Survey Report

Intelligent Decision Support Systems and Role of Ontologies for semantic interfaces in Healthcare Systems

Submitted To
Dr. Richard Frost

By
Ramya Vinothan

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ABSTRACT

In today's world, there is a growing trend for the implementation of healthcare information systems at all levels. This growth requires the unification of multiple standards and mechanisms for supporting diverse multidisciplinary needs and approaches to healthcare delivery. Most of these large-scale programs are being undertaken against the context of existing specialist and departmental information systems that often incorporate some decision-support functionality. This survey is an aim to explore the issues in defining useful and useable ontologies for decision-support functions in large-scale multidisciplinary healthcare systems.

ACKNOWLEDGEMENT

I have the honor to acknowledge the knowledge and support I received from Dr. Richard Frost throughout this survey. I convey my deep regards to my supervisor Dr. Robert Kent for encouraging me and helping me unconditionally. I would also like to thank my family and friends for providing me immense strength and support in completing this survey report.

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INTRODUCTION

Decision Support Systems

A Decision Support System (DSS) is an interactive computer-based system that supports decision making activities. As noted in Wikipedia, a DSS “compiles useful information from a combination of raw data, documents, personal knowledge, and/or business models to identify and solve problems and make decisions”. Few notable benefits of DSS include improvement in personal efficiency, expedited problem solving, better interpersonal communication, increased organizational control, new evidence based support for decision-making, and automation of the managerial processes.

History

According to Keen (1978), the concept of decision support evolved from the theoretical studies of organizational decision and the technical work on interactive computer systems. While the former was conducted during the late 1950s and early 1960s at the Carnegie Institute of Technology, the latter was carried out exclusively at the Massachusetts Institute of Technology in the 1960s. Various perceptions of the field of DSS at different points that have been reported as important (Eom and Lee, 1990; Silver, 1991; Power (2003,2004); Arnott and Pervan, 2005; McCosh and Correa-Perez, 2006). Sheng and Zhang (2009) note in their work that the history of DSS can be traced back to around 30 years, and that the first DSS was REVIEW, designed by Tymshare in 1969. From the middle to end of 1980s, the evolution of Executive Information Systems (EIS), Group DSS(GDSS), and Organizational DSS (ODSS), from single user and model-oriented DSS, took place. By 1990s, DSS encountered new challenges towards its design in the form of intelligent workstations. From the beginning of 1990, data warehousing and on-line analytical processing (OLAP) began broadening the realm of DSS. The millennium witnessed the introduction of new Web-based analytical applications within the DSS.

Structure of the survey

This survey mainly focuses on the semantic interfaces provided by ontologies in intelligent decision support systems within the health care domain. Section 2 covers the Intelligent DSS, and trends in the development of IDSS. Section 3, on the other hand, contains a detailed description of ontologies and the semantic interface provided by medical ontologies. The next chapter, section 4 deals with the development of certain IDSS that make use of ontologies for providing semantic interoperability in healthcare. The last chapter, section 5, provides some concluding comments.

2. Intelligent Decision Support Systems (IDSS)

A DSS couples intellectual resources of individuals with computer capabilities to improve decision-making. Proposed by Bonczek in the 1980s (Sheng and Zhang, 2009), IDSS is a term that describes DSS that make extensive use of artificial intelligence (AI) techniques. IDSS has the characteristics of open, distributed, resource reused, group intelligence experience integrated, web circumstance based, static programming decision breached, and man-machine combined (Liu et al., 2006). “Clinical decision support systems (CDSS) can significantly increase the quality of care while decreasing cost and effort” (Blynkh, I. et al., 2006).

IDSS is believed to solve many problems that traditional DSS cannot solve, through integration of techniques such as machine learning, knowledge representation, pattern recognition, etc. Many IDSS implementations are based on expert systems, a type of Knowledge Based Systems that encode the cognitive behavior of human experts using predicate logic rules and have been shown to perform better than the original human experts in some circumstances. Expert systems typically combine knowledge of a particular application domain with an inference capability to enable the system to propose decisions or diagnoses. Accuracy and consistency can be comparable to that of human experts when the decision parameters are well known (e.g. if a common disease is being diagnosed), but performance can be poor when novel or uncertain circumstances arise.

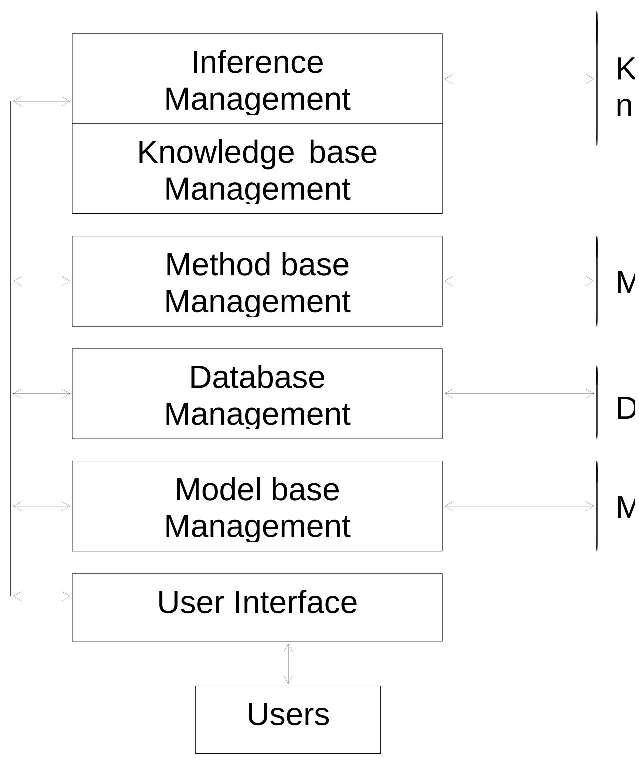

Figure 1: Structure of IDSS [Liu et al., 2006]

2.1. Trends of Development in Intelligent Decision Support Systems

- **Group Decision Support Systems (GDSS):** These systems are designed to enable a group of participants to work interactively in an electronic environment. GDSS systems help users to solve complex problems, prepare detailed plans and proposals, resolve conflicts, and analyze and prioritize issues effectively. They are excellent in situations involving visioning, planning, conflict resolution, team building, and evaluation. GDSS deal with many fields about technology and methods, including communication technology, structural group decision methods, and so on.
- **Distributed Decision Support Systems (DDSS):** Distributed decision support systems are composed of many information processing nodes, where every node of network has functions to support decisions or auxiliary decisions. Notable advantages for DDSS are reliability, efficiency in large-scale decision-making, and expandability. The range of research for DDSS relates to many fields.
- **Strategy Decision Support Systems:** Also called Strategy Information Systems, these play an important role for high hierarchy leaders to make strategic decisions. It is composed of database system, model and method system, knowledge system and case analysis system.

Research focused on enabling systems to respond to novel and uncertain issues in more flexible ways is starting to be used in IDSS. For example, intelligent agents that perform complex cognitive tasks without any need for human intervention have been used in a range of decision support applications. Capabilities of these intelligent agents include knowledge sharing, machine learning, data mining, and automated inference. It is expected that by 2020, IDSS using AI techniques such as case based reasoning, rough sets, and fuzzy logic, will be capable of fully performing many management roles currently undertaken by advisors, consultants, editors, and personal assistants.

3. Ontologies and Semantics

3.1. Ontologies

An Ontology is a data model that represents a set of concepts within a domain and the relationships between those concepts. It is used to reason about the objects within that domain. Ontologies are used in artificial intelligence, the semantic web, software engineering, biomedical informatics, and information architecture as a form of knowledge representation about the world or some part of it. Ontologies generally describe:

- *Individuals:* the basic or primary objects
- *Classes:* sets, collections, or types of objects
- *Attributes:* properties, features, characteristics, or parameters that objects can have and share
- *Relations:* ways that objects can be related to one another
- *Events:* the changing of attributes or relations

An ontology language is a formal language used to encode the ontology. They allow the encoding of knowledge about specific domains and often include reasoning rules that support the processing of that knowledge. There are a number of proprietary and standards-based languages for ontologies, such as:

- OWL – Ontology Web Language (OWL) is a family of knowledge representation languages for authoring ontologies, and is endorsed by the WWW Consortium.
- KIF - Knowledge Interchange Format (KIF) is a computer-oriented language for the interchange of knowledge among disparate computer programs.
- CycL - Ontology language for an AI project that attempts to assemble a comprehensive ontology and database of everyday common sense knowledge, with the goal of enabling AI applications to perform human-like reasoning.
- RIF - Rule Interchange Format (RIF) effort involves the development of a format for interchange of rules in rule-based systems on the semantic web. The goal is to create an interchange format for different rule languages and inference engines.

After CycL, a number of ontology languages, mostly declarative in nature, have been developed. These languages are either frame languages, or based on first-order logic. Most of these languages only define an upper ontology with generic concepts, whereas the domain concepts are not part of the language definition.

Ontologies are used in AI, Semantic Web, systems engineering, software engineering, biomedical informatics, library science, enterprise bookmarking, and information architecture as a form of knowledge representation about the world or some part of it. The creation of domain ontologies is also fundamental to the definition and use of an enterprise architecture framework.

3.2. Semantics

Semantics is the study of meaning. Semantics denotes ideas ranging from the most popular to the highly technical. In computer science, the term semantic is applied to certain types of data structures specifically designed and used for representing information content. The World Wide Web has been extended with additional semantic metadata to form the Semantic Web. This semantic modelling has been achieved using XML-based knowledge representation languages such as Resource Description Framework (RDF) and Web Ontology Language (OWL).

