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An ontology-based computer-aided diagnosis system in African traditional medicine: At the Sorcerer's Stone

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At the Sorcerer's Stone

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Abstract

Purpose – The purpose of this paper is to describe an AI (Artificial Intelligence) that can "think like an African traditional doctor". The system proposes to model and to use attitudes taken and concepts used by African traditional doctors when facing cases. It is designed to go deep into the concepts of African traditional medicine (ATM) by dealing with all the possible interpretations of those concepts, and to produce more much satisfying and accurate support for medical diagnosis and prescription than existing systems.

Design/methodology/approach – To take into account the sometimes strange concepts used and attitudes taken by African traditional healers, including mystical considerations, the system relies on a deep ontology describing all those concepts and attitudes in a more computer readable manner allowing a multi-agent system to have full access to ATM knowledge. Ethnological inquiries, literary analysis and interviews of traditional doctors (the holders of African medicine knowledge) were performed to gather sufficient data to achieve the work.

Findings – The paper addresses this question of how to build a practical large-scope computer-aided diagnosis and prescription system which can exploit deep descriptions of ATM concepts, including mystical considerations. The system also provides scientific interpretations to some concepts sometimes considered as mystical facts. It is a java web-based platform combined to a Java Agent Development framework multi-agent system accessing an ontology to provide its results.

Research limitations/implications – Because of the origins of healers involved in this research (from Gabon and Cameroon, countries of Central Africa), the ontology and the collected data may lack generalizability in the African scope and then it is a prototype. Therefore, ATM experts all over the continent are encouraged to participate to improve and standardize the ATM ontology and to populate the knowledge base. On the other side, the system cannot give scientific explanations to all the mystical considerations in ATM, there still some facts which cannot be rationally explained for now.

Practical implications – The paper demonstrates the practical usability of the implemented system on the diagnosis and the treatment of a patient case.

Social implications – The research describes a system which once validated by traditional experts, will serve as a tool to assist them in their day-to-day diagnosis and prescription tasks and will also serve as a reference on ATM practices for all interested users.

Originality/value – The paper provides an in-depth description of a computer-aided diagnosis system (CADS) that promotes indigenous technology from an African perspective. Comparing to the former systems identified in the literature, the proposed system is the first which deals with believes and mystical considerations in ATM, and also the first which provides a function to rank its results.

Keywords Ontology, African traditional medicine, Computer-aided diagnosis system, Diagnosis support, Multi-agent system, Prescription support

Paper type Conceptual paper

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1. Introduction

Traditional Medicine (TM), sometimes called alternative medicine or complementary medicine is increasingly used around the world especially in African countries where 80 per cent of the population depends on it for primary health care according to World Health Organization (WHO) which defines this medicine as "the total sum of knowledge, skills and practices based on the theories, beliefs and experiences indigenous to different cultures, whether explicable or not, used in the maintenance of health and in the prevention, diagnosis, improvement or treatment of physical and mental illness[1]". TM covers a wide variety of therapies and practices which vary from country to country and region to region. While the western medicine is fully documented and its health literacy is increasingly important, the documentation of TM especially of African Traditional Medicine (ATM) has just begun and much remains to be done in terms of health literacy. In fact, during centuries, ATM has been a medicine where knowledge were transmitted orally from masters to disciples and tended to deteriorate as time passes. Nobody but the initiated ones could practice this medicine. Since its recognition by WHO and its proven contribution to the well-being of many people, several scientific works have been done to document ATM. The knowledge gathered so far can contribute to the construction of a knowledge base (KB) to store, maintain, facilitate knowledge sharing on ATM and improve health literacy in the domain. This KB should be ideally based on an ontology (Uschold and Gruninger, 1996) in order to provide shared conceptualizations by formal descriptions of ATM concepts and relations between them. Our research aims to build a Computer-Aided Diagnosis System (CADS) on top of such an ontology to assist traditional healers and other ATM health professional with medical diagnosis and prescription tasks.

Processing information manually while making decisions is becoming increasingly difficult because of the huge amount of information involved. CADS form a significant part of the field of clinical knowledge management technologies through their capacity of modelling to support the clinical process, from diagnosis and investigations to treatment and long-term care. They link health observations with health knowledge to influence health choices by clinicians for improved health care. To engineer a CADS for TM is a challenging task if we consider the characteristics of this specific medicine. In TM, methods used by and attitudes of the different stakeholders to diagnose and to treat diseases are sometimes strange and inconsistent with principles of western medicine because of the common use of beliefs and indigenous experiences. Our goal is to build a large-scope CADS for ATM which addresses many of the problems of existing systems. Especially, it makes use of a deep ontology of ATM which fully describes the concepts used in this medicine. Particularly, the deep ontology enable the CADS to have full access to information on patients and traditional doctors, including their beliefs, their culture and their indigenous experiences, in order to infer patient-specific recommendations and to provide rational explanations and actual interpretations of these recommendations. Taking into account beliefs, the culture and indigenous experiences in our ontology-based CADS will help to keep track on ancestral knowledge and will help to enable "mystical" or psychological considerations of intervenors (traditional doctors and patients), thus maintening them in mental states favouring the success of operations (diagnosis and treatments). The rest of the paper is organized as follows. Section 2 discusses some CADS for ATM already proposed in the literature. The scope and the goals of the system, named MEDINETTE, are presented in Section 3 while MEDITRONTOLOGY, the deep ontology for ATM which is the backbone of the system, is described in Section 4. The features of MEDINETTE are covered in Section 5. In Section 6, we present an overview of the system anatomy and its main functionalities: diagnosis, prescription and scientific interpretations. Section 7 presents and discusses our results of using MEDINETTE on a case study. Finally in Section 8, we conclude and discuss how this work could be extended.

2. CADSs in ATM

The continuously growing interest in ATM motivated research on medicinal plants, diseases and herbal-based treatments. Some works as HagenBucher-Sacripanti (1981) describe the disease conception and some of their cultural significations in ATM, when the others as Aboughe Angone *et al.* (2009) and World Health Organization (1999) describe some plants used to cure diseases, hence contributing to document and to keep track on ATM knowledge. Concerning traditional diagnosis and prescription, previous works has mainly been focused on ethnobotanical survey forms containing descriptive information such as specifications of plants and their useful parts, names of the harvests, target diseases and medicine preparation methods. Our goal is to build an ontology-based CADS which deeply captures ATM practices and extend the scope of previous systems.

