MEDIC - Mobile Diagnosis for Improved Care

Eoin McLoughlin, Dympna O'Sullivan
School of Computer Science and Informatics
University College Dublin
Belfield, Dublin 4, Ireland
(eoin.a.mcloughlin,dympna.osullivan,
michela.bertolotto)@ucd.ie

David C. Wilson
Department of Software and Information Systems
University of North Carolina at Charlotte
Charlotte, NC 28223-0001, USA
davils@uncc.edu

ABSTRACT
Hospitals everywhere are taking advantage of the flexibility and speed of wireless computing to improve the quality and reduce the cost of healthcare. Caregivers equipped with mobile computers now have levels of interaction at the bedside not possible with traditional paper charts, and they can access accurate real-time information (patient records, medication and medical imagery) at the point-of-care to make decisions, diagnose and treat patients with greater speed and efficiency. Greater and more immediate information access, however, is giving rise to challenges in how to effectively select and present the most relevant aspects for given patient care tasks, as well as how to take advantage of the collaborative opportunities afforded by medical community connection. We propose a system that enables doctors to efficiently query, analyse and annotate patient information, in particular medical imagery, using current mobile technologies. The system allows entire profiles with known diagnoses to be retrieved and can be used to compare diagnosis and treatments for patients with similar symptoms or care records. The application can be employed by caregivers either working in the hospital setting or working remotely and off-site as well as a useful tool to facilitate education and training of medical staff.

1. INTRODUCTION
Hospitals around the world are beginning to employ new wireless technologies that allow healthcare providers to move freely in hospital buildings with constant access to real-time patient information. The advent of wireless technology has given rise to many new opportunities, for example, caregivers have access to other resources including up-to-the-minute laboratory test results directly at the bedside; a specialist located away from the hospital facility can help with diagnostics from a mobile device; or likewise, an emergency healthcare worker can transmit X-Rays to the hospital and receive analysis back on a mobile device.

The support of the Commercialisation Fund of Enterprise Ireland is gratefully acknowledged.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, to republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

SAC’06 April 23-27, 2006, Dijon, France
Copyright 2006 ACM 1-59593-108-2/06/0004 ...$5.00.

In addition to advances in wireless technologies there has been enormous progress in techniques for digital image capture and storage. However these breakthroughs are causing an information overload problem in the medical image domain with many new formats of digital imagery such as Computed Tomography (CT) scans, Magnetic Resonance Imaging (MRI) and ultrasound now available. Given the existence of such large repositories of heterogeneous medical data and imagery, physicians now require systems that can effectively integrate all patient information, allow them to interact with and manipulate patient data as well as to aid with pre-screening for medical diagnosis.

Medical diagnosis and decision-making involves interplay between vast numbers of medical knowledge resources [1, 2, 3, 4]. This can range from implicit knowledge held by healthcare workers to experimental and data-induced knowledge. Systems that can simultaneously access and combine relevant information from these various knowledge resources are crucial to the diagnostic process. From a decision support viewpoint, healthcare workers need complete, contextually-relevant information that is consistent with the patient’s current medical state and that is appropriately presented at the correct level of abstraction.

The aim of this work is the development of an innovative healthcare decision support system, MEDIC, that supplements existing Irish medical systems by providing healthcare workers with a facility to immediately access, update and compare all patient information contained in electronic patient records as part of an Electronic Health Record System (EHRS) including any associated medical imagery (e.g. X-Rays). By employing new wireless technologies, these actions can take place at any location in the hospital setting, even off-site and are no longer limited to traditional fixed information points. The type of functionality we are providing includes: multimedia annotation tools for medical imagery to support just-in-time collaboration (e.g., between a laboratory and a care giver), use of such annotations as well as associated electronic patient profiles to support retrieval of similar patient case histories to support more rapid and accurate diagnosis and as well as remote communication, and effective integration of image data with other patient information, both within a database and within an adaptive Graphical User Interface.