Ontological semantics, an integrated complex of theories, methodologies, descriptions, and implementations, attempts to systematize ideas about both semantic description as representation and manipulation of meaning by computer programs (Nirenburg and Raskin, 2004). Ontological semantics is a constantly evolving field, driven by the need to make meaning manipulation tasks such as text analysis and text generation work.

3.3. Semantic/Ontology Projects and Tools in Healthcare

There are many open source projects and tools available related to semantics and ontologies such as OntoWiki, Protégé, Jena, Powl, *Nepomuk Semantic Desktop Project, and* CuiTools. Examples of open source Medical Semantics/Ontology projects and tools are:

- *ARTEMIS Project* - A Semantic Web Service-based P2P Infrastructure for the Interoperability of Medical Information Systems. This project has been primarily developed to provide the exchange of meaningful clinical information among healthcare institutions through semantic mediation.
- *MII Medical NLP Toolkit* - This is a toolkit for medical natural language processing (NLP). The core engine is general enough to be used in a variety of text processing domains, though the toolkit includes specific support for medical reports and patient identification.
- *ONTODerm* - ONTODerm is a specialty specific ontology to integrate dermatology with medical software systems.
- *Medical Language Processing* - Natural language processing of free-text clinical documents into an information representation in XML accessible via a rich system of categories familiar to clinicians.

Other major health care related projects, tools and organizations include GALEN, Gene Ontology, UMLS, medSLT, SNOMED-CT, and SAPPHIRE. Some notable examples of published ontologies include Protein Ontology, WordNet Semantic Lexicon, Foundational Model of Anatomy (FMA

Ontology), Systems Biology Ontology (SBO), General Ontology for Linguistic Description (GOLD), and Gene Ontology.

3.4. Semantic Interoperability and Ontologies

Integrating ontologies for semantic interoperability systems within the healthcare domain results in more powerful information systems and also supports the need to transmit, re-use and share patient data. Ontologies can also provide semantic-based criteria to support different statistical aggregations for different purposes. Another significant contribution of ontologies to healthcare systems is their ability to support the indispensable integration of knowledge and data. Some other ways the healthcare system can be improved by using medical ontologies and semantic interoperability tools and practices include improvement in diagnosis accuracy by providing real time correlations of symptoms, test results and individual medical histories through standards-based systems for systematic cross-checking diagnoses, increase in prompt payment of claims by reducing billing questions through adoption of IT standards for clinical care codes, medical nomenclature, lab tests, etc., and reduction in fraudulent actions on the overall system by the use of semantic interoperability tools.

For General Semantic Interoperability issues, some form of foundation ontology, also called upper ontology, is sufficient to provide the defining concepts for more specialized ontologies in multiple domains. More than ten foundation ontologies have been developed in the past, but none have as yet been adopted by a wide user base. The need for a single comprehensive all-inclusive ontology to support Semantic Interoperability can be avoided by designing the common foundation ontology as a set of primitive concepts that can be combined to create the logical descriptions of the meanings of terms used in local domain ontologies or local databases.

4. IDSS and medical ontologies for semantic interoperability

Medical information systems need to be able to communicate complex medical concepts unambiguously, even those expressed in different languages. This task requires extensive analysis of the structure and the concepts of medical terminologies and can be achieved by constructing medical domain ontologies for representing medical terminology systems. An information model is needed to describe the relationships of different data elements in a patient's medical record. Assumptions are made for data elements and relationships in the information model.

4.1. Computerized Practice Guidelines

Computerized Clinical Practice Guidelines (CPGs) are more effective when embedded with the clinical workflow to enable practitioners to execute the CPG at the point of care, to collect / retrieve relevant patient data, standardize the delivery of care and optimize utilization of the institution's resources. Clinical Decisions are made with recommendations from Clinical Practice Guidelines (CPGs) that aim to guide decision making regarding diagnosis, management, and treatment in specific areas of healthcare. CPGs also define the most important questions related to clinical practice and identify all possible decision options and their outcomes. The following list of papers address intelligent decision making using CPGs.

Paper Title and Authors	**Year**	**Major contribution**
Ontology-based Modeling of Breast Cancer Follow-up Clinical Practice Guideline for Providing Clinical Decision Support, *Abidi, S. R.*	2007	Provide trusted CPG mediated recommendations for breast cancer patient data at the point of care
Ontology Driven CPG Authoring and Execution via a Semantic Web Framework, *Hussain, S. and Raza Abidi, S.S.*	2007	Automate CPG and integrate it within a CDSS to make decisions based on individual patient records.
KON^3: A Clinical Decision Support System, in Oncology Environment, Based on Knowledge Management, *Ceccarelli, M., Donatiello, A. and Vitale, D.*	2008	Recognizing methods and tools to make KON^3 system to represent semantic information in the oncology environment.

Table 4.2: Papers addressing Decision making using CPGs

4.2. Semantic Integration

Semantic integration is the process of interrelating information from diverse sources. Medical information in various healthcare institutions is heterogeneous, in terms of physical and logical structure, and semantics. Lack of integration between such health information systems leads to patients' medical records being scattered in various places, resulting in patients' not getting medical care in places where no medical record is readily available. Semantic interoperability contributes to improved health care by delivering the right meaning of medical terminology via a service-oriented web-based solution. The following list of papers address intelligent decision-making using ontologies for semantic integration and interoperability.

Paper Title and Authors	**Year**	**Major contribution**
KnowBaSICS-M: An ontology-based system for semantic management of medical problems and computerised algorithmic solutions, *Bratsas, C., Koutkias, V., Kaimakamis, E., Bamidis, P.D., Pangalos, G.I. and Manglaveras, N.*	2007	Aims to organize and manage unstructured/ semi-structured and widely scattered information related to Medical Computational Problems (MCP).
Semantic-based exchanger of electronic medical records, *Al-Safadi, L.A.*	2008	Addresses problems of integration, interoperability and schema matching in the healthcare domain without altering existing medical records (EMRs).
An Ontology-based Framework for Managing Semantic Interoperability Issues in e-Health, *Ganguly, P., Chattopadhyay, S., Paramesh, N. and Ray, P.*	2008	Promotes semantic interoperability by solving ontological mismatches by providing a dialogue mechanism and a decision support system.
Ontology driven semantic profiling and retrieval in medical information systems, *Bhatt,M., Rahayu, W., Soni, S.P. and Wouters, C.*	2009	Addresses problem of semantic interoperability and information validity by using a sub-ontology extraction module to be applied in Medical Information Systems (MIS).

Table 4.2: Papers addressing Decision making using Semantic Integration and Interoperability

4.3. Question Answering

Question Answering (QA) aims to provide inquirers direct and precise answers utilizing both techniques of Natural Language Processing (NLP) and Information Extraction (IE) (Athenikos, 2009). Trivial fact based questions that have developed into complex questions need to be answered in order to explore the semantic structures in QA. In recent times, question answering is progressing from identifying and interpreting simple facts to understanding and reasoning in the context of complex scenarios. Resolving a complex question is achieved by subdividing it into simple questions that can be answered easily. The following list of papers address intelligent decision making using ontologies and based on Question Answering.

Paper Title and Authors	**Year**	**Major contribution**
Situated question answering in the clinical domain: selecting the best drug treatment for diseases, *Demner-Fushman, D. and Lin, J.*	2006	Answering questions related to clinical patient care by portraying evidence-based medicine (EBM) in a semantic domain model to help QA performance.
Complex Question Answering Based on a Semantic Domain Model of Clinical Medicine, *Demner-Fushman, D., PhD Thesis*	2006	Complex question answering by using a semantic domain model within EBM to encode a clinician's information need and meaning of scientific publications.

Table 4.3: Papers addressing Decision making based on QA

4.4. Others

Due to the complexity and diversity of data, it is an exigent task to visualize and interpret patient data, which involves various structures and semantics that are not comprehensible to the system. Medical applications that provide diagnosis based on decisions from different users supported by remote knowledge databases use different nomenclature systems leading to terminological interoperability problems and lack semantic support and types. Clinical pathways, one of the main tools to manage quality in healthcare, support well-organized and proficient patient care based on evidence. The disadvantages of paper-based clinical pathways such as size of paper media, difficulty in transferring paper documents, and solutions of only certain predefined outcomes mentioned in the documents, make it necessary for development of web-based computerized systems. The following table provides a list of papers that address decsion-making using semantic visualization, and semantic modeling of medical information.

Paper Title and Authors	**Year**	**Major contribution**

Ontology-Driven Intelligent Decision Support of OOTW Operations: Health Service Logistics Support, *Smirnov, A., Chiloy, N., Pashkin, M. and Levashova, T.*	2005	Addresses the problem of implementing the aggregate of activities such as efficient knowledge sharing and integration for intelligent support of OOTW, using a constraint satisfaction approach for semantic interoperability.
OntoQuest: A Physician Decision Support System based on Ontological Queries of the Hospital Database, *Popescu, M. and Arthur, G.*	2006	Addresses the problem of reducing medication errors due to physicians' mistakes by using data driven Just-In-Time data mining technique on a hospital database.
Semantic Visualization of Patient Information, *Zillner, S., Hauer, T., Rogulin, D., Tsymbal, A., Huber, M., and Solomonides, T.*	2008	Solves the problem of visualizing hierarchical classification of patients by viewing the patient database with an ontology that encapsulates the semantics for database attributes.
A UMLS interoperable solution to support collaborative diagnosis decision making over the internet, *Pires, D. F., Teixeira, C. A., and Ruiz, E. E.*	2008	Addresses ontology interoperability problem by presenting a UMLS interoperable solution for clinical decision-making.
An ontology-based hierarchical semantic modeling approach to clinical pathway workflows, *Ye, Y., Diao, X., Du, G., Jiang, Z. and Yang, D.*	2009	Provides real-time monitoring in healthcare through a computerized clinical pathway workflow at a semantic level using an ontological approach.