The use of IT to support clinical decision in ATM began more than two decades ago. However, when in western medicine there are many mature clinical decision support systems (DSS) (see (Berner, 2009) for a state of the art published in 2009), sometimes combined with electronic health record to improve the quality of results, in ATM there are only few proposals. In 1992, one of the first CADS for ATM (Frasson *et al.*, 1992) named SEIBOGA had represented the diagnosis process and plants-based prescription through icons to make it more accessible for traditional healers often illiterate. SEIBOGA used Prolog rules to match symptoms to diseases and to associate each disease of the KB to a list of treatments. As in 2006, (Atemezing *et al.*, 2006) used software agents to model a CADS for ATM. The paper claims to use an ontology in the modelling but lacks of precision. In addition, the system was not actually implemented and then is very difficult to appreciate. During the year 2010, (Brou *et al.*, 2010) proposed MEDTRAD$^+$ an icons-based CADS to diagnose and to prescribe plant-based treatments in ATM. This proposal was not too different from SEIBOGA. In 2012, Ogirima *et al.* (2002) proposed a web-based DSS for prescription in ATM as in 2013 they proposed a mobile-based DSS (Ogirima *et al.*, 2013). Unfortunately, both works focus on the user interface and does not really show how the reasoning processes are implemented.

The common drawback of all the aforementioned clinical DSS for ATM is the non coverage of the entire ATM domain, thus limiting their scope. These previous systems actually limit ATM to herbal medicine which is only an aspect of ATM. The WHO definition of TM is clear about the fact that in addition to herbal medicine, TM deals with "[…] beliefs and experiences indigenous to different cultures, whether explicable or not […]". So, previous systems consider only the rational part of ATM while leaving aspects related to beliefs and empirical experiments of different stakeholders. To take into account those metaphysic aspects is a very interesting but a challenging task. The goal of our system is to address many of the problems, both in quality and accessibility of a CADS for ATM, thus enlarging the scope of previous ones. To achieve this, our CADS is build on top of a deep ontology for ATM which fully describe concepts of ATM and practices of different stackholders. We qualified our ontology to be "deep" as it extends the ontology described in Atemezing and Pavon (2008) by adding various interpretations and contexts of use in concepts descriptions. We provide a framework for the formal representation of the expertise of ATM practitioners including "mystical" associated aspects, this part of ATM often overlooked by previous ATM CADS and which earned ATM healers the pejorative name of sorcerers. The deep ontology for ATM is described in Ayimdji *et al.* (2011) and is summarized and improved in Section 4.

3. MEDINETTE: fitting ATM practices

Creating a CADS for ATM presents many challenges. Adequate knowledge representation formalism is needed to capture ATM practices. As the system is devoted to be exposed on the web with a potentially considerable number of user accessing information at the same time, queries must be handled quickly, at a convenient rate. In designing MEDINETTE, we have considered both the effective representation of all the knowledge of ATM and the efficiency of computations. MEDINETTE is designed to handle in a satisfactory manner the expertise of traditional doctors who sometimes behave in a way inconsistent with principles of western medicine. Their beliefs and attitude, sometimes strange, are essential in the diagnosis and therapeutic processes and have shown their efficiency for hundreds of years.

3.1 Functional purposes

The functionalities of MEDINETTE are well resumed in the use case diagram depicted in Figure 1. TM experts (traditional healers and researchers) will use the system to:

- infer case-specific advice (diagnosis support) from items of the patient data;
- have support for medicine prescriptions;
- have scientific interpretations of some concepts used by the system to provide diagnosis and/or prescription; and
- browse and update the KB.

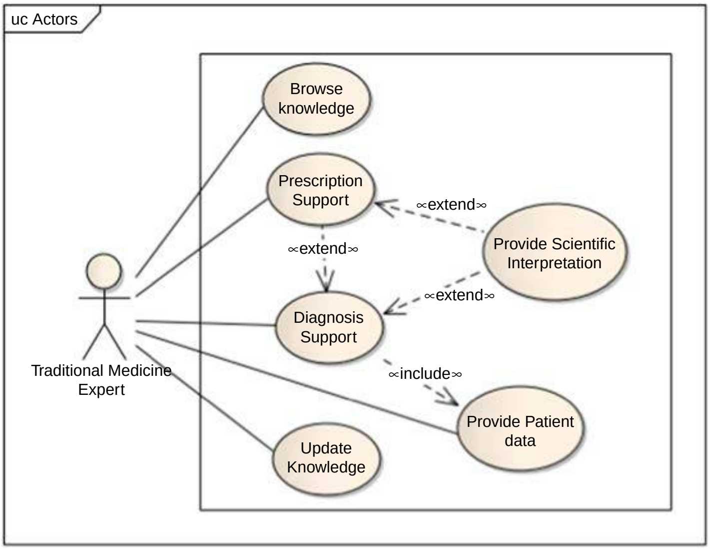

Figure 1.
Use case diagram of the ATM CADS

3.2 Design goals

Our main design goal is to improve the quality of CADS in TM, both by enlarging the scope of existing systems and by improving computations.

3.2.1 Enlarging the scope. An analysis of previous CADS shows that they neglect an important aspect of TM: beliefs and indigenous experiences. They all reduce TM to the single aspect of herbal medicine. Those systems were designed to match sets of rational symptoms to diseases and to recommend herbal-based treatments. However, we know that both patients and traditional doctors also consider traditional symptoms (such as bad dreams). In addition, traditional healers perform tasks such as rituals for the collection of some plants or for the treatment process, and give some apparently eccentric recommendations to patients. Therefore, to be more complete, a CADS for TM must, as much as possible, take into account all these aspects sometimes qualified as mystical. This will, for example, enable psychological considerations favourable to the recovery. In fact, our investigations show that the placebo effect has a great role in ATM when dealing with non-conventional knowledge. Some apparently magical considerations sometimes hide scientific interpretations. Some stakeholders, without knowing these scientific explanations are in a state of mind favourable to more accept "magical" implications of "magical" facts. MEDINETTE makes use of a deep ontology for ATM to enlarge its scope to deal with such considerations.

3.2.2 Improving computations. Another important design goal was to build a system that reasonable numbers of people can actually use. Usage was important to us because we think some of the most interesting research in MEDINETTE will involve leveraging the vast amount of usage data that will be available in its KB. We are convinced that while growing, the system will contain millions of concepts and data, and that millions of searches will be performed every day. MEDINETTE is a multi-agent based system to improve computations and request handling.

