MIKONOS: A Middleware-oriented Integrated Architecture for Clinical Knowledge based on Computational Intelligence Techniques

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Abstract- This proposal outlines the development of an infrastructure for the knowledge integration and interoperability in medical entities. The impact of this proposal resides in improving the quality of healthcare services by using semantic Web and computational intelligence techniques. As salient contributions, this work presents the use of semantic Web and Case-Based Reasoning techniques used for medical diagnosis and for developing a medical knowledge memory. Finally, we emphasize our work in comparison with related works in this field and we outline the future work.

Keywords: Case-Based Reasoning; Clinical Knowledge, Medical Diagnosis; Semantic Web.

1 Introduction

Healthcare is a field in which accurate record keeping and communication are critical and yet in which the use of computing and networking technology lags behind other fields. In current healthcare, information is conveyed from one healthcare professional to another through paper notes or personal communication. In an age of electronic record keeping and communication, the healthcare industry is still tied to paper documents that are easily mislaid, often illegible, and easy to forge. When multiple healthcare professionals and facilities are involved in providing healthcare for a patient, the healthcare services provided are not often coordinated [1]. For instance, in low-income countries health care services have become fragmented and organized by a specific health problem. Organization by a specific health problem or specialization usually means people need to visit separate and specialized clinics depending on their health problem [2]. Other aspect to be considered is the interoperability. Data sharing and exchange have always been considered the biggest challenge

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for autonomous heterogeneous medical information systems. It is frequently observed that the knowledge required to solve a healthcare problem is spatially distributed in different locations.

Nowadays, healthcare systems require architectures that offer more than enhanced interoperability and integration potential at local level. In recent years, Service-Oriented Architecture (SOA) has emerged as an architectural paradigm for creating and managing services that can software functionality and access these functions, assets, and pieces of information with a common interface regardless of the location or technical makeup of the function or piece of data [3]. SOA is playing major role in the development of healthcare system which helps to exchange the information between similar and dissimilar medicine applications. Clinical knowledge integration based on SOA can address some of these issues and problems. In this sense, a distributed Integration architecture for clinical knowledge integration through semantic Web and Case-Based Reasoning techniques for developing a knowledge capitalization tool offers to the user a way to automatically store and reuse the experience accumulated in the decision-making process for medical diagnosis. Having this into account, this paper presents a middleware-oriented integrated architecture for Clinical Knowledge Integration based on Computational Intelligence Techniques for medical diagnosis and for developing a medical knowledge memory.

2 Middleware-oriented Integrated Architecture

With an SOA infrastructure, we can represent software functionality as discoverable services on a network. SOAs have been around for many years but the distinctive feature of the SOAs is that they are based on Internet and Web standards, in particular, Web services. Web services are designed to provide interoperability among diverse applications. Nowadays, a growing number of enterprises, commercial and healthcare systems are redefining their processes under this technology. The platform and language independence of the Web services programming interfaces enable the seamless integration of heterogeneous Web based-systems. In this work, we proposed an SOA-based integration architecture. In Fig.1 each component of the architecture has a defined function, which are briefly described next.

Healthcare services registry: In this component, the healthcare services described as Web services descriptions and metadata information are stored. The category, properties, capacities, localization and access information of available services are inside the metadata information. For the knowledge search, classification and acquisition, the use of OWL-S ontologies in the clinical context is outlined. OWL-S is a Web service ontology, which supplies Web service providers with a core set of markup language, constructs for describing the properties and capabilities of their Web services in unambiguous, computer-interpretable form. Ontology defines the terms for using, describing and representing a knowledge field. For the development of ontologies was considered the use of METHONTOLOGY. The main steps of METHONTOLOGY are: (1) specification of the goal, the reach and granularity of the ontology, (2) Conceptualization that helps to organize and to structure the acquired knowledge using independent representation languages of the implementation languages, (3) Implementation that consists in the formalization and implementation of the conceptual pattern with formal languages such as Ontolingua, RDF / S (Resource Description Framework / Schema), OWL, and (4) Evaluation. This approach used conceptual maps for the development of ontologies for modeling the knowledge domain. The conceptual maps were built with CmapTools. The OntoTermTM system for the management of terminological databases was used [4]. This system allows user the creation of customized terminological database on a knowledge domain. Protégé was used for building and modeling the OWL ontology which was tested in the Jena framework. Jena allows the use of ontologies for developing Web applications. The queries are carried out with SPARQL.