Table 4.4: Papers addressing Decision making using other semantic approaches

5. Conclusions

The set of technologies associated with semantics and ontologies in health care are still in the early stages. Integration of major commercial database companies working in collaboration with large scale integrators on public-private sector projects will help break through some existing major barriers.

With Extended Markup Language (XML) as an emerging standard for lists posted in the Internet, a large number of medical ontologies will be available in the public domain in the near future.

ANNOTATIONS

ABIDI, S. R. 2007. Ontology-based Modeling of Breast Cancer Follow-up Clinical Practice Guideline for Providing Clinical Decision Support. In *the Twentieth IEEE International Symposium on Computer-Based Medical Systems (CBMS)*, 542-547.

Problem addressed

The authors have addressed this problem of computerization of CPG within a CDSS by employing a Semantic Web approach to model the CPG knowledge and provide trusted CPG mediated recommendations in response to breast cancer patient data at the point of care at primary care clinics.

Previous work and shortcomings

The author mentions that both CPG and CP are still under utilized at the point of care for decision support and care planning (Greco and Eisenberg, 1993). Also, the author notes that the work of Lobach and Hammond (1997) has shown that CPG embedded in CDSS provides a customized environment for patient at the point of care.

Architecture of the proposed system

The authors propose an ontology-based Breast Cancer Follow-up Decision Support System (BCF-DSS) based on the CPG. The main component of the BCF-DSS is the BC ontology that acts as the knowledge source to determine recommendations for patients. The CPG knowledge was captured and represented using the modeling formalism involved in computerization of the CPG. BC oncologists were consulted, literature was reviewed and personal experience was applied to resolve medical and semantic ambiguities. Protégé was used to build the BC ontology that models the encapsulated knowledge within the follow-up CPG. Eight main classes and two disjoint classes are defined, for which properties, property characteristics, instances, and inter-class relationships were specified from the conditional recommendations of the BC follow-up CPG. CPG execution was achieved using the GEM execution engine developed in Faculty of Computer Science at Dalhousie University. The execution engine has two main sub-modules; Rule Authoring Module and Execution Module. A GEM concept, called Knowledge Components, characterizes the clinical knowledge present in a CPG and sub-components, called recommendations, can be either directed or conditional.

Experiments and results

For experimental purposes, patient data has been recorded by the family physician system user interface and a set of relevant recommendations is returned. The physician can seek an explanation for any recommendation. The authors say that all explanation material is derived from the annotated BC CPG. No results have been noted because the main aim of this work has been to develop a BC ontology.

Claims, conclusions and future work proposed by authors

In this paper, the authors claim to have demonstrated the potential of Semantic Web technology for developing CPG-driven CDSS and computerize the BC follow-up CPG. Future plans include evaluation of the BCS-DSS in providing effective follow-up care to the breast cancer survivors. In conclusion, the authors wish to extend the functionality of the proposed system to provide personalized patient education material to support CPG-mediated recommendations.

Other related work done by the author

[1] ABIDI, S.R., ET AL. 2009. Operationalizing Prostate Cancer Clinical Pathways: An Ontological Model to Computerize, Merge and Execute Institution-Specific Clinical Pathways. In: *Riano, D. (Eds.) K4HeLP 2008, In LNCS (LNAI),* 5626, 1–12, *Springer, Heidelberg.*

Citations

[1] VITI, F., ET AL. 2009. Ontological enrichment of the Genes-to-systems Breast Cancer Database. In *Communications in Computer and Information Science*, 46, 178–182.

[2] JITENDER, D., AND WILLIAM, S. 2010. Conceptual Development of Mental Health Ontologies. In *Ras, Z.W. and Tsay, L.S. (Eds.): Advances in Intelligent Information Systems, Studies in Computational Intelligence*, 265, 299-333, *Springer, Heidelberg*.

AL-SAFADI, L. A. 2008. Semantic-based exchanger of electronic medical records. In *Proceedings of the 6th international Conference on Advances in Mobile Computing and Multimedia (MoMM),* Linz, Austria, *The Third International Conference on Convergence and Hybrid Information Technology (ICCIT),* 962-967, G. Kotsis, D. Taniar, E. Pardede, and I. Khalil, Eds.

Problem addressed

Medical information in various healthcare institutions is heterogeneous, in terms of physical and logical structure, and semantics. Integration of medical records leads to poor data collection at the point of care results, thereby resulting in critical medical errors and inefficiency in care process. To overcome this, standardization efforts like EHRcom, openEHR and HL7, are being made, but these necessitate changing the structure of existing patient records. The author has addressed this problem of integration, interoperability and schema matching in the healthcare domain without altering existing medical records (EMRs).

Previous work and shortcomings

The author mentions the systems CoOL (Strang, Linnhoff-Popien, and Fank., 2003), an ontology based model to reason about various context related issues, Artemis (Bicer et al., 2005; Christophilopoulos, 2005), a semantic WS based framework to address functional and semantic interoperability for healthcare, BioDASH (Neumann and Quan, 2006), a Semantic Web prototype of Drug Development Dashboard that integrates relevant data from several sources in a semantically consistent manner, and ASEMR(Sheth et al., 2006), a system that combines three ontologies with rules to enhance the accuracy of EMRs by providing clinical decision support as related previous works. The author does not mention any disadvantages of the existing systems, but notes that the above system models form the foundation of the proposed work, MREx.

Architecture of the proposed system

The proposed system, MREx, uses ontology mapping techniques for exchanging medical information in a complete distributed, semantic heterogeneous environment, without altering EMRs. The ontology mapping system is a schema manipulation process and is comprised of the ontology Mapper, two EMR schemas- local and standard, and the metadata. Each healthcare institution has its own metadata, which makes real-time exchange of EMRs possible. The search for EMR architecture follows a series of steps such as, passing the user requested query to all the members connected to the system, converting this local query into standard query, integrating all the EMRs of a specific patient, using local ontologies to convert the remote EMR into a standard format on the remote side and the resulting virtual EMR into the local format on the requester side, and viewing the target EMR that is the result of database search operations. MREx uses two schema matching approaches, named schema-level approaches and name matching. Two levels of schema matching namely element(for individual elements, such as table and attributes) and structured (for combinations of elements, such as complex schema structures) are supported. MREx Schema Mapper uses a linguistic-based approach based on names of schema elements to find semantically similar schema elements.

Experiments and results

MREx utilizes three ontologies, created jointly with experts in the medical field, namely, practice ontology (contains concepts which represent the medical practice such as facility, physician, and nurse), Drug ontology (contains all the drugs, classes of drugs, drug interactions, and drug allergies), and Diagnosis/Procedure ontology (includes concepts such as medical conditions, treatments, diagnoses, and procedures) to represent aspects of the healthcare domain. The author has not mentioned any experiments that have been performed to demonstrate the feasibility of the proposed system in the paper.

Claims, conclusions and future work proposed by author

The author claims that MREx provides caregivers real-time access to patients' medical history and medical cases in Saudi Arabia, recorded in different schemes and spread over various healthcare organizations, in a fast and accurate manner. The authors claim to have distinguished between matchers of schema, instance, element, and structure-levels. Further claims include enabling clear decision making in critical situations through integration, analysis, and delivery of on-demand and relevant information to the point of care. The author concludes with a belief that MREx will contribute to the Saudi eHealth projects towards a integrated health information system by solving the many medical information problems faced. In the future, the author expects that this system will allow real-time medical information to be shared at the point of care without altering patients' records.

Other related work done by the author and Citations

[1] AL-SAFADI, L. A. 2009. Electronic Medical Record Ontology Mapper . *International Journal of Advancements in Computing Technology.* 1(1), 85-97.

BHATT,M., RAHAYU, W., SONI, S.P. AND WOUTERS, C. 2009. Ontology driven semantic profiling and retrieval in medical information systems. *Journal of Web Semantics: Science, Services and Agents on the World Wide Web*, 7 (4), 317-331.

Problem addressed

Interoperability between various healthcare domains and timely retrieval of appropriate semantic information has been a major issue with continually developing e-health information systems. The authors have addressed this problem of semantic interoperability and information validity by proposing a system that uses a sub-ontology extraction module to be applied in a specific domain, in this case, Medical Information Systems (MIS).

Previous work and shortcomings

The authors have noted that ontology evolution and reuse in a distributed environment (Maedche et al., 2003) lacks semantic simplicity. The authors also bring to light that ontology-based applications, such as integration of medical terminologies (Gangemi et al., 1999), consolidating and merging biomedical ontologies (Bechhofer et al.; Kotis et al.; Lambrix and Tan, 2006), and using domain specific ontologies to build a knowledge repository (Tokosumi et al., 2007; Pires et al., 2008), focus on utilizing the whole ontology or a new medical ontology, rather than on extracting and optimizing a sub-ontology from a given large domain ontology. Protégé and OntoEDIT tools that allow to create, view, visualize, edit and align ontologies, do not address user-driven automatic extraction of valid sub-ontologies, semantic and structural optimization of the resulting ontologies, and semantic mapping. Finally, the authors mention that information retrieval and browsing systems such as Textpresso (Müller ,2004), and GoPubMed (A. Doms and M. Schroeder, 2005) have their own limitations such as text tokenization, etc. The authors mention that the above systems fail to focus on structuring the ontologies to meet user-specific needs and integrate them with ontology data extraction.