Our work attempts to leverage the insights from a caregiver’s (radiographer or physician) decisions and rationale as they diagnose and treat patients. As a caregiver interacts with an encapsulated electronic patient profile (patient age, gender, medical history, examination and laboratory findings, medical imagery etc) in the course of a diagnosis the system analyses their actions. This
enables the capture of human expertise and proficiency in diagnosing and treating the particular illness which in turn allows us to understand why relevant information was accessed and investigated in the course of that diagnosis and/or subsequent treatment. Once this expert domain knowledge is captured, it is stored as a knowledge resource in a knowledge base of encapsulated patient profiles. This information can then be used to retrieve and display the most relevant similar patient case histories from huge repositories of patient data to allow comparison of diagnoses and treatment procedures. Such information can be interactively explored by the caregivers and used to guide them towards appropriate and relevant information regarding diagnoses and treatments. Coordinating the development to address privacy and confidentiality concerns is paramount, of course. From our ongoing consultations with hospitals, we fully expect to meet these requirements while supporting the physician activities made possible by the MEDIC application.

Effective use of the knowledge base is made possible by the application of Case-Based Reasoning (CBR) techniques. CBR is a well established method for building medical systems [5], and one of the intuitively attractive features of CBR in medicine is that the concepts of patient and disease lend themselves naturally to a case representation. Also medical practitioners logically approach diagnosis from a case-based standpoint (i.e., previous specific patient interactions are as strong a factor as individual symptoms in making a diagnosis) and this trend has been exploited in many existing computed-based medical systems. For example, [6] is a system that uses a rich knowledge base of prototypical cases and practice guidelines to interpret medical cases and to guide a case-base reasoner. The system we are developing also has beneficial repercussions from a healthcare modeling view point [7], as explanatory models from amassed patient data could easily be created that could identify trends as well as comparing diagnosis, treatments and departments.

The rest of this paper is organised as follows. In the next section we introduce the MEDIC application. We continue in Section 3 to discuss the image retrieval component of the system. In section 4 we describe how previous patient case histories can be retrieved and reused to support caregivers as they diagnose and treat new patients. Section 5 gives a brief outline of the annotation tools we have developed to support radiologists as they complete medical imagery tasks. Our algorithms for calculating similarity between patient profiles are introduced in Section 6 and some related research is presented in Section 7. We conclude with a discussion and some future directions in Section 8.

2. SYSTEM DESCRIPTION

Based on an initial investigation of current standards in Ireland for healthcare information exchange we are designing our tools as software add-ons that integrate with electronic repositories of patient records. The system is based on a three-tier architecture: client, server and database. There are two primary client components: a desktop application that is used by a radiologist and a mobile component that is used by physicians.

The radiologist employs a suite of image processing tools provided by the desktop application to annotate medical images with relevant notes and information regarding the patient’s condition. The system can be queried to display previously annotated patient images from a knowledge base of previous patient profiles for comparative studies to aid with more effective diagnosis and treatment. Once an interaction with a patient is complete their images are added to their profile in a central repository and the images and/or their annotations can be retrieved/updated at a later date either by the radiologist or by another doctor examining the patient.

Physicians can use the mobile application on a Personal Digital Assistant (PDA) or a Tablet PC to retrieve and view patient profiles and to quickly enter information about patient progress into electronic charts in real-time. The PDA allows physicians to view textual abstractions of current patient data as well as other patient case histories and allows for improved mobility due to its reduced size and weight. The Tablet PC provides a more comprehensive user interface and additional functionality such as the ability to view and annotate medical imagery due to the larger screen size and higher processing power.

All the information for each patient is stored as an integrated patient profile in a database. All interactions with the patient profile by caregivers are recorded by the system and the profile is updated accordingly. Both the PDA and the Tablet PC can be used wirelessly at different locations around the hospital or in other situations where such facilities are not normally available (e.g. in an ambulance). They may also be used to access other resources such as online drug references or medical encyclopedias. The mobile devices may also be used to query the central repository of patient profiles with information specific to a particular illness to retrieve similar patient case histories that may help with a diagnosis by providing comparative assistance. The system is implemented so that it could be securely delivered over the Internet thus promoting knowledge sharing between healthcare workers in different physical locations, and points-of-care could be expanded to include General Practitioners offices, ambulances, nursing homes or indeed anywhere with access to the World Wide Web.