SOAP Message Analyzer: This component determines the structure and content of the documents exchanged in healthcare services involved. This component determines the information involved of the incoming messages by means of XML parsers and tools. A DOM API is used to generate the tree structure of the messages, whereas SAX is used to determine the application logic for every node in the messages. A set of Java classes based on JAXP [5] were developed to build the XML parser.

Discovery Service: It is a component used to discover healthcare services implementations. Given the dynamic environment in medicine, the power of being able to find healthcare services on the fly is highly desirable. A key step in achieving this capability is the automated discovery of healthcare services described as Web services. These Web services can be obtained from suitable service providers and can be combined into innovative and attractive ways. When there is more than one service provider of the same function, it can be used to choose one service based on the user's requirements. Inside the discovery service, there is a query formulator which builds queries based on the domain ontology that will be sent to the healthcare services registry. This module retrieves a set of suitable services selected from the previous step and creates feasible/compatible sets of services ready for binding.

Dynamic Binding Service: It is a component that binds compatible healthcare services described as Web services. The binding of a healthcare service refers to how degree of coupling with other service is. For instance, the technology of one healthcare service provider might be incompatible with that of another even though the capabilities of both of them match with some requirements. In this sense, the module acts as an API wrapper that maps the interface source or target healthcare services to a common interface supported by our approach.|

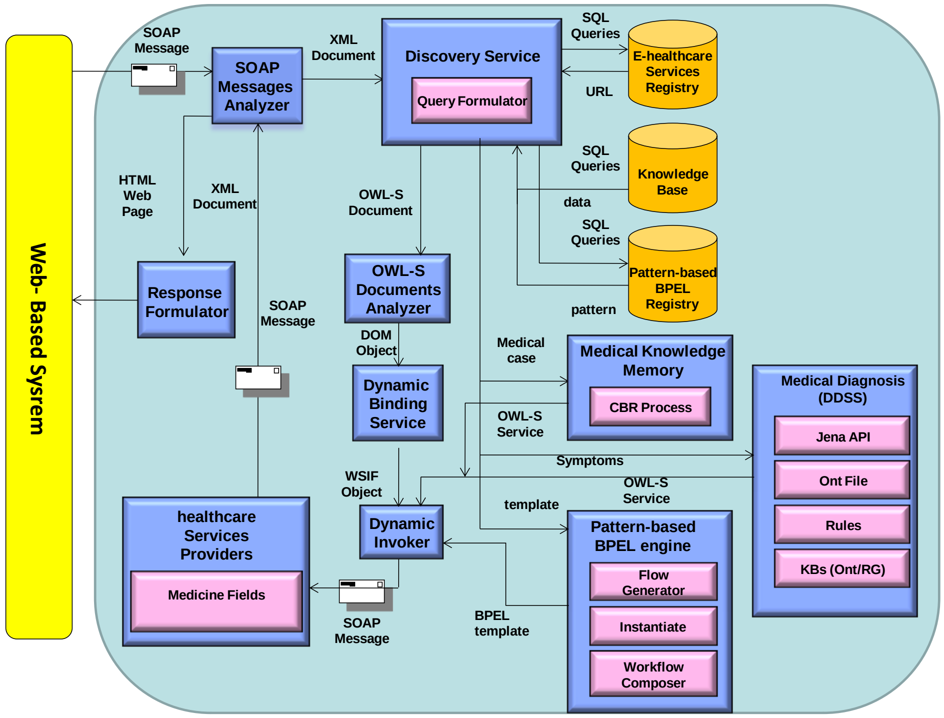

Fig. 1 General architecture for the clinical knowledge integration system

Dynamic Invoker: This component transforms data from one format to another. This component can be seen as a data transfer object which contains the data (i.e., request or response) flowing between the requester to the provider applications of e-healthcare services. We used Web Services Invocation Framework (WSIF) that is a simple Java API for invoking/consuming e-healthcare services described as Web services, no matter how or where the services are provided [6].