4. MEDITRONTOLOGY: the deep ontology for ATM

To enable machines to perform some reasoning tasks on knowledge, it is necessary to go beyond the keywords and to add an interpretation layer that seize the meaning, the actual semantics of resources. In some domains as ATM, socio-cultural differences (different experiences, different training, different cultures, different needs, different perspectives, different languages or jargons, different contexts of use, etc.) may cause real difficulties if different stakeholders do not have a common ontological basis. Ontologies are used to satisfy this need of dealing with knowledge semantics and to enhance reasoning capabilities. The aim of an ontology for ATM is to capture the semantics of the domain. However, to build an ontology depends on the domain, "different approaches are required for different circumstances" (Uschold and Gruninger, 1996). Here we summarize and improve the construction of the ATM ontology already started in Ayimdji *et al.* (2011). We follow the steps recommended by the well-known methodology named METHONTOLOGY (Fernandez Lopez *et al.*, 1997). These steps are: specification, knowledge acquisition, conceptualization, integration, formalization, implementation and maintenance.

4.1 Specification

The specification of the ontology is summarized in the following Table I.

Domain	African traditional medicine
Ontology name	MEDITRONTOLOGY
Purpose	Ontology about ATM concepts to be used when information is required in diagnosing and healing diseases. This ontology could be used to ascertain a plant is a medicinal one, to ascertain some diseases (as night poisoning) are mystical ones, or to identify the process of harvest of certain medicinal plants
Level of formality	Formal
Scope	List of (all) possible concepts used when diagnosing and healing diseases in ATM, including accessories, beliefs, experiences, whether explicable or not List of concepts: disease conception, abnormal disease, symptom, potion, prohibition, medicinal plant, process-of-harvest, attitude-of-Harvest, ritual, diagnosis, calabash, talisman […]
End-users	Traditional healers, researchers
Principal sources of knowledge	The Meditra Project, WHO documents and website links on ATM, IPHAMETRA research reports and publications, Atemezing's first ATM ontology (Atemezing and Pavon, 2008), some traditional healers from Gabon and Cameroon

Notes: The Meditra project was initiated in 1996 at the University of Yaoundé I (Cameroon) with the aim of building a knowledge base to preserve knowledge on ATM; World Health Organization, www.who.int/ (accessed 23 April 2015); Institut de Pharmacopée et de Médecine Traditionnelle, Libreville, Gabon

Table I. ATM Ontology specification document

4.2 Knowledge acquisition

As illustrated in Table I, knowledge is collected from documents produced in the frame of the MEDITRA Project, the WHO web pages and documents on TM, the first ATM ontology proposed by Atemezing and colleagues. We had workshops with experts of IPHAMETRA research centre (botanists, chemists, biochemists, etc.) and some traditional doctors whose intensive comments and experiences really improve the quality of the ontology. So, some informations were already available on paper or electronic format (MS Office Word and Excel, pdf, images, audio and videos) when some of the knowledge was gathered *in situ* on paper or in audio format using a voice recorder. We still acquiring knowledge as the maintenance is going on and will continue in order to enrich the KB during the ontology entire life. However, most of the acquisition was done simultaneously with the requirements specification phase, and decreases as the ontology development process moves forward.

4.3 Conceptualization

The huge amount of the work was done in this phase. The aim was to build the ontology conceptual model. We used our sources of knowledge to collect a set of terms including concepts and their relations, their properties being considered as relations with datatypes as *string, integer, float*, etc. The collection of instances satisfying these concepts, having these properties and related by these relations was performed at the same time. Table II presents some concepts, relations and instances of the ATM ontology.

To go deep into ATM conceptualization, let's consider the following statement made by one of the traditional healers with whom we collaborate; he described a strange attitude to adopt for the collection of some plant used for the treatment of Asthma: "This plant should be collected by a young man, early in the morning, before the daybreak. Once the plant is collected, the collector must run straightforward to home without stopping on the way, and the plant must be used immediately". Chemical analysis

Name	Description
Concepts	
Top	The top-level concept, all the other concepts are subconcepts of Top
Treatment	Charaterization of treatments
Disease	The abstraction of a disease
Abnormal disease	Subconcept of disease, abstraction of diseases known to be mystical one
Calabash	Fruit-based container to contain some medicinal potions
Relations (or objects properties)	
Treatment	Relation between a disease and one of its Treatments *Signature*: treatment(disease, treatment)
Adminmode	Links a Treatment to its administration mode (oral, bath, inhalation, poultice […], etc.) *Signature*: adminmode(treatment,AdministrationMode)
Properties (data properties)	
Name	A property of most concepts, a relation between a concept and its name *Signature*: name(top, string)
Instances	
Papayaroot	Instance of the concept MedicinalOrgan, an abstraction of vegetal and mineral ingredients used in potions
Mash	Instance of the concept PreparationAction, an abstraction of actions done while prepararing medicines
Eatindream	Instance of the concept symptom

Table II. Conceptualization of ATM Ontology

showed that plants that need to be collected this way contain essential oil which concentration is high when dawn is breaking and which volatily requires to use them in a short amount of time once collected, for more efficacy. That is why without knowing the hidden scientific explanation, some traditional doctors recommend the aforementioned collection process. The conceptualization process of such a statement highlights the importance of some concepts in the plant collection process: the specifications of the collector (young man), his attitude (run nonstop) and the period of the collection (early morning). The formalization of these concepts is done in the dedicated Section 4.5.

In ATM, there are many more statements and concepts like the preceeding. Another one can be found in Ayimdji *et al.* (2011). These knowledge based on experiences and beliefs, and transmitted from generation to generation are at the hearth of ATM and constitute its particularity. To keep these wonderful knowledge, we take them into account in the ATM ontology by dividing the ontology development process into two steps: the first step is dedicated to build a first ontology called the "primary ontology" where concepts are defined at the first glance, without any hidden aspects; the second step is dedicated to deepen concepts descriptions to obtain the "deep ontology". This second step involves various specialists (chemists, ethnobotanists, etc.) whose role is to iteratively and incrementally add the different hidden aspects. The formalization of the deepening process is also provided in Section 4.5.

4.4 Integration

To avoid reinventing the wheel and to speed up the construction of the ATM ontology, we started from the ontology proposed in Atemezing and Pavon (2008), and we considered it as the primary ontology to which we apply the deepening process to better describe the concepts already in their primary descriptions.

4.5 Formalization

To formalize the conceptual representation of the ontology we did in Section 4.3, we use the description logic language *SHOIN(D)* which is equivalent to *OWL DL*, our target implementation language (see (Baader *et al.*, 2003) for further information on description logics). The formalization takes into account the two steps of the construction of the ontology. The full process is detailed in Ayimdji *et al.* (2011). For illustration purpose, here we are going to apply the process on some examples.

