, by creating a parallel-task computing process; and on the other hand, facilitates the composition of tasks through the use of production rules, thus, partitioning large problems and creating a smoother work flow.

Each Persona will register itself on public directories so that it can locate other agents throughout the healthcare environment. The *agent directory service* provides a location where agents can register their descriptions, and where they can search for other agents they want to interact with. The agent directory service stores entries, where each agent name is bounded to one or more agent locators, i.e. addresses where agents can be contacted [7].

The *service directory process*, instead, provides a location where agents and other entities can register, and discover descriptions for available services. The
entries stored in the service directory, bind a service identified by means of a unique name, to a service type.

In our opinion, there could be a significant synergy between agents and grid, when the problem to be solved, concerns the execution of an application/service composed of a large set of independent or loosely coupled tasks. Particularly when some interactions among tasks and even some of the tasks to be executed may be only defined during the execution of the application.

Therefore, in order to define a flexible Persona, its context-aware framework would maintain a learning model, relating the interventions applied by the medical staff with the agent-based outcome, in order to enhance the efficacy of the automated monitoring system.

In fact, this kind of problem requires an intelligent movement of tasks, from a node to another one, to reduce the high communication cost for managing the interaction between remote agents (nodes); and requires an intelligent task composition and generation, to cope with the management of the new interactions and tasks defined during the execution of the application [21].

The context-aware framework in the Persona will assist in the processing mechanism, which incorporates different reasoning schemes based on the requirements; hence, constituting a knowledge base, to monitor the different types of information independently. The reasoning scheme of the Persona will be designed as a rule base, implemented with Java Expert System Shell (JESS) [51]. JESS is a rule-base engine that could be incorporated as a customizable module in JADE agents. Rules are based on medical parameter ranges, defined by the medical personnel either for group of patients, or for each specific patient.

JESS uses a special algorithm called “Rete” to match the rules to the facts. “Rete” makes JESS much faster than a simple set of cascading “if ... then” statements in a loop. Therefore, JESS adds an import factor and facilitator in maintaining a knowledge base and an inference engine (Ernest, 2003).

During patient monitoring, the Persona characterizes patient’s health condition and identifies potential transitions from normal to problematic status in medical parameters, and vice versa. As a first step, measurement values are classified as normal or problematic, according to ranges defined by the medical personnel for each patient or group of patients. Likewise, when answers to the symptoms/vital signs questions do not bear the “default” defined values, they are classified correspondingly.
In the second step, the frequencies and/or trends of all medical parameter states (normal/problematic) within a time window are taken into account, besides their current states. Transitions from normal to problematic, or persistent problematic medical parameters hold significant information, a problematic-to-normal transition indicates improvement of the specific parameter, while a stably normal parameter is a trivial situation. The outcome of this procedure is an overall characterization of the situation and a qualitative score (very serious, serious, mildly problematic, positively stable, and improving), which is derived from a weighted combination of all medical parameters.

Different symptoms may be identified; hence, their combinations generate the overall results. Thus, a negotiation protocol among the context-aware of the framework is incorporated. A negotiation plan is required, due to the contradictory results that may be generated, and the need to generate a more accurate outcome. Negotiation is based on the significance of the parameters for each patient, which is defined by the medical staff, and has to be medically sound. Based on the above-mentioned situations, the medical personnel are accordingly notified by the Persona about the severity of the situation and the related factors.

As a result, the most important criteria and Required Engineering that were triggered throughout the implementation of the Persona, are summed up to:

- Flexibility of implementation,
- Problem solving,
- Information sharing,
- Conducts distributed and parallel computation,
- Collaboration of users,
- System Integration, and
- Assisting the Patient, within the comfort of his home, by providing a better understanding and communication, throughout his medical treatment period.
DISCUSSIONS

In General, Multi-Agent Systems are difficult to evaluate, because there are no specific metrics widely accepted for the assessment of their architectural integrity, and the performance of their implementation [49]. A formal MAS-evaluation methodology, assessing agent-oriented software engineering, as well as agent platforms, has not been standardized yet. The proposed Persona constitutes of, a system of architectural complexity, a system incorporating reasoning in its operating logic, as well as in its functional model.