3. RETRIEVAL OF MEDICAL IMAGERY

Continuing advances in techniques for digital image capture and storage have given rise to a significant problem of information overload in the medical domain. It is becoming increasingly critical to provide intelligent application support to help manage large repositories of medical imagery. The majority of current medical image retrieval techniques retrieve images by similarity of appearance, using low-level features such as shapes or by natural language textual querying where similarity is determined by comparing words in a query string against words in semantic image metadata tags. The biggest problem arising from these techniques is the so-called semantic gap [8] - the mismatch between the capabilities of the retrieval system and user needs. In order to bridge this gap the MEDIC application aims to unite information about underlying visual data with more high-level concepts provided by healthcare professionals as they interact with medical imagery. For example, capturing a measure of the human expertise and proficiency involved in making a diagnosis from an X-Ray image allows us to understand why relevant information was selected (e.g. the highlighting a particular body organ) and also how it was employed in the context of that specific diagnosis (e.g. inferred from an added annotation). The approach allows us to capture and reuse best practice techniques by automatically constructing a knowledge base of previous user interactions using case-based reasoning techniques. This knowledge base can be exploited to improve future query processing by retrieving and reusing similar expert experiences as the illness or injury of a newly presented patient can now be grounded in the context of previous similar
The image retrieval component of the application can be employed by radiologists on a desktop machine as they perform image analysis and assessment tasks. For example a radiologist may be viewing an X-Ray image and may be having difficulty in diagnosing the problem from the particular image. The X-Ray, however may remind him of a similar image he viewed previously and he may remember some of the details of the previous patient. In this scenario the radiologist could input the details of the previous patient as search parameters to the application. The application will then filter out this patient’s profile as well as any similar profiles from the EHRS. The radiologist can then compare the current image to images from these previous case histories to try to find any similarities. If any of the similar images had been annotated while those patients were being diagnosed, the radiologist can study these notes for extra information regarding the specific injury or illness. By accessing these additional resources that are not normally available in an Irish hospital setting the radiologist would be able to make a more informed and confident diagnosis.

Take another scenario where a radiologist may be diagnosing a patient from an MRI scan. The radiologist may be having some difficulty in diagnosing the patient as they may not have previously encountered the particular problem outlined in the scan. In such a scenario the radiologist may wish to view other similar patient images and diagnoses to make a confident diagnosis and so they could enter the symptoms or presenting complaints of the current patient to the application. The system will present them with a list of retrieved profiles, including any relevant medical imagery ranked according to their similarity to the current patient context. The radiologist could compare the images from these profiles to the MRI scan he is currently diagnosing and if he found any similar images he could compare the associated diagnoses. In this way the application could be used as a decision support system.

If the radiologist in either of the situations outlined above chooses to perform an image search then the resulting matching images are returned to them as part of the interface depicted in Figure 1. In order to allow multiple candidates to be displayed we present the matching images as a ranked list of thumbnails. We also include their associated matching percentage score. A subset of the patient and image data for each image is available as tool tip text when mousing over the image. The radiologist can browse the images retrieved in the results screen and select any relevant images for further investigation or manipulation.

4. PRIOR CASE HISTORY RETRIEVAL

As the system builds up encapsulated user interactions, another type of retrieval is enabled, retrieving entire previous patient case histories. This enables a physician or radiologist to look for previous patient analyses that are most similar to the current patient profile both to find relevant patient data and medical imagery and as well as to examine the decisions and rationale that went into diagnosing and/or treating the previous patients. The caregiver can retrieve relevant patient case histories by entering the relevant patient details to the application.

For example a physician may have diagnosed a patient as having a particular illness but may not be entirely sure what the best treatment to recommend would be. The physician can enter his diagnosis as a parameter to the application which can filter out and retrieve a list of patients from a central medical repository that were similarly diagnosed. He can then study this list of patients to find those whose diagnosis is most relevant to the current patient. Once he has done this he can access the full treatment planning processes for each of these patients as well as any recorded outcomes. He could also use the application to access the hospital’s medical reference resources about the drugs and medicines prescribed as part of these treatment processes.

