An Intelligent Data Management Reasoning Model within a Pervasive Medical Environment

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Abstract. Large quantities of sensory data may be generated within a pervasive medical environment. Using the information gathered, intelligent systems may be developed to assist our medical practitioners in real-time. Patient datasets require constant scrutiny and must be analysed in the context of other available information (e.g. patient profile, medical knowledge base). An accurate real-time overview of a patients state of health is not always possible as communication links may break or servers fail. Therefore it is essential that the information provided on a patients state of health in taken in the context of available datasets. Presented is a Data Management System-Tripartite Ontology Medical Reasoning Model (DMS-TOMRM). It is built on three input streams 1) External stimuli (e.g. patient vital signs, patient location), 2) Medical knowledge base (medical database, ontologies) and 3) User profiles (medical history and patient properties). All three pools of information are merged together to provide the medical practitioner with a real-time diagnosis assistant. A key element of the DMS-TOMRM is its ability to cope with physical failures. For example, if the medical knowledge base fails, the DMS-TOMRM may still provide a diagnosis based on the users profile and current real-time sensor values. This supports the DMS principle of providing a higher quality of service at the patient point of care. Presented is the DMS-TOMRM and how it intelligently interacts with a context rich medical environment.

1 INTRODUCTION

The importance placed on data management techniques has increased due to low-cost sensory devices and the emergence of ubiquitous environments. Current and future pervasive environments may produce large volumes of sensory data. Appropriate processing and data management techniques are required to provide an effective service for the end user. The medical based DMS (Data Management System) [1] contains large volumes of static and dynamic data. Static data sources typically include databases containing patient records, and files containing medical practitioner profiles. Dynamic data may include patient real-time sensor readings and medical practitioner location information. The DMS-TOMRM performs intelligent processing on the available static and dynamic datasets. It correlates this information, highlighting anything of significance (thereby alerting the medical practitioner). The monitoring and handling of data is achieved through an intelligent agent middleware, JadeX [2]. JadeX provides built in reasoning and goal oriented facilities which are ideally suited for our context rich medical environments.

The relationship and meaning of important data variables within our medical environments need to be defined. The basis for this careful management of data is the underlying semantic model. A semantic model implies precise definition of the meaning of concepts and terms. Within medical informatics a variety of methods exist which provide precision in biomedical information. These range from medical terminologies which provide a list of terms with basic hierarchical structures to very comprehensive representations of medical concepts, encompassing a rich set of relationships between a specific set of concepts. Basic representations may be useful for domains such as information retrieval. While sophisticated representations may be suitable for reasoning. Within a medical environment, different ontologies address specific concerns. HL7 [3] is related to medical data exchange terminologies; SNOMED CT [4] is concerned with the precise definition of clinical terms. UMLS [5] addresses the need for "information integration through terminology integration"; it builds on over a hundred source vocabularies and contains over one million concepts. With DMS-TOMRM, the objective is different to that of an ontology model such as UMLS. The goal is to provide meaning to all available medical data. Specifically how we interpret our available datasets in real-time. This leads to a very concise and responsive application-specific ontology rather than a broader, general purpose one.

The computational and communication constraints of an application deployed within a Wireless Patient Sensor Network (WPSN) are directly addressed by the ontology model developed. From this baseline a generic reasoning model may be created to meet application specific requirements. If necessary detailed ontologies and reasoning models may be integrated into the DMS-TOMRM while maintaining the same application targets. A high-level overview of the current DMS-TOMRM prototype is outlined in figure 1.

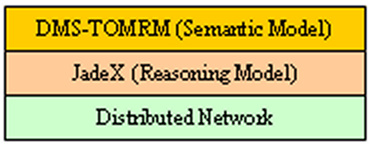

Figure 1. A Logical Overview of the DMS Architecture.

The DMS-TOMRM is based on three inputs 1) External stimuli 2) Medical knowledge base 3) User profiles. If one of these input streams should fail, alternative JadeX plans will be activated based on the current context of the patient and their surroundings.