Let's consider the concept "Calabash" described in natural language in Table II. Its description in the primary ontology reduces it to a fruit-based container and the formal description is: Calabash $\sqsubseteq$ Container $\sqcap$ $\forall$madeFrom.Fruit

However, depending on the context, the calabash sometimes refers to a dosage and/or a restriction (the medicine must be kept exclusively in a calabash otherwise it would not be effective). The last aspect however eccentric has a scientific basis because in many cases, the fruit forming the Calabash helps in a better preservation of the potion than a metal container where there can be a risk of corrosion or some chemical reactions between the liquid (potion) and the container. Therefore, the deep description adds the formalization of these aspects as follows:

$$\text{Calabash} \sqsubseteq (\text{Container} \sqcap \forall \text{madeFrom.Fruit}) \sqcap (\text{NI} \sqcup \exists \text{ia.Dosage} \sqcup \exists \text{ia. Restriction})$$

where NI (which stands for "Not Interpreted") is a special concept introduced to indicate the absence of hidden interpretation or hidden aspects. This special concept is used to restrict the concept description to the primary one when there is no hidden aspect found for a concept.

Second, let's consider the statement of the traditional healer mentioned in Section 4.3. We can formally describe this statement by specifying the collection process of a plant as follows:

$$\text{Collection\_Spec} \sqsubseteq \forall \text{collector.Collector\_Spec} \sqcap \forall \text{period.Period\_Spec} \sqcap \forall \text{attitude. Attitude\_Spec}$$

Let Collection_Spec1 to be the concept describing the statement of our example. By introducing more specific concepts, we formalize this collection process as follows:

$$\text{Young\_Man} \sqsubseteq \text{Collector\_Spec}$$
$$\text{Run\_Non\_Stop} \sqsubseteq \text{Attitude\_Spec}$$
$$\text{Early\_Morning} \sqsubseteq \text{Period\_Spec}$$
$$\text{Collection\_Spec1} \sqsubseteq \forall \text{collector.Young\_Man} \sqcap \forall \text{period. Early\_Morning} \sqcap \forall \text{attitude. Run\_Non\_Stop}$$

Finally, there are hidden interpretations not explicitly stated by the healer though they can be formally represented in the ontology. The concept Early_Morning, specifying the appropriate collection time hides the aspect of essential oil concentration while the concept Run_Non_Stop specifying the attitude of the collector hides the aspect of the volatility of an active ingredient:

$$\text{Run\_Non\_Stop} \sqsubseteq \text{Attitude\_Spec} \sqcap (\text{NI} \sqcup \exists \text{ia. Volatility\_Constraint})$$
$$\text{Early\_Morning} \sqsubseteq \text{Period\_Spec} \sqcap (\text{NI} \sqcup \exists \text{ia. Essential\_Oil\_Concentration\_Constraint})$$

4.6 Implementation

The ATM ontology is implemented in Protegé Editor and converted in OWL (Web Ontology Language), the standard ontology language for the semantic web.

4.7 Maintenance

The maintenance phase takes place once the ontology is already implemented and deployed. For MEDITRONTOLOGY, it consists to continue adding new concepts and properties, adding hidden interpretations, detecting and correcting inconsistencies. This maintenance phase will continue as the ontology will be used.

5. System features

MEDINETTE has two important features that help it produce high-quality results. First it makes use of an ontology to determine reliable and traditional compliant diagnosis and prescription recommendations. This ontology is an ontology for ATM. The use of an ontology is based on the fact that it is impossible to make good decisions without information. So MEDINETTE uses an ontology, which better represents ATM concepts. Second, MEDINETTE utilizes multi-agent systems technology to distribute roles and improve operations.

5.1 Ontology for ATM: capturing knowledge

The deep semantics of the concepts underlying ATM is an important thing that has largely gone unused in previous attempts to build CADSs for ATM. We have created an ontology for ATM which fully fits the definition of TM as given by WHO, taking into account all aspects, including indigenous experiences and beliefs. This ontology makes it possible to software agents to have full access to information on patients and traditional doctors, including their beliefs and indigenous experiences, in order to infer patient-specific recommendations and to deeply explain these recommendations. Taking into account beliefs and indigenous experiences in the ontology-based CADS helps traditional doctors to enable psychological considerations. Indeed, many people using TM are not yet ready to accept that, behind some diseases known to be of unnatural origins, are sometimes scientific explanations. It is then necessary to harmonize diagnosis and treatment processes with their cultures and beliefs in order to put them in psychological state of mind favouring recovery. We think that, in the medical domain, science is not the only master; all that matters is effective treatments whatever their origin.

To legitimate the use of the deep ontology for ATM, let us consider the following recommendation given by a traditional healer: "Drink a calabash of the potion every morning". To take into account the deep semantics of the concept CALABASH in the ontology, it is considered not only as a container but is also interpreted as a possible constraint for the good preservation of the potion, and a possible constraint to specify the quantity to drink (the posology). Some patients receiving the aforementioned recommendation could believe that the constraint to drink only in the calabash is a mystic process and could rapidly recover if they think they are suffering from unnatural disease (the placebo effect).

5.2 Software agents

To improve its performances, MEDINETTE is based on the distribution of roles into software agents which collaborate to give the expected results. There are four main types of agents in MEDINETTE:

Interface agent (IFAgent) role is to gather and filter data from the user.

Traditional expert agent (TEAgent) plays the role of a scientific researcher or a traditional healer in the system. It is the one which provides both the diagnosis service and the medicine prescription service.

KB agent (KBAgent) is responsible of accessing the KB.

Scientific interpreter agent (SIAgent) is in charge of providing scientific interpretations, if any, of some concepts used in diagnosis or treatment indications.

Figure 2 illustrates the interaction model of MEDINETTE agents.

5.3 Other features

Aside from the usage of an ontology and software agents, MEDINETTE has several other features. First, it uses location information for patients and herbal plants and so it makes use of proximity in search. For example, the system prioritizes prescription recommendations that include herbal plants available in patients' locations. Second, MEDINETTE is a web-based system and so, once deployed, its KB will be populated by experts worldwide and it will be used by traditional healers wherever they are.

6. System anatomy

First, we will provide a discussion of the high-level architecture. Then, there are some in-depth descriptions of some important components. Finally, the major applications: diagnosing, prescribing and interpreting will be examined in depth.

6.1 MEDINETTE architecture overview

In this section, we will give a high-level overview of how the whole system works as pictured in Figure 3. Further sections will discuss the components not mentioned in this section. All of MEDINETTE is implemented in Java for robustness, efficacy and portability so that they can run in each server (whatever the OS and the CPU) having a Java Virtual Machine.