Architecture of the proposed system

The authors propose OntoMOVE, a system that uses ontology driven meta data and a novel sub-ontology extraction framework called Materialized Ontology View Extraction (MOVE), for achieving interoperability and effective information retrieval for the MIS domain. The ontology is represented using OWL and knowledge sources are the UMLS Semantic Network (UMLS-SN) and UMLS

Metathesaurus. Four categories of optimization schemes, namely, requirements consistency, semantic completeness, well formedness, and total simplicity of solution have been applied for deriving a independent sub-ontology from a base ontology. OntoMat is used for annotating the collection of Medical Therapeutic Guidelines (TG). For consistency with industry based medical vocabularies, only those terms that can be identified with concepts present in the UMLS Metathesaurus have been used for annotations. A built-in Annotation-Indexer maintains and builds index entry relationships between the existing semantic types and their instances in the medical TG. The authors mention that reduction in the search space of information retrieval is an objective of this work, and that the resulting valid ontology is semantically complete independent of the base ontology.

Experiments and results

The systems has been implemented in the Medical Therapeutic Guidelines (TG) with large size document resources. All documents related to Cancer Palliative Treatment from within the TG and documents related to Cancer DNA Mutation from the biosciences PubMed document repository have been retrived. The contextualization capability has been evaluated based on sub-ontology extraction mechansim and semantic requirement profiling. For demonstrative purpose, 1156 UMLS Metathesaurus terms from 170 TG documents were selected for annotation on the basis of their UMLS-SN semantic type, and 98 semantic types from 135 have been utilized. A collection of four sub-ontologies (referred to as *A*,*B*,*C* and *D*) or user profiles were obtained. It was noted that the semantic scope of profile *A*, which consists of 107 concepts, spans 168 documents, whereas with profile *D*, the scope is narrowed down to 113 documents.

Claims, conclusions and future work proposed by authors

The authors say that this work mainly focused on sub-ontology profiling technique to perform contextual search and to filter relevant documents based on user requirements. The authors claim that their work applies the notion of reuse in ontology engineering. Limitation as mentioned by the author is that the annotations are not performed by a domain-expert, thereby lacking a global annotation strategy. The authors conclude by outlining their future intentions as evaluation on real domain experts to perform a realistic empirical study, semi-automate the annotation process by using the deep annotation technique, explore ontological reasoning facilities that are available for OWL described resources, and automate requirements specifications for any application to use the system.

Other related work done by the authors

[1] SARI, A.K., RAHAYU, W.J., AND WOLLERSHEIM, D. 2010. Utilization of Ontology in Health for Archetypes Constraint Enforcement. In *The International Conference on Computational Science and*

Its Applications (ICCSA), 380-394.

Citation

[1] BEYAN, O.D. AND BAYKAL, N. 2010. A Knowledge Based Search Tool for Performance Measures in Health Care Systems. *Journal of Medical Systems, Springer*, 1-21.

BRATSAS, C., KOUTKIAS, V., KAIMAKAMIS, E., BAMIDIS, P.D., PANGALOS, G.I. AND MANGLAVERAS, N. 2007. KnowBaSICS-M: An ontology-based system for semantic management of medical problems and computerised algorithmic solutions. *Journal of Computer Methods and Programs in Biomedicine*, 88 (1), 39-51.

Problem addressed

Existing MCP information is scattered and poorly organized, resulting in search engines not focusing on algorithmic solutions and failing to provide results in a structured and comprehensive way. Existing repositories lack semantic level qualities like comprehensive organization and description. The authors have aimed to solve this problem by developing a system, which provides an open and semantically enriched environment, for organizing and managing unstructured/ semi-structured and widely scattered information related to MCPs.

Previous work and shortcomings

The authors mention that UMLS lacks the specific semantic model required for MCP description, while other repositories such as MedAl (Kantor et al., 2001), and PhysioNet (Henry et al., 2001) lack description for heterogeneous problems and algorithms at a semantic level. Problems and algorithms are semantically described and made available through a Web portal in OpenCPS(Lee et al., 2003), and an ontology-based IR model using tf-idf algorithm (Song et al., 2005) are reported, but the above systems do not target the medical domain. The authors mention that ontology-based IR models that use indexing mechanisms (Kohler et al., 2006), and the classic Vector Space Model (VSM) approach (Castells et al., 2007), are not sufficient for annotating and organizing MCP-related information. The authors note that KnowBaSICS-M is a modular system to provide organize, retrieve and manage knowledge related to MCPs.

Architecture of the proposed system

The authors propose a system, KnowBaSICS-M (Knowledge-Based System for Integrating Computational Semantics in Medicine), to assist clinicians, students or researchers to search for potential algorithmic solutions of a medical problem, to acquire knowledge about specifications and implementation details of algorithms, and to provide knowledge describing the semantics of new MCPs. KnowBaSICS-M is comprised of four major subsystems namely, the Semantic MCP Repository (backbone of KnowBaSICS-M that conceptualises and manages the MCPs and contains the MCP Ontology, the corresponding MCP KB, and the Knowledge Insertion Module), the Medical Terms Annotator (annotate query MCP descriptions via terms obtained from UMLS and consists of the UMLS KB and Medical Concepts Extractor), the Query Engine (aware of the MCP Ontology schema and consists of the Query Formulator, Query Processor and Resultset Retrieval module) and the Ontology VSM (provides a semantic similarity calculation mechanism of MCPs and consists of the Vector Constructor and Similarity Calculator). Interaction with the system is through a client-server based UI that encapsulates the above functionalities for MCP. The code was developed using Protege and the MCP ontology was built using OWL.

Experiments and results

For experimental evaluation, physicians tested the system on a corpus of MCPs retrieved by the MedAl medical algorithms repository. Cardiology (123 MCPs), and pulmonary (109 MCPs) medicine categories were examined and the KB included 13,748 instances. The authors note that the physicians formed 68 clinical questions in a very descriptive form. Four users were presented with the existing MCPs in the KB, and the physicians manually marked the relevant MCPs in the KB corresponding to these questions and observed that four questions were not answered from the existing MCP repository and the users defined them as new MCPs. The users found acceptable answers to 51 of the 64 questions, and defined 13 as new MCPs, out of which 5 returned similarities between 61% and 74% and the other 8 returned less than 40% similarities. 65 relevant MCPs were manually identified, 32 of which constituted the same medical problem as the searched MCP, and on execution of the search process, it was found that 18 of the 32 had 80% or above similarities, while the remaining 14 had similarities over 85%. It was noted that at similarity level over 70%, the average precision and recall characteristics for the users was approximately 87.36% and 89.84%, respectively. The authors mention that the overall system usage was very satisfactory.

Claims, conclusions and future work proposed by authors

The authors claim that users reported that the application was easy to interact with, effective, and assisted them in their quest for specific medical algorithmic solutions. The authors also mention that the physicians were satisfied with the similarity level of the matching MCPs and reported that such a system could help towards automated evaluation decision process. The authors conclude by saying that the users were able to obtain integrated solutions to MCPs along with additional information needed for execution. Future intentions mentioned include further extension and evaluation of the system for a larger number of test users and a wider range of MCPs for additional medical specialties. Also, the authors have mentioned improvement on the UI design for formulating queries on the MCP corpus, wizard-like procedure for MCP insertion, and automated insertion of the content in existing repositories in the MCP KB.

Other related work done by the authors

[1] BRATSAS, C. ET AL. 2009. Towards a Semantic Framework for an Integrative Description of Neuroscience Patterns and Studies: A Case for Emotion-Related Data. In *Proceedings of Medical Informatics Europe (MIE)*. In *Medical Informatics in a United and Healthy Europe, K.-P. Adlassnig et al. (Eds.)*, 150, 322-326.

Citations

[1] GUO, Q. AND ZHANG, M. 2009. Semantic information integration and question answering based on pervasive agent ontology. *Journal of Expert Systems with Applications*, 36(6), 10068-10077.

CECCARELLI, M., DONATIELLO, A. AND VITALE, D. 2008. KON^3: A Clinical Decision Support System, in Oncology Environment, Based on Knowledge Management. In *Proceedings of the IEEE International Conference on Tools with Artificial Intelligence (ICTAI)*, 2, 206-210.

Problem addressed

In this paper, the authors address the problem of recognizing methods and tools to make the KON^3 system as a CDSS to represent semantic information in the oncology environment at a reasonable cost. They have attained this by using an ontology to represent the guidelines that can be integrated with the clinician's workflow. The authors stress that rules in ontology help clinicians get suggestions to make decisions.

Previous work and shortcomings

Work done on approaches for developing computer-based guidelines has been mentioned as previous works to this system. The authors refer to theoretical approaches in CPGs systems (Siddiqi, J. et al., 2006), an ontology based model on ADL to make health information systems properly interoperable and safely computable (Beale and Heard, 2007), and a model that defines entities and relationships for CPGs based on patient data and concepts on heterogeneous clinical information systems (Tu, S.W. et al., 2007), as a basis for this work. The authors have not mentioned any problems with the previous systems, but have reported that these are standard approaches that share clinical knowledge obtained from verified medical data.

Architecture of the proposed system

The authors have proposed a system KON^3 (Knowledge ON ONcology through Ontology), based on the development of a CDSS especially for the treatment of breast cancer. The authors state that a guideline is a set of recommendations consisting of contexts and tasks such as actions, and decisions.