The initial DMS version [1] was built on a Jade [6] agent middleware, working alongside a Jess expert system and Protege ontology models. The current DMS version integrates a JadeX adapter. With

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JadeX a true agent DBI (Desires, Beliefs and Intentions) model is applied. It contains beliefs, goals and plans. Beliefs are all known facts about the real-world environment. From this belief base a JadeX agent may activate plans (i.e. intentions) which may contain a set of sub plans (enabling the JadeX agent to react to multiple scenarios.). Finally desires, what does the agent wish to achieve? When a goal is outlined the JadeX agent will use all knows avenues to reach it. The DMS-TOMRM requires a dynamic middleware to cope with intermittent communication links and sporadic end user requests. With JadeX an intelligent agent middleware provides the necessary service (i.e. activate alternative plans/goals on all known contexts).

In section 2, a review of how ontologies, sensors and agent middlewares have been applied in developing reasoning models within our pervasive environments. Section 3 introduces the DMS-TOMRM and how it reasons based on available datasets. An example scenario of the DMS-TOMRM model and how it integrates with JadeX is given in Section 4. Finally, a conclusion on the effectiveness and importance of the DMS-TOMRM model and its future development is outlined.

2 RELATED WORK

A number of ambient reasoning models have been developed based on well defined ontologies. How our sensors and knowledge bases are integrated plays a pivotal role in their effectiveness [7]. As our pervasive environments are coupled together based on multiple distributed objects, an intelligent agent middleware may provide the necessary capabilities in delivering an effective service. This may assist software developers in meeting the data management requirements of our medical practitioners.

2.1 Ontologies

Ontologies within context rich medical environments have been shown to play a key role in providing effective reasoning architectures. In developing a biomedical based context ontology model it is important not to view it "as a mere knowledge representation tool" [8]. It is extremely important that, the true meaning of each data variable is not only understood but is explicit under all related contexts (e.g. a partial DMS-TOMRM model, a patient blood pressure reading of 150/90 mmHg, may not retain the same meaning if the user profile were not available). The term biomedical ontology covers a large range of systems. A number of ontologies have been developed in the following areas, these include:

2.1.1 Service Oriented Context Ontologies

As communication links and servers fail, a query injection into a context environment does not always provide the desired result. [9] describes a context information service which serves ontology-based context queries. It is an important characteristic within a pervasive environment. As well defined relationships between the knowledge base and medical practitioner requirements provide the basis to deliver succinct datasets to the mobile user. Another development within service ontologies is the Web Service Modelling Ontology [10]. Here ontologies are utilised to imply "meaning to all resource descriptions as well as all data interchanged during service usage". [11] presents the SOCAM (Service-Oriented Context-Aware Middleware) architecture. It is designed to manipulate and access context aware information. It presents a formal and extensible context model based on the OWL (Web Ontology Language) ontology.

2.1.2 Ontology based context models

A number of general purpose context ontologies have been developed. They outline some of the fundamental aspects required in developing an effective reasoning ontology within our ambient environments. In [12] the approach of decoupling application composition from context acquisition and representation is applied. This enables key features of the application to be designed from the Top-down, thus providing a pure design approach. The CONON (CONtext ONtology) is a domain specific ontology built on a hierarchal structure enabling domain specific extensions to be added if required, based on a formal extensible structure [13]. As our pervasive environments contain multiple heterogeneous devices, development of a common terminology between all participating devices would provide a solid base to develop context reasoning models. In [14] all devices contain a list of services which it may provide within its ambient environment. A generic ontology for the description of context information was developed.

A number of key areas highlighting how ontologies have been applied within our ambient environment were outlined above. Development of a complete ontology model which represents every single aspect of our real-world environment is a major challenge. Defining relationships between multiple data sources is extremely complex. Ontologies are most effective when developed for a specific application domain with a well defined collection of datasets and context environment guidelines.

2.2 Sensors

Ambient sensors come in many guises. They provide our medical community with the ability to measure patient vital signs [15] [14] [16] and provide an overview of the real-world environment (e.g. room temperature, natural light levels) in real-time. In merging patient and real-time environment datasets with a patients profile and medical knowledge base, the potential for a higher QoS within our medical environments is increased.