Or in a different example a physician may have diagnosed a patient and be aware that a new drug is currently being tested on patients with the particular illness. The physician may be interested to see if this patient qualifies for the new treatment based on information such as age, allergies etc. In this scenario she may query the application for other patients who are currently being prescribed the new drug to compare them to the current patient. She may also be interested in viewing information as to how these patients are responding to the new treatment which could be contained in up-to-date patient status reports. She could also access online information regarding the new drug, its effects and success rates. All of this information can be accessed, viewed and analysed quickly and easily at any location using wireless technologies through the one integrated application thereby reducing the time and complexity in recommending the new treatment.

An obvious application of this facility to retrieve and reuse similar patient case histories is that of medical education and training. Medical students who are preparing to work with real patients in hospital wards could have access to this rich knowledge resource that offers actual experiential advice and instructions on how to diagnose and treat patients according to all kinds of patient data including presenting symptoms, examination findings, laboratory results, and medical imagery.

One challenge in retrieving previous case histories has been how to present an entire case history in a manner that is compact enough to allow multiple results to be viewed simultaneously while still providing enough information for the user to discriminate potential relevancy. Figure 2 shows an example of our results for retrieved case histories.

Each row represents a patient case history and is summarised to show the most important information for that patient. It includes the matching percentage score between the current query and the similar patient profile, as well as the symptoms, diagnosis, applied treatments and outcomes for similar case history. The user can double-click on a particular row of the table to view the full case history (including any medical imagery) of that patient.

Because the application is tightly coupled with the caregiver’s interactions, the system also has the capacity to make proactive...
recommendations in a natural and unobtrusive manner by monitoring the radiologist’s or the physician’s current context. Based on the information accessed and annotations provided, the system can correspondingly anticipate and update what previous experiential knowledge would be relevant at that stage, making it available to the user. This information is provided unobtrusively, so that it need only be accessed if required. Thus the process of knowledge retrieval does not distract from the task at hand, yet makes relevant knowledge available just-in-time.

We identify three main advantages offered by our application in reusing patient case histories. Firstly by reusing the collective knowledge in support of similar diagnoses or treatments the time required to diagnose and treat a new patient can be significantly reduced. Secondly, this approach facilitates knowledge sharing by retrieving potentially relevant knowledge from other patient case histories. Finally contextual knowledge relating to particular patients, diagnoses, symptoms, treatments and outcomes may now be stored to create accessible organizational memory.

5. IMAGE ANNOTATION TOOLS

The annotation tools provided by the application are used by radiologists to annotate medical imagery with relevant diagnostic information. When a radiologist takes a patient X-Ray the image can be displayed in the screen depicted in Figure 3. Using the tools provided the radiologist can annotate the image in an appropriate fashion while diagnosing the patient. By providing an interface such as this one we have achieved the goal of capturing important contextual patient/diagnostic information by situating intelligent support for gathering it inside a flexible environment. This information is collected implicitly to shield the radiographer from the burden of explicit knowledge engineering. From their perspective, the image interaction tools support them in carrying out their task (e.g., a radiologist producing a report on the current patient) by making it easier for them to select and highlight relevant features, to store insights and to summarize aspects of their work progress. However from a system perspective they are employed to monitor and record the radiologist’s actions and ultimately to capture contextual diagnostic knowledge to improve the ability of the application to recommend other patient profiles for comparing diagnostic information and treatment procedures.

We have developed tools for direct image manipulation, including filters, transformation, highlighting, sketching and post-it type tools. The user can add media annotations to images as a whole or to particular highlighted image aspects. Currently, the system supports annotation by text (including a facility to upload web documents), audio and video. All textual, audio and video annotations can be previewed before being incorporated as part of the knowledge base, and once recorded they can be saved and uploaded to the image as a knowledge parcel associated with the patient in question. The system also supports annotation by cut, copy and paste between a given image and other images in the dataset, as well as any application that supports clipboard functionality for the given operating system.