The Persona will smooth the progress of monitoring and collecting medical data in the homecare environment; hence, facilitating disease prediction and diagnosis. Moreover, reducing face-to-face consultations and shortening hospital stays. Home-care technology can help in compensating healthcare resource inadequacy, while maintaining or improving care quality. Furthermore, the Persona will assist in providing a grounded base for tracing and investigating the medical treatment process; thus, concluding with knowing “whom to blame”, either a doctor for bad diagnostics, or a software engineer for not implementing the best requirement engineering for this architecture.

Moreover, we have focused the discussion in designing a collaborative and fully distributed model for supporting patients. Despite the existence of several “distributed” approaches in the design and realization of Computer Supported Cooperative Systems, we note that, distributed processing has been used to solve problems deriving from the existence of multiple physical resources (users, databases, workstations …), which need to be shared on one or more networks. Our perspective was different; in fact, our goal was to adopt a high-level paradigm of distributed and concurrent computing to define an open computational model for collaborative environments.

As a result, this methodology will improve the overall medical treatment performance, increase the knowledge base of sharing experiences, and case studies; which, consequently, improves home-care, and smooth the workflow of nurses.
CONCLUSIONS AND FUTURE WORK

Throughout the thesis, we have identified several positive aspects of the Agent technology and Grid computing approaches to Home-Care domain. Moreover, believing that the emerging intelligent Persona-Grid framework, applied to the patient’s environment, enhances and provides interesting opportunities. We have introduced the advantages of Multi-Agents Systems in assisting healthcare environment, developing towards an architecture appropriately supporting the any-time/any-place access of health services. The reason we introduced such a concept, is to create a mediator between the medical sensors and the healthcare domain; thus, facilitating the complex computing and monitoring processes, and offering a significant paradigm in service and information sharing for further research and thorough analysis.

The key software design that we employed, involved the offering of improving the ability of the healthcare workers, to cope with dynamic situations. In addition, facilitating the delivery of a wider range of medical services; hence, improving the productivity of the healthcare practitioners, as well as, increasing their ability to offer low-cost, patient-friendly medical services.

Our approach to Home-care in using the Persona’s methodology has made it very scalable. The plexus network supplies us with unlimited expandability, allowing homecare networks to grow to as many agents/nodes as one might need. We do not have the resources to experiment with such a massive network, so it is not possible to comment on how the system responds to having many agents communicating.

Nevertheless, this research had conducted the qualitative evaluation, explaining the pros and cons of the suggested Agent-based/Grid Computing approaches to existing solutions. On the other hand, the quantitative approach of these solutions based on experiments, has not yet reached a mature phase; because of time limitation and the few fielded “on the ground” experiments; thus, further more researches and prototypes need to be conducted in this area.

Thus, there are three main milestones yet to complete on our proposed Persona. We briefly outline what each of those milestones is and how we believe, we can attain them.
i. Since our environment contains huge heterogeneous chunks of information that are spread throughout the world’s different healthcare centres, communication protocols and message propagation, needs to maintain a standard list of ontologies for communicating. Thus, one major obstacle that we are in need to resolve is, to send, understand, and be able to harvest data across different architectures, which include clinical, laboratorial, hospital, and home-care centres. Once the message object structure is revised, adding additional agents will be a straightforward process.

ii. Regarding scalability and performance testing, once more agents are added to the Persona, we will be able to test more accurately how the system responds with additional Agent-Controllers. Once we have a large network set up, we can more accurately test how well the grid computing structure works, as well as, how well the agents perform with the addition of more communication.

iii. Since there are no standards for the evaluation process of Multi-Agent systems, and, since our Persona interacts with different Agents (Human and software), our proposed architecture needs to be evaluated using several experiments, case studies, surveys, and ethnographies processes to validate and improve the overall structure.

Finally, this encapsulation presumes that standardization and integration are not synonymous with simplicity. The ever-growing profusion of the heterogeneous infrastructures [23], no matter how smoothly integrated, leads to profound levels of complexity. Consequently, the industry must find ways to deal with this complexity, keeping it from intruding on the user, and making the infrastructure perform efficiently.

REFERENCES


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