2.3 Agent Middlewares

The benefit of deploying intelligent agent middlewares within our medical environments is well documented. They provide sufficient reactive and proactive capabilities to deal with complex, parallel tasks. Scheduling resources for patients within a medical environment is a complex task. Outlined in [17] is the MedPage architecture which contains Jade agents and JadeX agent adapters. Here agents negotiate with each other based on the current and future states of their respective ambient environments. An Ontology-Driven Software Development in the context of the semantic web is presented in [18]. Here suggestions are given on how to develop ontology oriented software through Protege and OWL with an underlining agent platform.

Ontologies, Sensors and Intelligent agent middlewares provide the necessary tools in developing effective reasoning domain specific applications. Ontologies may be designed for very specific to the very broadest of ambient environments. It is clear that attention to detail, particularly in the area of relationships and context management is paramount in developing a successful ambient application.

3 Context Reasoning

Presented is the DMS-TOMRM context reasoning model. It is developed specifically to assist medical practitioners to monitor cardiovascular patients in a non-critical environment. It achieves this through the use of low-disturbance wireless patient sensors (cf. figure 2). At present, vital signs being monitored include blood pressure, pulse, body temperature and electrocardiogram (ECG).

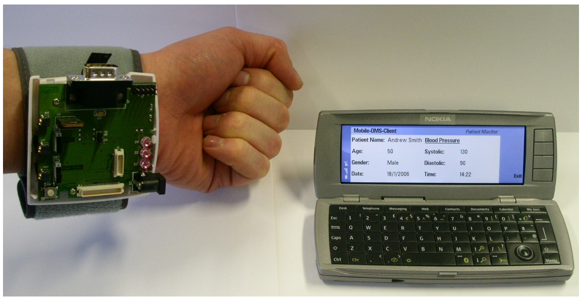

Figure 2. The Tyndall-DMS-Mote Measuring a Patients Pulse Rate while interacting with the Nokia 9500 Communicator.

For this application scenario, the ontological model is partitioned to reflect three main sources of information (cf. figure 3). This is called the Data Management System-Tripartite Ontology Medical Reasoning Model (DMS-TOMRM) it consists of:

1. Cardiovascular measurement (external stimuli), dealing with the dynamic measurements of the heart and circulatory system as a separate bio-mechanical entity. This model defines how we produce characteristic cardiovascular measurements (for example, systolic and diastolic pressure parameters) from raw sensor datasets.
2. Patient profile record (user profile), providing static information on the individual whose cardiovascular system is being monitored.
3. A Medical knowledge base, describing the relevant clinical knowledge and rules in this particular domain. It provides real-time medical based assistance during diagnosis of a cardiovascular patient. It works alongside external stimuli and user profile domains.

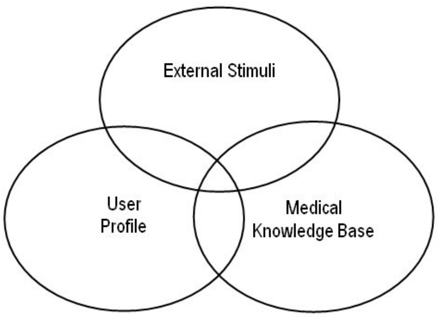

Figure 3. The Data Management System-Tripartite Ontology Medical Reasoning Model (DMS-TOMRM).

The overlaps in figure 3 of the DMS-TOMRM model indicate that as well as using all three sources of information, we can make use of any two sources to assist our medical practitioners. Thus, in the absence of a User Profile, the medical knowledge base could assist the interpretation of the cardiovascular measurements. This may be important in a wireless network environment where not all sources of information may be simultaneously available. An essential task of the DMS is correlating dynamic and static information. The DMS-TOMRM ontology reflects this division, dynamic (external stimuli e.g. sensors) and static (medical knowledge base and patient profile).

Medical practitioners interact with the DMS-TOMRM through the DMS-Server (cf. Figure 4). As a medical practitioner examines a patient he/she notes the patients symptoms onto his/her mobile device (e.g. PDA, Tablet PC). This information is then processed by the DMS-TOMRM where it correlates all known information and provides the medical practitioner with a list of known possibilities (diagnosis). This list of possibilities can be rejected or explored further.