Once the radiologist has finished interacting with the medical imagery their entire work process is stored along with all the other patient data as an encapsulated patient profile in the knowledge base.

6. CALCULATING PATIENT SIMILARITY

Retrieval within the system is taking place in the context of an overall workflow. Some of the most important steps in this workflow (which may or may not be relevant to all patients) are: entering preliminary patient details to an EHRS, recording results of a preliminary examination, inputting presenting conditions and laboratory findings, uploading and annotating medical imagery, recording diagnoses and recommending treatments. Most patient profiles will consist of some if not most of the information described above. Given a textual representation of these patient profiles we can match textual queries entered by a radiologist or a physician about current patients to these previous patient contexts. Our retrieval metrics are currently focused on text, using Information Retrieval metrics (e.g., [9]) as a basis for similarity. The retrieval system employs indexes in separate spaces for each constituent segment of the patient profile. When a caregiver enters a query to the MEDIC system the parameters they enter are compared to the corresponding indices of other patient profiles and a weighted average is used to compute similarity between the current patient and other patients from the central medical database. These indices are used to calculate similarity in both the retrieval of medical images and the retrieval of patient case histories.

7. RELATED RESEARCH

In traditional diagnostic systems, expert knowledge tended to be captured in the form of empirical classification rules [10]. Such diagnostic systems often had limited application in the medical do-
main as highly professional healthcare workers were unwilling to accept such a master-slave relationship [11]. Other shortcomings of these knowledge-based systems are described in [12] where it is suggested that ignoring user interactions with these applications can frequently be a cause of failure. These systems tended to be system-centric rather than either task-centric or user-centric like our application which concentrates on deciphering and supporting complex work procedures in real-time as they are performed by expert users. In this research we have drawn on medical knowledge management initiatives that promote the collection, integration and distribution of a single medical modality [13]. This allows us to build encapsulated patient profiles that are used both to effectively store patient data and also for the purposes of comparison with new patient profiles for diagnosis and treatment. We have investigated work performed by [14] on integrating patient case histories with associated medical imagery.

In this research we are working with large collections of experience and user context. As in [15], we believe that user interactions with everyday productivity applications provide rich contextual information that can be leveraged to support access to task-relevant information. We have drawn from work that extracts relevant information during document browsing to support users in fulfilling tasks [16]. Our methods for annotating multimedia are related to annotation for the semantic web [17] and multimedia indexing [18] where the focus is on developing annotated descriptions of media content. Multimedia database approaches such as QBIC [19] provide for image annotation but use the annotations to contextualize individual images. In this work we are concerned with a task-centric view of the annotations, where we employ annotations to tell us how an image relates to a current domain task by using image annotations to contextualize experiences.

8. CONCLUSIONS AND FUTURE WORK

The current practice of recording patient information using paper charts is cumbersome, time-consuming and does not facilitate knowledge sharing. Heterogeneous information, including imagery, is stored in different locations and valuable time is often lost trying to correlate data to diagnose and treat patients. This system can address such issues by providing doctors with instant access to information that will allow them to make critical decisions with greater speed and efficiency. It facilitates knowledge sharing and supports effective communication about the most effective ways in which to treat patients by linking similar patient case histories. It adds more value to imagery and image transmission by combining it with patient records to support more thorough communication, examination and diagnosis. The approach also facilitates education and training by allowing medical personnel, including medical students access to a central repository of encapsulated patient information for the purpose of analysing and comparing medical procedures.

The algorithms for calculating image and case history similarity have been tested on another image and context retrieval system [20] and promising results were observed. We are currently carrying out an extensive evaluation of the MEDIC system and expect to see similar results when the algorithms are applied to the medical domain. We also hope to conduct trials with domain experts in the near future. We intend to supplement the textual retrieval by including a medical ontology as well as by performing some more complex textual analysis (e.g. lexical chaining). We are also interested in extending the system to include additional elements from supported media such as speech-to-text as part of the retrieval metric.

9. REFERENCES