Response Formulator: This module receives the responses from an e-healthcare service provider about a requested clinical service. This module retrieves useful information from the responses and builds a XML document with information coming from the service registry and the invocations' responses. This XML document is presented in HTML format using the Extensible Style sheet Language (XSL).

OWL-S Document Analyzer: This internal validates OWL-S documents that describe e-healthcare services. OWL-S documents employ XML Schema for the specification of information items either technical information or healthcare services operations. In this context, this component reports the healthcare services operations, input and output parameters, and their data types in a XML DOM tree.

Workflow Engine: This module coordinates Web services by using a BPEL-based healthcare services language. It consists of building at design time a fully instantiated workflow description where Web services descriptions are dynamically defined at execution time. We have designed and implemented a repository of generic BPEL workflow definitions which describe increasingly complex forms of recurring situations abstracted from the various stages from an integration process. This repository contains workflow patterns of interactions involved in integration scenarios for healthcare services. These workflows patterns describe the types of interactions behind each healthcare service, and the types of messages that are exchanged in each interaction.

Healthcare services providers: This component represents information subsystems that have attended the clinical diagnosis by using CBR and Semantic Web techniques. These subsystems are located in different domains of health such as pathology, neonatal, pediatrics, among others.

Medical case-based memory: In this module users have access to a set of solutions derived from real problems and the praxis of an expert panel. The medical case memory has its theoretical foundation over the Case-Based Reasoning (CBR) process. The subjacent approach of the CBR was developed in the Artificial Intelligence (AI) field as a flexible and easy to evolve tool for problem solving. Furthermore, artificial intelligence and more precisely knowledge management approaches try to use past experiences in order to solve new problems.

In the next section, we describe how semantic web technologies and the case-based reasoning process were integrated in our architecture for developing a medical knowledge memory and a medical diagnosis system. These are the more relevant aspects of our approach.

3 Using semantic Web and Case-Based Reasoning techniques for medical diagnosis and for developing a knowledge capitalization tool

Semantic Web Technologies [7] have emerged as an attempt to provide machine-processable metadata to the ever increasing information resources on the Web. These software standards and methodologies may be applied to particular application domains in order to make maximum use of Semantic Web representation specifications such as RDF. Such specifications can define the terminology of a scientific domain as a computer-interpretable ontology, using XML as the syntax for data interchange. In our work, we have integrated a medical diagnosis system based on Semantic Web capabilities namely ODDIN [8]. The system was initially constructed and named Ontology DDx (ODDx) where DDx stands for "differential diagnosis". This work was based on the development of this system in Java language programming, with the use of ontologies as knowledge database or knowledge representation in order to allow inference engines to work with the system. The ontology used by the system was built using the international classification of diseases version 10 [9], diseases implemented by the WHO [10]. Figure 2 represents the ontology built and some of the relationships that exists between classes and properties. The most of the relationships (ObjectTypeProperties) established in the ontology were used to establish a relation between Diseases and Symptoms, or Diseases and Laboratory Tests. However, there are other kind of relationships like the relation between Medicines and Symptoms, in order to set possible reactions (signs or symptoms) that a medicine can provoke. The DataTypeProperties are used to describe the sign, disease or any other item of the ontology. The typical properties are set, like name, description, etc. One important property is “code” that identify the code of the sign (normally, using ICD codes). The figure 3 shows how the diseases and their relationship with the symptoms or laboratory tests are described.