In MEDINETTE, the KB is populated via an author module through an authoring interface used by ATM experts. The rule authoring process for diagnosis and treatment prescription is conducted through this module. The authoring process is guided by the knowledge, relationships and constraints represented within the KB. This KB can be logically divided into two parts: a TBox which describes the concepts used in ATM and

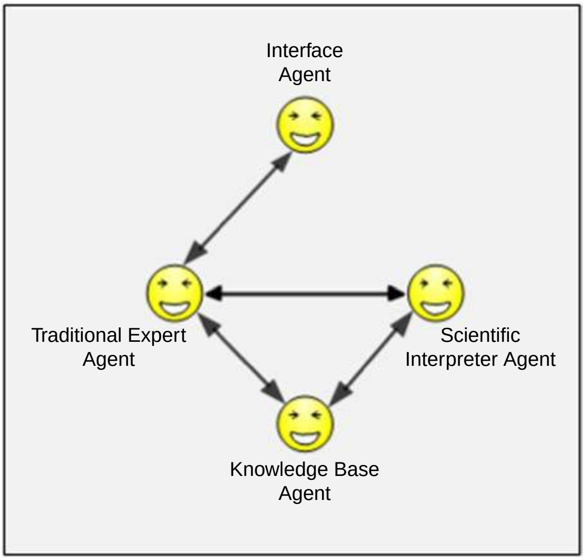

Figure 2. The interaction model of MEDINETTE agents

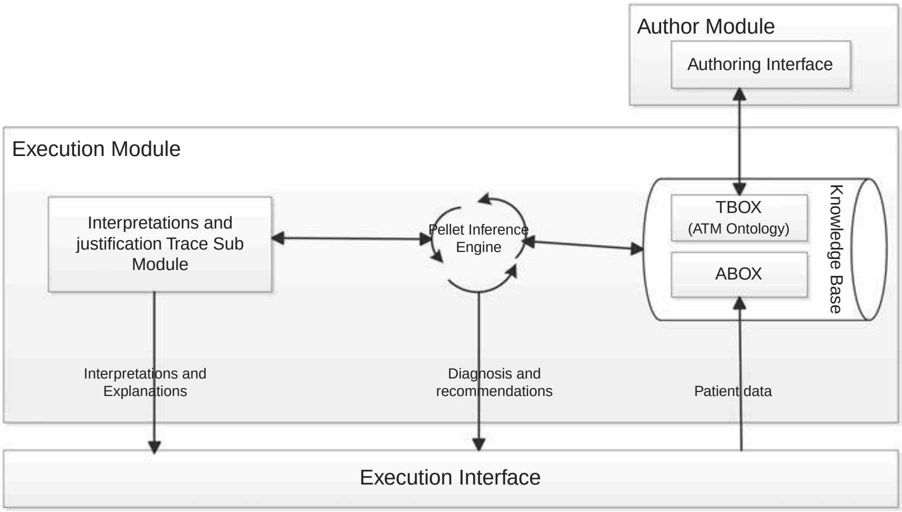

Figure 3. MEDINETTE high-level architecture

corresponds to our deep ontology, and an ABox which contains assertions on individuals identified in the domain. The patient data contained in a working memory are associated to the data in the ABox to constitute the whole information needed to handle a case. Patient data are provided by users through an execution interface which role is to ensure a user-friendly communication with the system.

Pellet reasoner (Sirin *et al.*, 2007) is at the heart of the system. It performs logical inference on data from the KB and those from the users to generate diagnosis and treatment prescriptions. The Pellet reasoner runs the rules (in SWRL Syntax) authored by ATM experts through the author module to achieve its goals.

We designed the Justification Trace Sub-Module to have two important features: on the one hand, to provide explanations on how it finds solutions (the trace of inferences); on the other hand, to provide scientific interpretations of some particular concepts if any. In fact, the justification trace sub-module here is not only limited to explain the inference mechanisms, in addition it explains the hidden aspects of some concepts as described in the ATM ontology. For instance, a prescription can include the use of a "Calabash" and highlights the constraint to keep a potion only in the Calabash for effectiveness. This warning appearing at a first glance as a mystical consideration is clarified by the justification module as the possibility of the deterioration of the medicine if not kept in a non-metalic container, e.g., a Calabash.

6.2 Physical distribution of major architectural components

To think a convenient high-level logical architecture of a system is interesting, but to actually implement it in the better way while taking into account application and technological constraints is a real challenge. MEDINETTE is designed and implemented in a High-Tech architecture which combines the high availability of JEE applications and the efficiency and reasoning capabilities of multi-agents systems (see Figure 4). MEDINETTE consists of Java Server Faces (JSF) pages and JSF Managed Beans (MB)residing in a JEE Web Container which communicates with a Java Agent Development framework[2] (JADE) platform containing agents which realize the most part of the job through inferences on data in the KB.