The authors say that the guidelines to develop the system were realized using NCCN (National Comprehensive Cancer Network). The authors also mention that Protégé (open source ontology editor), SWRLTab (Protégé plug-in to write SWRL rules), and Jess, have been used to develop the system to make inference on ontology, build guidelines and get recommendations. The authors have described the architecture of the system, the ontology, and the rules in DCIS (Ductal Carcinoma In Situ). These rules are to create guidelines for the basic actions and decisions to be taken. They further say that the architecture is comprised of four different layers, namely, distributed database layer, semantic layer, knowledge service layer, workflow system, and interface layer.

Experiments and results

The authors report that they have developed this system using the oncology Taxonomy ontology. They have divided breast cancer into two types, Non-Invasive, and Invasive. They have used the DCIS domain as a test case in this paper. The authors have presented a set of actions for the work-up phase, and after work-up phase, and generated a possible SWRL, which helps to take some actions and make decisions, based on a list of possible recommendations.

Claims, conclusions and future work proposed by authors

The authors claim that they have shown the main approaches to realize a CDSS based on ontology for patient data, guideline and oncology taxonomy. The authors conclude by saying that the set of rules in the ontology can help build guidelines as well as a decision support system to provide recommendation to assist clinicians to make better decisions.

Other related work done by the authors and Citations

[1] CECCARELLI, M. ET AL. 2009. A Guideline Engine For Knowledge Management in Clinical Decision Support Systems (CDSSs). In *Proceedings of the 21st International Conference on Software Engineering & Knowledge Engineering (SEKE 2009)*, Boston, MA,USA, 252-257.

DEMNER-FUSHMAN, D. AND LIN, J. 2006. Situated question answering in the clinical domain: selecting the best drug treatment for diseases. In *Proceedings of the ACL Workshop on Task-Focused Summarization and Question Answering,* Sydney, Australia. 24-31.

Problem addressed

The authors of this paper deal with answering questions related to patient care in clinics. They have handled this by elucidating how an archetype called evidence-based medicine (EBM) can be portrayed in a semantic domain model. The authors have also pointed out that integration of such a semantics based system can help in QA performance.

Previous work and shortcomings

The authors mention that the need to answer questions has been well studied and documented. The authors argue that existing systems such as PubMed are often unable to provide relevant answers appropriately (Gorman et al., 1994; Chambliss and Conley, 1996). Work done on MesH terms with basic clinical tasks (Mendonc¸ and Cimino, 2001; Haynes et al.,1994), and PICO frame based tools in query formulation (Booth, 2000) have been mentioned as previous works to this system. The authors point out that PICO is just surface-based querying and does not solve complex QA. Other works mentioned by the authors include the work done to automatically identify conclusions (Niu and Hirst, 2004) and the PERSIVAL system (McKeown et al., 2003). The authors also mention that existing systems employ lexical, syntactic and semantic analysis for processing texts and knowledge resources. The authors say that to provide users with accurate answers, systems should aim to go past these semantic and syntactic practices. The authors articulate that their work is similar to the PERSIVAL system, which focuses on personalizing information by reranking search results.

Architecture of the system proposed

The authors say that a successful clinical QA involves integration into a physician's daily schedule. The authors propose a clinical QA system that accomplishes the above by focusing on the question "What is the best drug treatment for X?" where X is any disease. The authors say they believe that focus on a subset of therapy questions is highly influential in the society due to the frequent occurrence of this question type. In this work, the authors have outlined the significance and need of relevant clinical QA. Also, they have mentioned that EBM uses current best evidence, and this evidence is obtained from MEDLINE database in this work. Another important factor that has been stated is the high precision in response. The authors go on to say that EBM offers three aspects, namely, clinical tasks, PICO elements, and strength of evidence, to form a model to deal with complex clinical information. The architecture of the system proposed encapsulates a query formulator, a knowledge extractor, and a semantic matcher. The query formulator converts a clinical question into a PubMed search query, identifies the clinical task, and extracts the relevant PICO elements. The records returned by PubMed are analyzed by the knowledge extractor, which identifies the clinically relevant elements and sends it to the semantic matcher. The top ranked citations are returned as answers.

Experiments and results

The authors report that they have used the PubMed search engine to realize semantic matching, instead of the MEDLINE database because of the large number of records in the latter. They report to have mined the June 2004 edition of Clinical Evidence (CE) Journal to create a test collection for the system, from which they randomly extracted thirty diseases and created a test set of twenty-five questions and a development set of five questions. The authors also say that they conducted evaluations to compare the original PubMed records using the ROUGE technique and the output of the semantic matcher of this system. They assert to have found a statistic difference in the performance of the EBM-reranked hits and original PubMed hits for all document hits. Also, they mention that the quality of output in this system is higher than original PubMed documents.

Claims, conclusions and future work proposed by authors

The authors claim that the system developed contributes to both computational linguistics and medical informatics, by proving to be efficient in answering questions at a semantic level and showing EBM can be integrated to support physicians, respectively. The authors claim that the performance gains seen in the development set proves the generality of the methods employed by them. Further claims made by the authors include the usefulness of automatic evaluation with ROUGE and an improvised semantic matching algorithm. The authors conclude by saying that this work can be extended to develop a more formal system for EBM.

Other related work done by the authors

[1] DEMNER-FUSHMAN, D. AND LIN, J. 2007. Answering Clinical Questions with Knowledge-Based and Statistical Techniques. *Journal on Computational Linguistics*, 33(1), 63-103.

Citations

[1] ZHANG, Y. AND PATRICK, J. 2007. Extracting semantics in a clinical scenario. In *Proceedings of the Fifth Australasian Symposium on ACSW Frontiers,* 68, *ACM International Conference Proceeding Series, Australian Computer Society,* 249, 241-247.

DEMNER-FUSHMAN, D. 2006. Complex Question Answering Based on a Semantic Domain Model of Clinical Medicine. PhD Thesis, University of Maryland, College Park.

Problem addressed

Information retrieval systems are capable of understanding and delivering a user’s information need in the desired form. The author has addressed the problem of complex question answering by using a semantic domain model developed within the paradigm of Evidence Based Medicine (EBM) to encode a clinician’s information need expressed as a question and the meaning of scientific publications to produce a common interpretation.

Previous work and shortcomings

The author notes that this work derives knowledge and information collected from intensive research. The author talks about EBM, comprised of clinical tasks, PICO framework, and document appraisal. Richardson et al. (1995) proposed PICO, a framework for constructing well-formulated questions. The author notes that the PICO framework was used by Booth and O’Rourke (2000) to retrieve documents, and by Niu and Hirst (2004) to search a database of reviews that summarize and appraise clinical evidence. Review of literature also includes document retrieval using DynaCat (Pratt et al., 1999) and organization of documents, either by subject, or strength of evidence groups based on publication types (Demner-Fushman *et al.* 2004), and multi-document summarization (McKeown, Elhadad, and Hatzivassiloglou 2003), and Open and Closed Domain QA. The author mentions that this work is more towards closed domain QA and focus lies on using the medical domain knowledge and the existing framework to develop clinical questions and the main difference between the CQA-1.0 system developed in this work and the systems described above is in the level of abstraction provided by consistent application of the semantic domain model in question answering.

Architecture of the system proposed

In this work, the author has proposed a system that employs a hybrid approach for question answering combining the classic AI frame-based approach with statistical NLP methods, and synthesizing and presenting answers from multiple documents. The proposed CQA-1.0 system works as follows: given a question, the system finds relevant documents, estimates their validity and relevance to the question, and presents information in a multi-tiered fashion. These steps performed by the system are based on the three fundamental components of the EBM-based semantic domain model. The major clinical tasks are etiology, diagnosis, therapy, and prognosis. PICO helps to standardize and improve the process of formalizing information needs of clinicians. Evaluation includes checking validity of results and relevancy of information to the patient's condition. The author also says that the development of a question answering framework based on the semantic domain model can assist in clinical decision making, and developing annotation guidelines and test collections for information extraction and QA evaluation. The system has been implemented by matching the semantic representation of the user's information needs and the documents automatically derived from MEDLINE citations. The QA process starts with a manually constructed clinical question encoded in a PICO frame and results in either a multi-tiered full answer, or the best answer.

Experiments and results

Real life clinical questions have been evaluated to demonstrate the feasibility of complex question answering and high accuracy information retrieval. The resources used by the the CQA-1.0 system to generate answers include domain knowledge encoded in UMLS, database of citations into MEDLINE, such as PubMed, and other online databases, search engines such as Essie to retrieve MEDLINE citations, and tools to identify biomedical entities and relations in a given text . Three sources: Parkhurst Exchange, Family Practitioner Inquiry Network , and Clinical Evidence, and three test collection sets: PICO-annotated, FPIN and CE, were used for development and evaluation of the CQA-

1.0 system. Evaluation metrics such as precision, recall, MAP, and MRR, as well as statistical measures were used to determine the scores. The author reports differences between answer precision achieved by CQA-1.0 and the PubMed baseline on all answers were statistically significant for the family physician and surgeon at the 95% and 99% significance levels, respectively, and that CQA-1.0 significantly outperforms the PubMed baseline in the best answer generation.

Claims, conclusions and future work proposed by author

The author justifies her choice of clinical question answering by stating that the medical domain contains innumerable resources to provide proof of hypothesis such as question taxonomies, tools for document understanding and analysis, and several models ranging from conceptual to comprehensive models of the clinical process. The author concludes by saying that this work provides a positive outlook to the application of semantic domain model to question answering by generating successful answers to complex clinical questions. Future work mentioned includes application of the schema in another domain and an in-depth study of the many components of the prototype system.