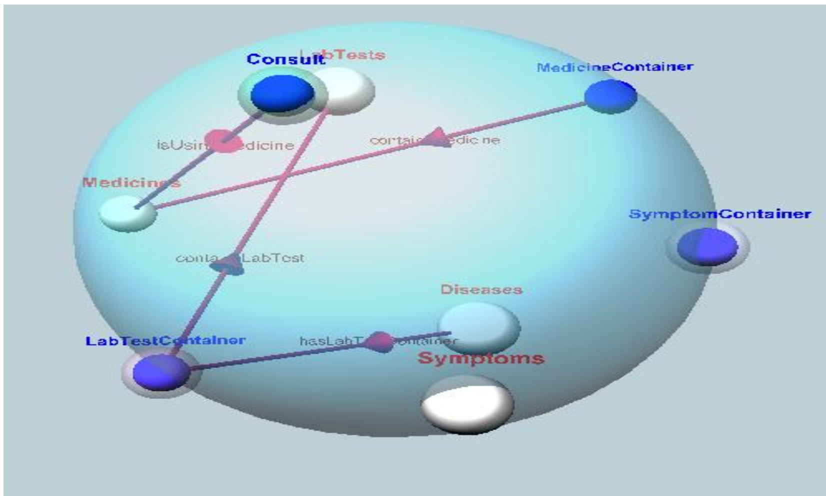

Fig. 2. Representation of the ontology for medical diagnosis.

The main representation of this disease in the ontology is as follows:

- hasSymptom: Used to make relationship between diseases and symptoms.
  - SYM A
  - SYM E
- hasLabTest: Used to make relationship between diseases and laboratory tests.
  - LT 1

All the ObjectTypeProperties connect instances, so, in this case for example for “SYM_A”, the connection is as follows:

DIS_X (Instance of DIS_X_Class) hasSymptom SYM_A (Instance of SYM_A_Class)

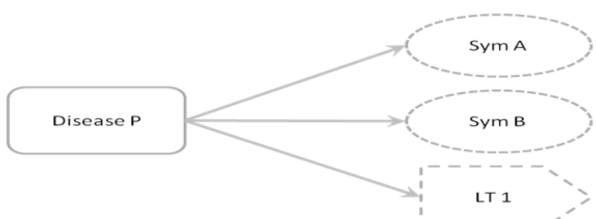

Fig. 3. Representation of a disease

The inference system used to build this system was based in Jena Rules [11]. The description represented in Figure 3 is translated from Description Logics (DL) to this kind of rules. The Inference Architecture is represented in Figure 4. In these cases, forward chaining and backward chaining rules were used.