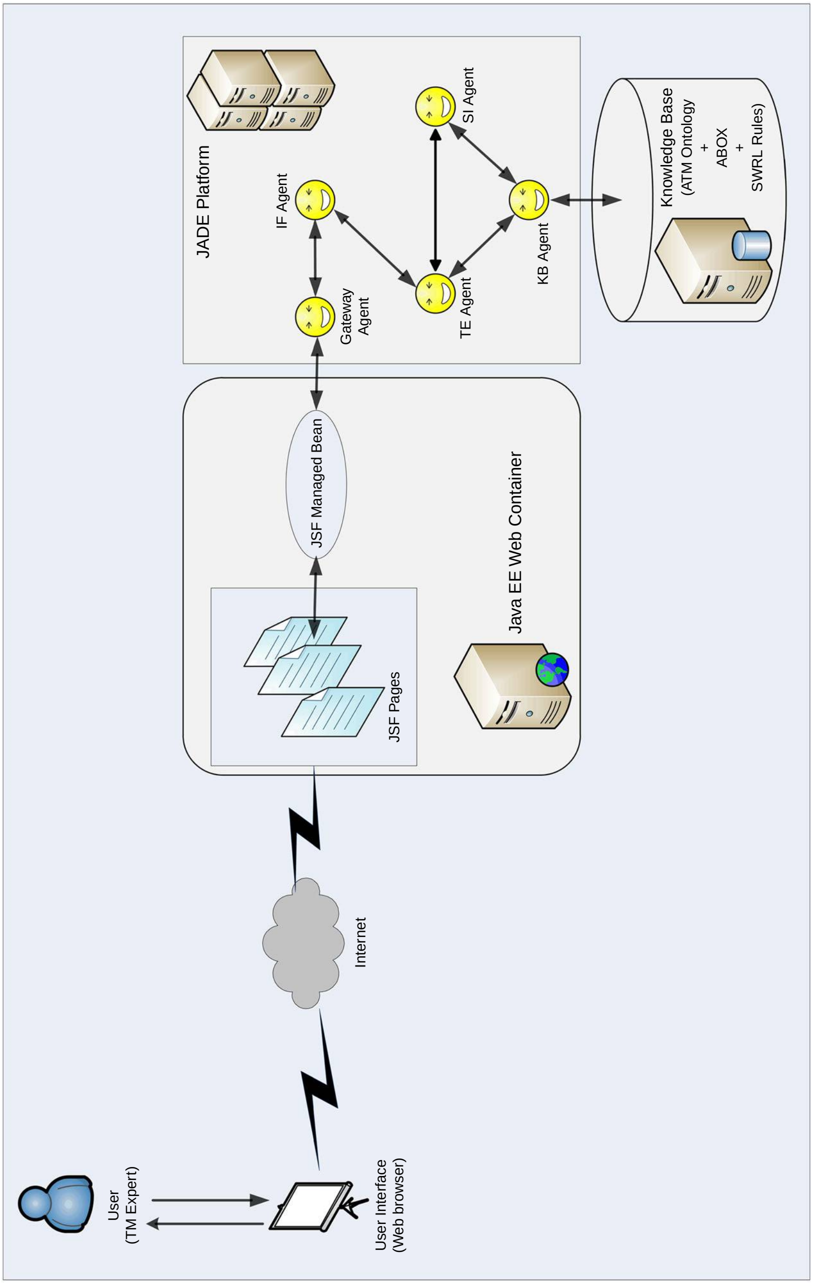

Figure 4.
MEDINETTE physical architecture

6.2.1 JSF pages. The execution interface and the author module pages are all implemented in JSF technology which makes it easy to construct a user-friendly interface from a set of reusable UI components and provides a simple model for wiring client-generated events to server-side application code[3].

6.2.2 JSF MB. JSF pages work with JSF MB which handle users request data. Moreover, in our system, JSF MB acts as the gateway to the JADE platform in which MEDINETTE agents evolve. So they participate to the bridge between the web tiers of the system and the MAS tiers (which is actually the Business tiers).

6.2.3 The gateway agent. The gateway agent in JADE platform is a specific agent which allows the connection to third party systems. In MEDINETTE, it is responsible for the direct link with the JEE Web Container. He receives data from the MB and transmits it to MEDINETTE agents.

6.2.4 MEDINETTE agents. There are four main types of agents actually realizing operations in MEDINETTE: IFAgent, SIAgent, TEAgent and KBAgent.

The classic workflow of information between these agents is as follow: upon the reception of a request, the JADE gateway agent sends the request parameters to IFAgent which check data and forward the request to TEAgent. When TEAgent receives requests, it triggers SWRL rules to generate case-specific diagnosis and prescription while querying KBAgent to access the KB. For each plausible diagnosis or prescription, it also queries SIAgent (which also rely on KBAgent) to look for plausible scientific interpretations of concepts involved in the generated results.

6.2.5 The KB. The KB contains the ATM ontology which is the TBox containing concepts and properties, SWRL rules descriptions and the ABox which contains assertions on concepts described in the ontology. Only assertions which tend to be more permanent are directly represented in the KB (e.g., `BacterialDisease (typhoid), AbnormalDisease(nightpoisoning)`). The more dynamic assertions (e.g., `symptom(peter, eatindream)`) will be stored into the working memory during the utilization of the system. To verify that the system and the ontology have the potential of being effectively used, we have already added 157 concepts in the TBox and 160 individuals in the ABox, this initial knowledge just serves for the proof of concept. The scope of our work is to set a framework. The actual KB will be constructed by certified experts of the ATM domain, those who have knowledge. The construction of the ontology in Protégé Ontology Editor (version 3.3.1) can be seen in Figure 5. This visual ontology is then exported in the OWL format to facilitate access and queries performed by MEDINETTE agents. It is worth mentioning that even though there is a clear distinction between the parts of the KB (the TBox, the ABox and SWRL rules), for simplicity, we stored them in a single OWL file instead of having them in three separate files.

6.3 Diagnosing cases

The goal of the diagnosis in ATM is to efficiently match a list of symptoms and social considerations to some plausible diseases. Running a diagnosis investigation in ATM is a non-trivial task. There are tricky reliability and performance issues and even not the least importantly, there are social issues. The diagnosis is the most delicate application since the prescription of drugs relies on it and moreover, the health of patients depends on it. In order to produce reliable and large scope diagnosis results, TEAgent, as the most other agents, relies on the KB, i.e. on the ontology and some particular logical rules.