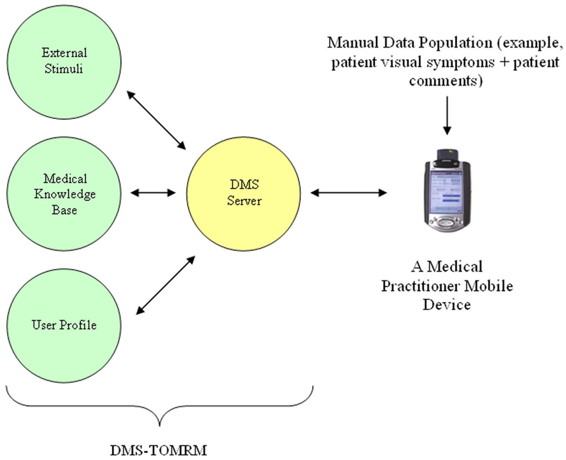

Figure 4. Medical Practitioner interacting with the DMS-TOMRM through the DMS-Server.

A brief overview for each of the DMS-TOMRM divisions is given:

3.1 Medical Knowledge Base

Blood pressure is taken as an example of a cardiovascular measurement for this paper. Blood pressure is defined as the pressure exerted on the arterial walls by the flow of blood [19]. This pressure is clearly related to the pumping output of the heart and the resistance of the blood vessels. However there is a sophisticated regulation system for blood pressure that seeks to maintain blood pressure within a certain range. In addition to the heart, other important elements in the regulation system are the kidneys, the internal cellular lining of the blood vessel walls, and the baroreceptors in the heart [19]. Without going into detail, it is clear that a sophisticated ontology is required to fully model blood pressure, its regulation, and its interaction with other body functions.

In our application, the wireless patient sensor node provides two measurements:

1. the systolic pressure, i.e. specifically the maximum arterial pressure during contraction of the left ventricle of the heart, and
2. the diastolic pressure, i.e. the minimum arterial pressure during relaxation and dilatation of the ventricles of the heart.

These measurements are important indicators. High systolic blood pressure appears to be a significant indicator for heart complications in all ages, but especially in older adults. High diastolic pressure appears to be a strong predictor of heart attack and stroke in young adults. The difference between systolic and diastolic readings (pulse pressure), although not usually considered, may be a predictor of heart problems particularly in older adults.

Apart from defining blood pressure within the medical knowledge base (i.e. specific range, category), patient symptoms and associated causes may be coupled with a specific blood pressure range. This narrows the possible diagnosis list which will be transmitted back to the medical practitioner.

3.2 External Stimuli

Patient and ambient sensors return raw data values. In isolation such datasets may assist medical staff in providing a better quality of service. By merging this information with a structured medical knowledge base and user profile, better data analysis techniques may be employed to re-examine the patients previous state of health. It may also be used to predict future conditions. In relation to blood pressure the Tyndall-DMS-Mote may return Systolic values in the range of 0-300 mmHg and Diastolic values in the range of 0-150 mmHg.

3.3 User Profile

The medical knowledge base is a collection of facts and relationships binding relevant realities together. This source of information is based on the pure mechanics of the human body (for example, if a patients blood pressure level remains severely elevated over a large period of time, specific organs will begin to fail. This in turn may cause further complications). By merging external sensor values with this medical knowledge base, early detection of such conditions may prevent unnecessary risks.

Both the medical knowledge base and external stimuli are valuable sources of information. However they both lack patient specific realities including:

1. Patient details, such as Age, Gender.
2. Current symptoms (e.g. heart palpitations, chest pain).
3. Medical history (operations, family history, allergies).
4. Medication (current and previous medication).

This collection of patient specific data is defined as a user profile within the DMS architecture. This valuable set of information greatly enhances the identification process in isolating a patients medical condition.