Other related work done by the author

[1] DEMNER-FUSHMAN, D., OVERBY, C. L., AND TARCZY-HORNOCH, P. 2009. The potential for automated question answering in the context of genomic medicine: an assessment of existing resources and properties of answers. *Journal of BMC Bioinformatics.* 10 (Suppl.9): S8.

Citation

[1] DEMNER-FUSHMAN, D., CHAPMAN, W.W., AND MCDONALD, C.J. 2009. What can natural language processing do for clinical decision support? *Journal of Biomedical Informatics.* 42(5), 760-772.

GANGULY, P., CHATTOPADHYAY, S., PARAMESH, N. AND RAY, P. 2008. An Ontology-based Framework for Managing Semantic Interoperability Issues in e-Health. In *Proceedings of the IEEE International Conference in e-health Networking, Applications and Service (HEALTHCOM),* Singapore. 73-78.

Problem addressed

Communication between various ontologies is essential to enable cooperation among agents. In this paper, the authors have addressed the problem of solving ontological mismatches by providing a framework that comprises of a dialogue mechanism and a decision support system. The authors stress that the proposed context-driven framework allows for real-time modifications for the ontologies involved.

Previous work and shortcomings

The authors refer to a formal dialogue game framework for automated agent dialogues concerning consumer durable purchase negotiations (McBurney et al., 2003) and an extended work that acts as a decision-support system and generates particular feedback sequences in interaction with a user of the system (Beun and Ejik, 2004) as previous works. The authors have also mentioned similar works for ontology negotiation mechanisms such as extended ONP (Ganuguly, et al., 2006) and game board rules (Beun and Ejik, 2004). The authors have not mentioned any problems with the previous systems, but noted that the proposed framework involves both dialogue game and a DSS to resolve ontological mismatches.

Architecture of the system proposed

The model presented by the authors combines a dialogue game and a DSS to resolve semantic ontological mismatches. The system working comprises of six steps, namely, adopting rules of dialogue games, adopting a DSS for ontology mapping, generating a dialogue mechanism based on the decision made above, defining the syntax of the dialogue mechanism, defining different decision mechanisms that invoke different types of locutions at different points, and defining transitional rules for linking dialogue locutions and decision making mechanisms. The authors mention that inferences about ontologies can be made using the reasoning mechanism in description logic on which OWL language is based upon. The authors also note some rules for mapping through dialogue mechanism between agents. The dialogue model generated can be one of the following- open dialogue, informed, form mapping criteria, assess mapping criterion, negotiated, confirmed or closed. The locution rules specify the precondition, meaning, and response to the locutions, and effect on information and confirmation stores made by the agents. The authors also mention that dialogue invocation mechanisms are internal and specific to each agent. The authors go on to say that outcomes of the decision are associated with communication of locutions, which causes the transition between states of the mechanism, denoted by relevant locution numbers.

Experiments and results

The framework proposed by the authors has been realized in the context of diet management in diabetes. The diabetes ontology has been built using Protege ontology editor. The authors report that they have tested their model assuming the dietician has advised the patient to have eggs for protein. The authors mention that if the concept is missing in the ontology, the mapping dialogue starts and a flow of steps follow as per the transition rules. The authors have used a mapping algorithm to illustrate the example.

Claims, conclusions and future work proposed by authors

The authors claim that they have presented a framework to resolve ontological mismatch. The authors mention that even though the example in the paper is very simple, it highlights the features of the system proposed. The authors conclude with a table depicting the comparison of various Ontology negotiated protocols. Future work mentioned by the authors includes full implementation of the above architecture in various OWL type ontologies.

Other related work done by the authors

[1] RAY, P. AND CHATTOPADHYAY, S. 2009. Fuzzy awareness model for disaster situations. *Journal of Intelligent Decision Technologies*, 3(1), 75-82.

Citation

[1] DOGDU, E. 2009. Semantic web in eHealth. In *Proceedings of the 47th Annual Southeast Regional Conference,* Clemson, South Carolina. ACM, New York, NY, 1-4.

HUSSAIN, S. AND RAZA ABIDI, S.S. 2007. Ontology Driven CPG Authoring and Execution via a Semantic Web Framework. In *Proceedings of the Hawaii International Conference on System Sciences (HICAS),* Waikoloa, Hawaii. 125-135.

Problem addressed

There are numerous efforts to automate CPG and integrate it within a CDSS to guide health professionals make clear decisions. In this paper, the authors address the challenges posed in developing a CPG-guided CDSS such as appropriate conversion of decision logic into significant medical decision rules, validation of the transformed knowledge to provide reliability in the suggestions given, and execution of the computerized CPG to obtain decisive conclusions. They have achieved this by employing an ontology-based approach within the semantic web and executing the computerized CDSS based on individual patient records.

Previous work and shortcomings

Work done on Ontology similarity techniques in fuzzy web databases, web searching and bioinformatics, has been mentioned as previous works to this system. The authors refer to rule-based expert systems (Buchanan et al., 1984), ontological query concepts (Andreasen, 2003), ontology similarity calculation using Gene Ontology (Lord et al., 2003, Popescu et al., 2005), and ontological methods related to web searching (Hartmann et al., 2005) as a basis for this work. The authors have not mentioned any problems with the previous systems. The system proposed combines all the above methods to provide for efficient data mining.

Architecture of the proposed system

The authors have proposed a semantic web based CDSS using three ontologies namely the CPG ontology (computerized structure of the CPG), a Domain Ontology (medical knowledge related to the

CPG), and a Patient Ontology (patient health information to execute decision logic). The authors mention that the decision logic has been represented using JENA rules. The CDSS consists of two main modules, namely, CPG Authoring System (requires a text-based CPG and domain ontology), and CPG Rule Authoring and Execution System (provides a framework for defining the decision logic rules in a CPG and executing them based on the patient clinical data). Decision rules converted into JENA rule syntax, is input to an inference system JENA, which uses the rule set to infer recommendations based on patients clinical situation. The authors also stress that the architecture of the system supports generation of an automated derivation trace of inferred recommendations for enhancing the plausibility of the decision. The authors go on to say that they believe that a better collaboration between CPGs in the Semantic Web can be achieved by semantically annotating text-based CPGs into RDF and defining their concept hierarchies and properties in OWL.

Experiments and results

The authors mention that for a given patient instance, the CDSS will be able to derive CPG based clinical recommendations. The authors report that they have tested their system on the EU Radiation Protection 118 Referral Guideline for Imaging CPG, using the pre-defined RPG Ontology and a Patient Ontology. The authors also mention that the patient ontology incorporates patient properties such as age, gender, medical history. The authors also say that the text-based RPG was encoded into the CPG Ontology by the CPG-EX system, and then the CPG rules were transformed into JENA, after which the JENA reasoner was invoked to query the deduced recommendations based on selected patient profiles. An example based on RPG testcase depicting the above process has been illustrated in the paper.

Claims, conclusions and future work proposed by authors

The authors claim that they have established a CDSS and linked a CPG Domain Ontology in the semantic environment and logical elements in the CPG ontology for decision making. Other claims include implementation of an automated derivation/justification generation module for tracing inferences to make health care professionals aware of the underlying principle of the recommendation system. The authors conclude by saying that further developments to the system can be made by providing methods for multiple CPGs for more practical decision making, adopting the Algorithm tag for recommendations, using the ARDEN syntax for CPG decision rule authoring, and providing validation of recommendations in natural language.

Other related work done by the authors

[1] ABIDI, S. S. AND HUSSAIN, S. 2007. Medical Knowledge Morphing via a Semantic Web Framework. In *Proceedings of the Twentieth IEEE international Symposium on Computer-Based Medical Systems* (CBMS). IEEE Computer Society, 554-562.

Citations

[1] DINGLI, A. AND ABELA, C. 2008. A pervasive assistant for nursing and doctoral staff. In *Proceeding of the 2008 Conference on ECAI 2008: 18th European Conference on Artificial intelligence*. M. Ghallab, et al. Eds. Frontiers in Artificial Intelligence and Applications, 178, 829-830.

PIRES, D. F., TEIXEIRA, C. A., AND RUIZ, E. E. 2008. A UMLS interoperable solution to support collaborative diagnosis decision making over the internet. In *Proceedings of the 2008 ACM Symposium on Applied Computing (SAC)*, Brazil, ACM, New York, NY. 1400-1404.

Problem addressed

Medical applications that provide diagnosis based on decisions from different users supported by remote knowledge databases use different nomenclature systems leading to terminological interoperability problems. Such applications lack semantic support and types leading to difficulty in collaborative decision- making. In this paper, the authors have addressed ontology interoperability problems by presenting a UMLS interoperable solution for collaborative clinical decision-making in a distributed environment. The authors use a case study to demonstrate DDSOnt ontology that extends UMLS Semantic Network (SN) and mention that they have concentrated on using clinical data exchanged to create knowledge bases to provide semantic collaboration in a CDSS.