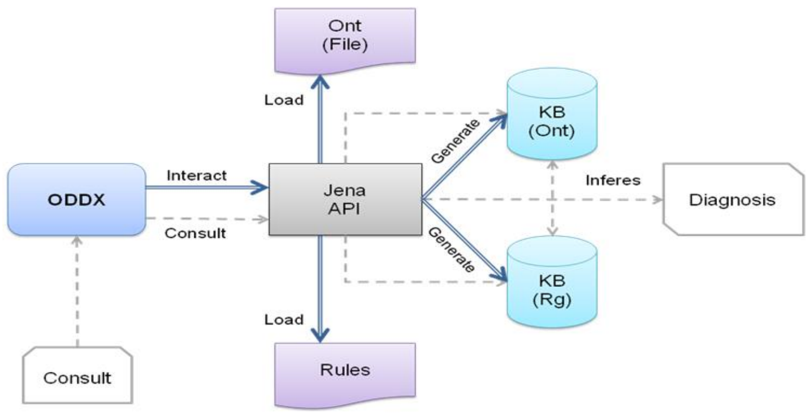

Fig. 4. Representation of the architecture of the inference system

In another hand, we implemented a Case-Based Reasoning (CBR) process for building a medical knowledge memory that facilitates knowledge transfer and training. Because this memory facilitates the storage and transfer of knowledge that could be reused when a similar context is identified, our proposal address a student centered teaching /learning approach and active student participation in the process of medical assessments and treatments. The main idea in CBR is that similar problems have similar solutions. Basically in a CBR system, users search to solve a new problem by establishing some common characteristics between the initial problem (the problem to solve or target problem) and some previous solved problems. Then, the CBR process reutilizes and adapts earlier successful solutions in order to solve the new problem, which in fact imitates everyday human problem solving process. CBR traces its roots to the work of Schank [12] on dynamic memory. In our proposal, we describe the memory-based approach to reasoning, which means that human memory is dynamic because the experiences acquired while solving problems, radically modify the way to face new problems. Thus, these new experiences which inherently contain some lessons learned in a particular context could be used to face new problems. A case is then a solved problem in a particular domain that has been characterized, captured and indexed in a memory for further utilization. A case is usually composed of three elements: the problem description, the solutions applied and its intrinsic result. Eventually it is also added the strategy to deploy or apply the solution. Then an expression of a case is: Case (Pb, Sol (Pb), Re), where Pb represents the problem description, Sol the associated solution for this problem and Re, the obtained result that could be success or a failure.

CBR involves a process where learning is a capital benefit. If a CBR system is intensely used, its case-memory will have more problem situations and then its capacity to create more solutions will increase. CBR is a very flexible process because as cases are added to the memory, the system should be able to reason in a wider variety of situations and with a higher degree of refinement and success. A CBR system assists users when reasoning with incomplete or imprecise data and concepts. This condition is materialized when measuring similarity between two problems. The difference should be explained and surmounted in order to propose an efficient solution and thus, impelling reasoning. Avoiding repeating all the steps that need to be taken to arrive at a solution, because the solving process starts remembering previous solution. This process also allows capitalize the steps taken to reach one solution in order to be reused for solving other problems. The CBR process has a wide application domain. It can be used for many purposes, such as creating a plan, making a diagnosis, and arguing a point of view. Therefore, the data dealt with by a CBR system are able to take many forms, and the retrieval and adaptation methods will also vary [13]. Thus, a CBR system solves problems by acquiring knowledge and reusing this knowledge in a similar context. This is a four stages process usually called the 4R´s process for retrieve, reuse, revise and retain [14], [15]. These processes have been implemented using the JColibri 2.1framework [16] useful to build CBR systems. The main objective of this system is to offer a knowledge base for pneumonia treatment in the neonatology department. Figure 5 shows the essential components for a case stored in the knowledge memory. This system stores knowledge extracted from a panel of experts and then this knowledge is socialized in a collaborative Web by proposing a comparative interface. In this interface a non-expert could propose a treatment for a solved pneumonia case and then this treatment is compared with the treatment proposed by an expert to measure the similarity. Figure 6 shows this collaborative interface.