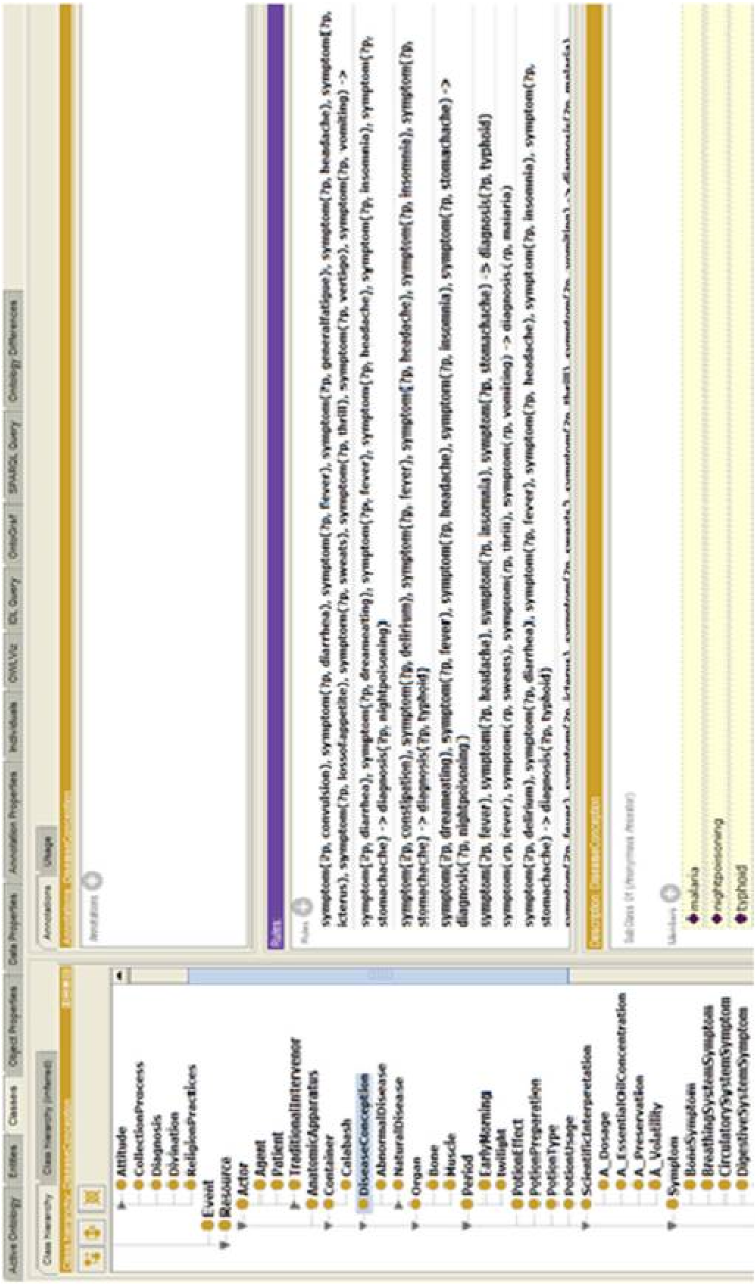

Figure 5.
ATM Ontology in Protégé 3.3.1 editor

Let p a patient and d a disease. The patient is characterized by his profile (e.g., gender, age, matrimonial status, ethnic origin, etc.) and a set of signs or symptoms (e.g., stomach ache, fever, bad dreams, insomnia, etc.). The diagnosis depends not only on the symptoms but also on the patient profile. The diagnosis of the disease d on the patient p is specified by a set of rules whose general form is:

$$profile_1(p, p_1), \ldots, profile_k(p, p_k), symptom\,(p, s_1),$$
$$\ldots,\ symptom\,(p, s_n) \rightarrow diagnosis\,(p, d)$$

where $profile_1, \ldots, profile_k$ are the different types of profiles and $p_1, \ldots, p_k$ their values for the patient p, and $s_1, \ldots, s_n$ the signs observed on p.

The following rule is one of those which permit to diagnose malaria (note that in this example, malaria doesn't depend on the patient profile, so the profile is not taken into account):

$$symptom(p, fever), symptom(p, headache), symptom(p, vomiting)$$
$$\rightarrow diagnosis(p, malaria)$$

The powerfulness of Pellet inference engine is solicited to trigger and execute the rules. The diagnosis is a set of plausible diseases (ranked by order of pertinence) afflicting the patient. The MEDINETTE diagnosis process is described in Algorithm 1: MEDINETTE Diagnosis Algorithm.

(1) Parse the query.
(2) Convert each symptom and patient profile elements into URI.
(3) Add symptoms of the patient and his profile to the ontology model.
(4) Scan through the SWRL diagnosis rules until there is a rule that matches all the symptoms and the profile in the query.
(5) Compute the rank of the inferred disease for the query.
(6) Sort the set of diseases that have matched by rank and return the ordered set.

To compute the rank of an inferred disease, we designed and coded the ranking function to take into account the elements of the patient's profile, his symptoms and all the rules whose head conclude on this disease. For each rule R_i concluding on the same disease, we compute an intermediate rank by the formula: $\frac{1}{2}(k/k_i + n/n_i)$ where k and n are, respectively the number of profile elements and the number of symptoms of the considered patient and, k_i and n_i are, respectively the number of profile elements and the number of symptoms appearing in the triggered rule. Note that $k \leqslant k_i$ and $n \leqslant n_i$. The final rank of the disease d is given by the max of all intermediate ranks:

$$rank\,(d) = \max_i \left[\frac{1}{2}(k/k_i + n/n_i)\right]$$

It should be noted that the rank is a value between 0 (not included) and 1 which defined the level at which the patient condition matches the inferred disease: $rank(d) \in (0,1]$.

6.4 Prescribing medicine

The KB of MEDINETTE contains a set of medicinal prescriptions for each disease. Medicine prescriptions consist of medicine preparation and medicine administration. They are described in the KB at the ABOx level in terms of assertions on TBox concepts like `Treatment`, `Preparation`, `Posology`, `MedicinalOrgan`, `CollectionProcess`, `AdministrationMode`, also on object properties like `treatment`, `ingredient`, `preparation`, `adminmode`, `posology`, `collectionprocess`, and on data properties like `description`. An example of ABOx descriptions of a treatment of malaria with papaya roots is given by the following assertions:

```
treatment(malaria,malariatreat1),preparation
(malariatreat1,malariaprepa1),MedicinalOrgan
(papayaroot),Preparation(malariaprepa1),
Treatment(malariatreat1),PreparationLine
(malariaprepa1Line1),action(malariaprepa1Line1,
mash),ingredient(malariaprepa1Line1,papayaroot),
action(malariaprepa1Line1,mix),ingredient
(malariaprepa1Line1,lukewarmwater)

Posology(posology1),AdministrationMode(oral),
posology(malariatreat1,posology1),adminmode
(malariatreat1,oral),quantity(posology1,onecup),
time(posology1,morningandevening),duration
(posology1,threedays)
```

Note that the involved concepts, object properties and data properties are all described in the ATM ontology. Assertions are entered into the KB through a convivial web-based GUI which also provides a natural language communication with the user. The system is in English but should be internationalized to take into account many languages and increase the number of potential users.

6.5 Interpreting concepts

A wonderful property of MEDINETTE is to provide scientific interpretations of some apparently magical concepts used in diagnosis or prescriptions.

Let's recall the statement of one of the traditional doctorr with whom we collaborate. The statement describes a strange attitude to adopt when collecting some plant to use to treat asthma:

> This plant should be collected by a young man, early in the morning, before the daybreak. Once the plant is collected, the collector must run straightly at home without stopping on the way, and the plant must be used immediately.

We have constructed the ATM Ontology to formalize such statements (see Ayimdji *et al.*, 2011 for details). So, MEDINETTE is capable of recommending the previous collection process but it accompagnies it with scientific explanation to inform the user on the necessity to take care of the plant with respect to its volatility. To keep track of such wonderful knowledge contributes not only to use them to create placebo effect for those strongly attached to their beliefs, but also to preserve beliefs of traditional intevenors though an essential aspect of ATM.

7. Results, discussions and performance

The most important measure of a CADS is the quality of its results. While a complete patient evaluation is beyond the scope of this paper, the following shows our own experience with MEDINETTE for a specific clinical case.