4 JadeX and Context Reasoning

To manage our data effectively within a pervasive medical environment a JadeX agent platform is employed. It contains similar qualities to Jade [6], however JadeX contains a higher abstract level of reasoning. All JadeX agents are given a specific goal which they must reach in order to complete their life cycle. It achieves its goals through a set of plans or through a collection of sub goals. If one of the plans is not executable (e.g. communication failure) it may activate an alternative plan or a sequence of sub goals. All known facts in relation to the monitored environment are stored within the belief base. A belief base may come in the form of an agent tuple set or a local database. JadeX agents react to stimuli in two ways:

1. Internal Events may be activated based on a condition trigger within the belief base. Such events activate a deliberation process to see if any other events or plans need to be activated (for example if a patients pulse level becomes elevated, a JadeX agent will examine all known data sets. If it discovers that the patient is currently running, it may not raise an alarm). If a predefined plan is not currently active then a new plan is instantiated to ensure that the agents final goal is reached. If the final goal can not be reached then new goals may be adopted.
2. External ACL Messages (Agent Communication Language). Here mobile agents throughout the distributed environment may communicate with each other through ACL messages. Within JadeX all ACL messages must go through a deliberation process. All know goals and plans are identified and activated if in accordance with the belief base.

Presented in Figure 5 is the DMS-TOMRM reasoning model in relation to the JadeX architecture. Aside from JadeX administration agents such as AMS, DF etc, Four DMS JadeX agents reside on the DMS-Server, they include:

1. User Agent, The user agent manages all incoming and out going ACL messages (i.e. requests, informs) from external agents residing on PCs, PDAs. Once initialised the User Agent registers with the Dictionary Facilitator where it may locate other registered agents including User Profile, Medical Knowledge Base and External Stimuli. The User Agent is responsible for correlating all known data sources (e.g. User Profile, Medical Knowledge Base and External Stimuli) in coming to an overall conclusion on the patients state of health. A new User Agent is created for each mobile user who wishes to interact with the DMS-Server.
2. User Profile Agent, The User Profile manages all relevant information in relation to a specific patient. All patient data may reside within their mobile device, local database or on the DMS-Server.
3. Medical Knowledge Base Agent, The Medical Knowledge Base (MBK) may come in many forms e.g. local database, ontology, XML document. The MKB stores all know medical facts in a structured manner (protege ontology model) which enables the MKB agent in real-time to filter and locate relevant information.
4. External Stimuli Agent, Our ambient environment may contain many sensors which transmit vast quantities of information back to a central server. In relation to the DMS-TOMRM model all patient vital sign readings are instantly compared against known facts (i.e. User Profile and/or MKB). This activates a series of sub goals to identify possible irregularities (for example, high blood pressure).

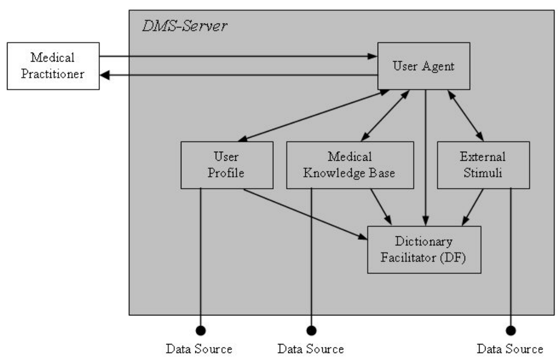

Figure 5. A JadeX agent based DMS-TOMRM Reasoning Model.

5 CONCLUSION

Data management within our ubiquitous medical environments require an intelligent, sophisticated middleware to combine all know resources in an effective manner. Ontologies may be utilised to define many aspects of our pervasive environment from the very simple; definition of medical terms (i.e. blood pressure ranges, categories) to the very complex, complete medical reasoning models. Presented is the Data Management System-Tripartite Ontology Medical Reasoning Model (TOMRM). This novel approach is designed to assist medical practitioners in providing a higher quality of patient care within a pervasive medical environment. It correlates all known sources of data to assist medical practitioners during diagnosis. A JadeX agent platform is employed to provide the necessary real-time DMS-TOMRM reasoning features. The DMS-TOMRM executes a best-effort approach, as a User Agent on the DMS-Server will assist medical practitioners during diagnosis with "all known" data sources. The DMS-TOMRM provides a single focal point for all reasoning in relation to each patient. Thus providing, a distinct advantage over current disjointed data gathering approaches, which may be found in the majority of medical communities. The current prototype of the DMS-TOMRM is still under development. Key evaluation areas include; partial and complete DMS-TOMRM model analysis. The effectiveness of the DMS-TOMRM will be based on the quality of diagnosis returned to the medical practitioner.

ACKNOWLEDGEMENTS

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