Previous work and shortcomings

The authors note that the digital thesaurus UMLS Metathesaurus (Schuyler et al., 1993) helps in achieving terminological compatibility during exchange of electronic healthcare records. The authors say that previous medical ontologies such as the Open Galen CRM (Rector and Glowinski, 1995), UMLS SN (Smith et al., 2004), and HL7 RIM do not support semantic types for decision-making. The system reported by Achour (2001), and EGADSS (Bilykh et al., 2006), based on HL7 technologies, have been mentioned as previous works to this system. The former employs a knowledge acquisition tool to allow databases to be reusable, and uses both UMLS SN and UMLS Metathesaurus to obtain ontology and terminology compatibility, while the latter uses RIM ontology semantic types to represent semantic information. The authors mention that the focus of the previous works was knowledge database content representation, whereas their work focuses on clinical data exchanged and creating knowledge databases using the data.

Architecture of the proposed system

The authors have presented a web-based collaborative diagnosis decision-making system using shared information. The proposed solution consists of the DDSOnt ontology that extends UMLS SN to create a new set of semantic types needed to define a structure to carry shared knowledge database oriented ontology. Two specifications, namely DDSOntWs and JDDSOnt, which specify computer mechanisms to create, share, search, and use knowledge bases through Web services and RDF semantic documents are also presented. DDSOntWs allows the exchange of electronic healthcare information during web collaborative diagnosis decision making. JDDSOnt is a set of software components to facilitate the use of DDSOntWs services, by mapping DDSOnt semantic types to RDF semantic documents. These Java components can be used to invoke DDSOntWs services and to help reading and writing activities related to RDF documents. The authors mention that two software modules have been created with DDSOnt and TIDIA-Ae multimedia communication tools support to help teachers, monitors and students in learning activities. The first one designed for teachers and monitors, helped in establishment of the environment settings, definition of pathology to be studied, of signals and diagnosis, creation of clinical cases, and generation of a knowledge database. The second module has been designed for students, helping them to search knowledge databases to get diagnosis responses.

Experiments and results

Experiments have been performed in the TIDIA-Ae Web environment, a set of tools for collaboration and distance learning supported by high-speed networks. The authors say that the purpose of the application of the DDSOnt solution to the TIDIA-Ae environment was the creation of a Web virtual place that offers medical learning activities, and allows refinement of knowledge databases that help diagnosis decision, and where teachers, physicians and medical students interact. The authors report that both modules in the case study were supported by DDSOnt, DDSOntWs and JDDSOnt, and can instantiate TIDIA-Ae multimedia communication tools for collaborative purpose and use jUDDI for registry services.

Claims, Conclusions and Future Work Proposed by authors

The authors mention that they have integrated an ontology to create, share, search, and use knowledge databases through Web services and RDF semantic documents, and demonstrated the same in a TIDIA-Ae environment. The authors claim that this system contributes to the medical domain in collaborative decision-making by allowing information sharing mechanisms. The authors conclude by saying that the contribution of this work is the definition of semantic types in a ontology way to improve and promote semantic compatibility during collaborative diagnosis decision.

Other related work done by the authors

[1] TEIXEIRA, C. A. et al. 2009. Toward Semantic Web Services as MVC Applications: from OWL-S via UML. In *Proceedings of the 2008 ACM Symposium on Applied Computing (SAC)*, 675-680.

Citations

[1] BHATT, M. et al. 2009. Ontology driven semantic profiling and retrieval in medical information

systems. *Journal of Web Semantics: Science, Services and Agents on the World Wide Web.* 7(4), 317-331.

POPESCU, M. AND ARTHUR, G. 2006. OntoQuest: A Physician Decision Support System based on Ontological Queries of the Hospital Database. In *Proceedings of the 2006 American Medical Informatics Association (AMIA) Annual Symposium.* 639–643.

Problem addressed

Medical errors are one of the most common reasons for patient death. In this paper, the authors address the problem of reducing medication errors as a result of physicians' mistakes. They have tackled this problem by designing a decision support system that employs data driven Just-In-Time data mining technique on a hospital database. The authors have also stressed that assimilation of such a system can help in data mining using past data.

Previous work and shortcomings

Work done on Ontology similarity techniques in fuzzy web databases, web searching and bioinformatics, has been mentioned as previous works to this system. The authors refer to rule-based expert systems (Buchanan et al., 1984), ontological query concepts (Andreasen, 2003), ontology similarity calculation using Gene Ontology (Lord et al., 2003, Popescu et al., 2005), and ontological methods related to web searching (Hartmann et al., 2005) as a basis for this work. The authors have not mentioned any problems with the previous systems. The system proposed combines all the above methods to provide for efficient data mining.

Architecture of the proposed system

The authors have proposed a prototype of a physician decision support system (PDSS), OntoQuest, which retrieves information from the hospital data base for previous decisions made in cases similar to the current one using ontological queries, and also allows for computerized physician order entry. The authors say that the above mining process results in reduction of medical errors. The authors have stated that OntoQuest is a Query By Example System, which identifies the medication recommended to similar patients by the physician, thereby allowing for verification of his/her own therapeutic recommendations. The authors have defined an ontological query as that which describes the semantic correspondence between patients. The authors have implemented the ontological query by proposing a method for patient similarity computations, which uses ontology and ontology related algorithms. The patients used for similarity computation are represented by sets of ICD-9 diagnoses. The authors claim that the data driven PDSS reflects the current medical knowledge and current practice procedures in a hospital, thereby making it advantageous over knowledge driven PDSS.

Experiments and results

The authors report that they have used different similarity measures to analyze the effects of similarity on retrieval of patients. They also claim to have validated the ontological similarity by assessment of patient pairs chosen at random from a set of 2077 patients from a hospital database, using only two ICD-9 codes for each patient. The authors also say that they conducted the experiment by assigning 26 drugs to each patient, to obtain the similarity frequency.

Claims, conclusions and future work proposed by authors

The authors claim that the system developed is useful for computing patient similarity and correlates very well with the physician perceived patient similarity. Further claims made by the authors include comparison of the performance of OntoQuest with normal database queries. The authors conclude by saying that OntoQuest can extend the ontological query methodology to a diagnosis support system, and also to compare services, quality and outcomes among patient and provider groups, such as using larger ontologies such as Snomed or UMLS to compute the ontological similarity, and assigning important coefficients to each disease and then incorporating it in similarity measures.

Other related work done by the authors

[1] KELLER, J.M. ET AL. 2006. Gene Ontology Similarity Measures Based on Linear Order Statistics. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 14(6), 639-661.

Citations

[1] POPESCU, M. 2007. Identification of co-occurring diseases using ontological data mining techniques. *In Proceedings of the 2007 AMIA Annual Symposium*, 1080.

SMIRNOV, A., CHILOY, N., PASHKIN, M. AND LEVASHOVA, T. 2005. Ontology-Driven Intelligent Decision Support of OOTW Operations: Health Service Logistics Support. In *Proceedings of the IEEE International Conference on Integration of Knowledge Intensive Multi-Agent Systems (KIMAS)*, Waltham, MA. 522-527.

Problem addressed

Efficient knowledge sharing is a key element for successful management of coalition-based OOTW in a network-centric environment. There is a necessity for integration of the right knowledge from distributed sources to be transferred to the right person at the right time within the right context. The authors have addressed the problem of implementing the aggregate of these interrelated activities, referred to as knowledge logistics (KL), for intelligent support of OOTW. The authors mention that constraint satisfaction technology forms the basis for this approach, where KL is combined with ontological knowledge representation to provide semantic interoperability.

Previous work and shortcomings

No previous work for support of OOTW has been mentioned by the authors in the paper. However, the authors have mentioned that the KL problem addressed consists of many loosely coupled knowledge sources (collectively called KSNet) (Smirnov et al., 2003,2004). The authors have also noted that the constraint satisfaction solver employed for implementation of the KSNet approach is ILOG (www.ilog.com, 2004).

Architecture of the proposed system

The model presented by the authors is directed towards using ontology for knowledge representation from various sources. The application ontology (AO) serves as a cross-domain ontology, represents the context of the problem to be solved, and plays a major role in request processing by translating the requested ontologies and the ontologies from various KS into AO terms. The authors have mentioned that the KSNet system uses intelligent software agents to access heterogeneous Kss and implements adaptive agents to modify themselves when solving a problem described by the AO in the ontology library for successful situational awareness. The MAS architecture is based on Foundation for Intelligent Physical Agents (FIPA) Reference Model. The problem-oriented agents specific for KL and scenarios of their collaboration developed for this system are translation agent, knowledge fusion agent, configuration agent, ontology management agent, expert assistant agent, and monitoring agent. The dynamic compilation mechanism has been based on a preprocessed user request that defines what AOs and KSs are to be used, and C++ code generated on the basis of information extracted from the user request, appropriate ontologies, and suitable Kss, which is directly compiled into an ILOG-based program. Failed compilations or executions do not interrupt the system work on the whole, and an appropriate error message is generated. The KSNet approach described by the authors has been realized for a disaster relief operation from Health Service Logistics (HSL).

Experiments and results

Experiments have been performed with an on-the-fly portable hospital configuration in the Binni region in Africa. The hypothetical scenario, “Binni – Gateway to the Golden Bowl of Africa”, deals with development of transportation plans for evacuation of injured personnel. The authors report that analysis of the AO built necessitated them to create sub-problems related to finding and utilizing KSs containing information related to hospital, available friendly suppliers and providers of transportation services, geography and weather information related to the Binni region, and the political situation. The authors also mention that these sub goals have been described via the Common Application Ontology.

Claims, conclusions and future work proposed by authors

The authors say that the scenario presented is to demonstrate an application of the KSNet-approach to intelligent support of OOTW. The authors conclude by saying that utilizing ontologies with modern standards enables semantic interoperability with other knowledge-based systems and services and facilitates knowledge sharing, and this work can be extended to more complex real-world problems. Future work mentioned by the authors includes introduction of context management to organize contextual information, applied ontology management to identify and define problem, and consider other constraint solving mechanisms.