We have assisted a traditional doctor during the treatment of a specific case and we utilized MEDINETTE to compare its results to those of the practitioner:

> The traditional doctor X welcomes a patient complaining to have fever, insomnia, general fatigue, headache, abdominal pain, constipation, and abdominal bloating. On the basis of this clinical tab, the practitioner refers to malaria and typhoid.
>
> We introduce symptoms into MEDINETTE and we obtain a set of diseases with Typhoid as the most relevant and Malaria as the second. Typhoid topping proposals, we consult the listing for this disease and we take this opportunity to recall knowledge about its symptoms. We discover that this disease is frequently encountered in underdeveloped areas such as villages in which people eat lot of grilled meat or/and where latrines are not always well equipped. Turning back to the case of the patient, and by browsing the list of proposals, we consult the record of Malaria and we realize that cases of constipation and big belly are rare for patient suffering from malaria.
>
> In his side, before confirming the diagnosis, the traditional healer asks the patient if he had bad dreams during the night. The patient reveals that he had dreams in which unknown individuals force him to eat some meat. The traditional healer concludes on a night poisoning.
>
> We introduce this new fact on the patient in our system as a traditional symptom (more specifically a bad dream symptom) and then the system infers night poisoning (rank = 0.85) and rank it on top of Typhoid (rank = 0.55) and malaria (rank = 0.35).
>
> The traditional healer then prepare some herbal-based medicine to treat the "mystic attack" on his patient. This treatment consists of a two months long consumption of a mix of honey, lukewarm water and leaves of a plant whose scientific name is "ageratum conyzoides", well known as "roi des herbes" in the francophone side of Cameroon, or "king grass" in the Anglophone side.
>
> MEDINETTE also suggest the same prescription in the list of its proposals.

Facing a system like MEDINETTE, the biggest problem of a user is the quality of the results he gets back. Some results can be very interesting and expand the user's horizon, when other results can be very frustrating and time consuming. MEDINETTE is designed to continuously enrich the user experience as the KB continues to grow rapidly. While evaluation of a CADS is difficult, we have subjectively found that MEDINETTE returns higher quality and large-scope results than the existing ATM CADS: the above use case supports it. It is the first one which deals with beliefs and mystical considerations in TM, and also the first which provides a function to rank its results. Finally, the use of patient profile and proximity information (localization of users) helps increase relevance for many queries. For example, the prescription support takes into account the availability of medicinal plants in the geographical area of the traditional healer. In order to reach this performance, MEDINETTE relies on its deep ontology consisting of ATM concepts and relations between them and, on Pellet inference Engine, a well known, approved and improved reasoning engine.

Table III shows a comparison of MEDINETTE and the existing systems with respect to some relevant criteria.

In addition to being a high quality and large scope ATM CADS, MEDINETTE is a research tool. In fact, the system enables the user to explore the KB to have a wide

	A	B	C	D	E	F	G	H
MEDINETTE	x	x	x	x	x	x		
SEIBOGA	x						x	
Atemezing *et al.*		x	x					
MEDTRAD+	x						x	
Ogirima *et al.*	x							x

Notes: Where the first column represents MEDINETTE and the other CADS found in the literature and the columns labeled from A to H represent the comparison criteria. A cross (x) in the table indicates that the system satisfies the criterion: A, is implemented; B, uses an ontology; C, takes into account traditional diseases (diseases known as "mystical", which cannot be tested by the western medicine); D, provides scientific explanations when handling some strange or mystical concepts; E, takes patient profile into consideration (age, sex, ethnic group, virgin, twin, etc.); F, ranks the results; G, provides an iconic GUI; and H, provides a mobile GUI

Table III. Comparison of MEDINETTE and the existing CADS for ATM

range of knowledge about ATM while handling cases. The data MEDINETTE KB has collected and will collect on ATM has already resulted in other papers presented in conferences and published in scientific journals, and many more on the way. This means that MEDINETTE is not only a valuable tool for research but also an interesting one for a wide range of applications. We hope MEDINETTE will be a resource for researchers all around the world and will enhance research on the next generation of TM knowledge-based systems.

To provide high-quality results is not the only interesting property of MEDINETTE. Beside that, MEDINETTE is designed to scale. It must be efficient in both space and time. The OWL format used to formalize the ontology has a good compression rate and there remains too many concepts, relations and SWRL rules to add in the file to reach a size that can really negatively influence the rapidity of search. Besides, the MEDINETTE's architecture allow it to handle an important concurrent users' requests. Although we expect to be able to build an ontology with about 5,000 concepts, 5,000 relations, 5,000 diagnosis rules and to have 5,000 users in the next months, we are too far to worry about scale.

Improving the performance of MEDINETTE was not the major focus of our work up to this point. However, the designed architecture and the technologies used to build MEDINETTE guarantee the performance of the system and permit it to scale with the size of the KB and the number of concurrent users. Our experiments show very fast responses (about two second) from the second query from each GUI view, the first one being more slow (about five seconds) because of the construction of JSF UI classes and agents' initialization. We performed our test on a localhost computer with an Intel dual core (1.86Ghzx2) and a RAM of 3 Gbytes. Our way to work with ATM ontology data are to load the ontology axioms and instances at runtime from an OWL file which current size is about 140 Kilobytes. This is a very flexible approach which works well for now, but has limitations. In particular, the application must parse the source documents each time it is run. For very large ontologies, as MEDITRONTOLOGY is intended to be, this can be a source of significant overhead. We intend to store the knowledge persistently in a database. This will saves the overhead of loading the model each time, and means that we will store OWL models significantly larger than the server's main memory, but at the expense of a higher overhead (a database interaction) to retrieve and update OWL data from the model. JENA's persistent database model will help us to manage this.

8. Concluding remarks

MEDINETTE is designed to be a large-scope ATM CADS that behaves like an African traditional doctor by providing support to medical diagnosis and prescription, and scientific interpretations of some of its results containing "mystical" knowledge. The primary goal is to provide high-quality results over a rapidly growing KB. MEDINETTE employs a number of techniques to improve search quality including a deep ATM ontology, multiple agents, concepts interpretations and proximity information. Furthermore, MEDINETTE is a complete architecture to allow ATM experts to enrich the KB and to perform search queries over it. A large-scope TM CADS is a complex system and much more remains to be done. Our immediate goals are to enrich the ATM ontology and to deal with patient records. To favour the KB growing, it is important to actually host MEDINETTE on a server accessible through internet to allow ATM Experts all around the world to propose updates. Patient records could improve case-specific search efficiency. For now, none of existing TM CADS considers the patient medical history though an important aspect of clinical decisions. We think that the medical history of a patient will improve the diagnosis ranking function which will then take into account the medical background to compute the rank of each plausible disease. We are planning to add a feature supported by other ATM CADS such as Frasson *et al.* (1992) and Brou *et al.* (2010): the use of an iconic GUI to facilitate utilization and to allow illiterate traditional doctors to rapidly learn to use MEDINETTE. A CADS is a very rich environment for research ideas, especially for a domain-like ATM. We have far too many to list here so we do not expect future works to be exhaustive.

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