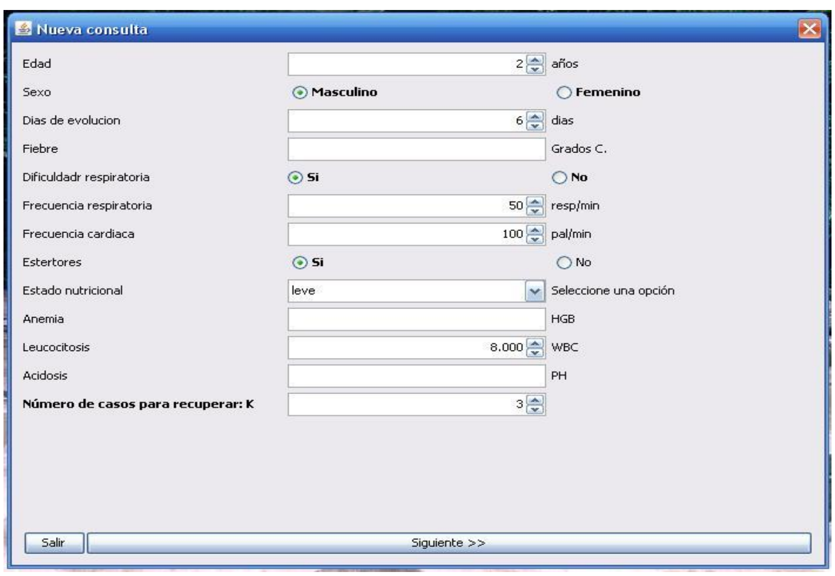

Fig 5. Case description using JColibri

Fig.6. The collaborative interface

We validated our proposal developing a Web-based system to improve the quality of the services that offer the regional hospital of Rio Blanco (HRRB) located in Veracruz, Mexico with the purpose of helping in the process of decision taking, research and specialist's formation and medical residents. It is a medical center which has different medicine fields.

4 Related Works and Discussion

In recent years, different approaches have been proposed for building healthcare systems by using Semantic Web technologies. These initiatives go from the description of integration architectures to the use of emergent IT. Some of these works have obtained outstanding partial results for the clinical knowledge integration. In comparison with our work, these proposals do not cover all the features presented here. For instance, service-oriented architectures in healthcare systems are presented in [1, 17, 18, 19, 20, 21, 22, 23, 24]. These works only propose layered architectures for support of doctors, nurses and patients but they did not implement computational intelligence techniques.

The development of Medical Differential Diagnosis and Therapy systems using computational intelligence has gained momentum over the last years [25]. Approaches in research which apply the use of combined techniques such as the current one include neuro-fuzzy methods [26], the application of genetic algorithms (GAs) for rule selection [27], or the unification of genetic algorithms with fuzzy clustering techniques [28]. Other methods apply a single approach, applying neural networks, GAs, or fuzzy inference systems [29, 30, 31]. A large number of medical diagnosis systems is also available, including DiagnosMD, DXPlain [32], eMedicine, Isabel [33], IWSMD [34], EasyDiagnosis, ADM [35], and Your Diagnosis. Other types of systems exist, such as those based on the PDP model [36]. Nevertheless, the application of Semantic Web to this concrete field (medical diagnosis in particular) is not fully exploited. Actually, exists a lot of papers about clinical knowledge representation like OBO Foundries [37], Biological Ontologies [38], Ontology-Based Support for Human Disease Study and Medical Ontologies to support human disease research and control [39], and Relations in biomedical ontologies [40]. Other works, talk about the construction of a medical domain ontology to build medical decision support systems [41], or the use of ontologies for the patient modeling in medical management systems [42].

Finally, some works have used Case-Based Reasoning for developing medical diagnosis systems and medical trainers. A case-based analysis of health care data quality problems in a situation, where data of diabetes patient are combined from different information systems is presented in [43]. In [44], a medical reasoning system by using differential diagnosis is described. This style of reasoning consists of the following three kinds of reasoning processes: exclusive reasoning, inclusive reasoning and detection of complications, which corresponds to screening, differential diagnosis, and close examination of each case.

5 Conclusions

In this work was presented an SOA-based approach with workflow-enabled capabilities beyond integration and interoperability within the healthcare organization. The proposed architecture enables clinical knowledge integration through a set of loosely-coupled software components as a proof-of-concept implementation by using semantic Web and computational intelligence techniques for medical diagnosis and for developing a medical knowledge memory. This integration covers several advantages: the system is useful to assist decision taking and to facilitate service selection for a patient; it is a very valuable resource in research activities; it is an axis that support organizational learning because experiences are shared through an organizational memory, increasing efficiency in the learning process of medical residents and students, for mentioning a few.

The proposed architecture follows design principles like interoperability, integration, dynamism, abstraction and scalability. Future research will focus in designing and building a healthcare service bus that will be able to manage rich, complex, and high-value workflows across applications, departments, and geographic locations. A healthcare service bus will be a standards-based platform that will combine messaging, web services, data transformation, and intelligent routing to reliably connect and coordinate the interaction of diverse applications across extended healthcare systems with transactional integrity.

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