Other related work done by the author(s)

[1] SMIRNOV, A. et al. 2010. Hybrid Technology for Self-Organization of Resources of Pervasive Environment for Operational Decision Support. In *International Journal on Artificial Intelligence Tools*, 211-229.

Citations

[1] SMIRNOV, A. et al. 2005. KSNET-Approach Application to Knowledge-Driven Evacuation Operation Management. SIMA.

YE, Y., DIAO, X., DU, G., JIANG, Z. AND YANG, D. 2009. An ontology-based hierarchical semantic modeling approach to clinical pathway workflows. *Journal of Computers in Biology and Medicine*. 39(8), 722-732.

Problem addressed

Clinical pathways, one of the main tools to manage quality in healthcare, support well-organized and proficient patient care based on evidence. The authors of this work address this problem of real-time monitoring by modeling a computerized clinical pathway workflow at a semantic level using an ontological approach. These computerized systems enable efficient implementation for improving the quality of and decrease costs of healthcare services.

Previous work and shortcomings

Previous research work mentioned by the authors on computerization of clinical pathway workflows includes the electronic versions of paper-based clinical pathway systems (Chang et al., 2002, and Wakamiya and Yamauchi, 2006), and workflow applications in the healthcare domain such as systems based on guidelines (Quaglini et al., 2000), evidence based care system for post-stroke (Panzaraza et al., 2002), and home care assistance systems (Ardissono et al., 2006). The authors mention that paper-based systems are based on checklists and do not explicitly model outcomes and their relationships. The authors have also reported that the lack of emphasis on patient care and use of XML technologies is a disadvantage to the workflow applications. The authors cite that since XML uses only tags for information representation and does not provide the means of capturing its semantics, XML-based workflow languages fail to convey the semantics of process information, without explicit ontological definitions. The authors also bring to light that the ontology design in systems such as transfusion ontology (Ceravalo et al., 2006) and respiratory waveform ontology (Lee and Wang, 2007) do not consider the semantic representation of healthcare processes and focus solely on their respective fields. Finally, the authors point out that recommendations provided by clinical practice guidelines (CPGs) assist practitioners and patient decisions only for specific circumstances. The authors mention that the variety of diseases and procedures requires a general modeling method for describing all the pathways.

Architecture of the proposed system

The authors propose an ontology-based system to model clinical pathway workflows at the semantic level. The CPO developed by the authors uses the skeletal methodology presented by Uschold and King and includes four stages, namely, purpose identification, ontology building, evaluation and documentation. The building activity is further decomposed in to three activities: ontology capturing (identifying terms referring to key concepts and relationships in the domain of interest and the production of their unambiguous text definitions), coding (explicit representation of the conceptualization captured in some formal language), and integrating existing ontologies. In this work, the classes and relations of CPO are captured using Protégé-OWL and visualized using OntoViz. OWL (Web Ontology Language) is used for ontology coding because of its compatibility with other ontology representation languages. The semantic modeling framework consists of a clinical outcome pathway layer and an intervention layer connected by visual links. The authors mention that this two-way layering is similar to the work done by Chu and Cesnik, the difference lying on the emphasis on semantic descriptions of clinical pathway workflows and related temporal relationships based on semantic web rule language(SWRL). The modeling approach provides flexible support for representation of variance-related changes and temporal relationships are time interval relations between two interventions.

Experiments and results

The authors have used a clinical pathway for cesarean section to illustrate the proposed approach in describing the knowledge semantics to automatically schedule and monitor clinical interventions. The clinical pathway has been developed as several paper charts by a maternity department in a hospital in Shanghai, China, which contain expected outcomes and standardized clinical interventions during 7 days after patient admission. The case study mainly focuses on the second and third days. Time interval relationships between the interventions are modeled as four temporal rules. The authors have assumed that the semantic model has been applied to the care of a pregnant woman and a nurse observes that her bleeding volume is more than 500ml when performing the intervention *MonitorBPHRSaO2* in the evening shift of the delivery day. The authors have identified a variance *PostpartumHemorrhage*, an instance of *Clinical_Variance* and associated that to the intervention through *occurs-during* property. The authors say that the variance analysis determines whether ergonovine should be given to the patient via intra muscular injection. Then, the definition of the composite intervention *CSDay2IE* needs to be modified by adding the *ErgonovineIntramuscularInjection* intervention and the descriptions of other processes keep unchanged.

Claims, conclusions and future work proposed by authors

The authors claim that the approach proposed provides reusability, flexibility, and efficiency of semantic descriptions for all clinical pathways through the combination of different outcomes and interventions, different layers of abstraction, and modular components. Other claims include consistent and sufficient semantic model through meaningful representation of temporal knowledge through the integration of temporal entities in the CPO model and SWRL- based temporal rules in clinical pathways. The authors also mention that even though the case study considers only two care days, the proposed methodology can enable explicit, structured semantic descriptions during other days and for other clinical pathways for specific clinical conditions in the same way. The authors conclude by mentioning knowledge-based variance analysis, handling methods and algorithms, and implementation of semantics-based clinical pathway workflow systems as future work.

Other related work done by the authors

[1] YE, Y. ET AL. 2008. An ontology-based architecture for implementing semantic integration of supply chain management. In *International Journal of Computer Integrated Manufacturing*. 21(1), 1-18.

ZILLNER, S., HAUER, T., ROGULIN, D., TSYMBAL, A., HUBER, M., AND SOLOMONIDES, T. 2008. Semantic Visualization of Patient Information. In *the IEEE International Symposium on Computer-Based Medical Systems (CBMS), IEEE Computer Society Periodical.* 296-301.

Problem addressed

Diagnostic approaches such as visualization are very important for the comparative evaluation of data, especially in CDSS. Due to the complexity and diversity of data, it is an exigent task to visualize and interpret patient data, which involves various structures and semantics that are not comprehensible to the system. In this paper, the authors address the problem of visualizing the hierarchical classification of patients. They have solved the problem by viewing the patient database with an ontology that encapsulates semantics for attributes of the database.

Previous work and shortcomings

Previous work done on visualization and analysis of patient data include hierarchical and ontological approaches. The authors say that the work done in ontology based systems such as Isaviz (Pietriga, E., 2002), and Ontosphere (Bosca, A. and Bonio, D., 2005), give the user a complete visualization of the concepts within the ontology. On the other hand, hierarchical approaches, such as anonymous clustering and lexicographic methods use similarity distance and various visualization techniques such as treemaps, correlation plots, and so on (Tsymbal, A. et al., 2007). The authors note that the shortcomings in the above mentioned systems are the direct navigation of the ontological concepts, and complexity in capturing the meaning of the clusters itself. The work done by the authors involves instance data visualization using knowledge and reasoning from a medical ontology, and not the concepts directly.

Architecture of the proposed system

The aim of the system proposed by the authors is two-fold, namely, to align patient data with germane ontologies, and to deduce a basic prototype for improved patient data visualization, comparison and analysis. The authors have stated that the information organization obtained as a result of mapping patient data to ontological concepts will be used for classifying and putting together patient records. The authors mention that the steps in preparing the patient data for improved visualization involved identifying the relevant ontology fragment, transforming the Health-e-Child patient data into OWL DL representation, establishing a classification ontology for determining the patient data classification within the reasoning process, integrating all created ontologies, and deploying the inferred ontological model into the visualization software. The authors mention two ontology based visualization scenarios, namely, semantic facet browsing and semantic treemap visualization. The Semantic Facet Browser enables the navigation of patient records along relevant patient characteristics. The Semantic Treemap Visualization demonstrates the use of inferred hierarchical classification for the purpose of patient browsing and visual data mining.

Experiments and results

The authors report that they have used the two patient visualization applications, with their clinical partners, to exhibit the behavior of external semantics. The Health-e-Child database for brain tumor data captures, for each patient record, more than 100 attributes of medical history and status data. The authors explain that the clinicians pointed out the relevance of inferred knowledge as implemented by the facet browser, as it helps the clinicians to find patients along a particular direction, and also locate previous patients under the same classification. The authors also inform that the treemap approach was acknowledged by the clinicians as basis for analyzing and visualizing correlation of multiple characteristics of patient data.

Claims, conclusions and future work proposed by authors

The authors claim that the system developed aims to improve visualization of patient records through coalition of external semantics. The authors also say that deciding which external knowledge sources are relevant for a particular concept is important for valuable integration of external semantics. The hypothesis presented by the authors is that using the semantics of some of the attributes, patients can be better classified and visualized. The authors also highlight that though their system does not give clinicians any new information, the advanced visual organization has been helpful to navigate the information. The authors conclude by saying that future area of research focus lies on comparison of T-Box and A-Box reasoning in terms of scalability and performance.

Other related work done by the authors

[1] ZILLNER, S. ET AL. 2008. An Architecture for Semantic Navigation and Reasoning with Patient Data - Experiences of the Health-e-Child Project. In *Proceedings of the International Semantic Web Conference*, 737-750.

Citations

[1] ADNAN, M., WARREN, J. AND ORR, M. 2009. Enhancing Patient Readability of Discharge Summaries with Automatically Generated Hyperlinks. *Journal of Health Care and Informatics Review Online*, 13(4), 21-27.

[2] JIMENO-YEPES, A. ET AL. 2009. Reuse of terminological resources for efficient ontological engineering in Life Sciences. In *Journal of BMC BioInformatics*, 10(10):S4, 120-133.

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