Health Informatics And Patient Care: A Case Study in Collaboration

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ABSTRACT

1. INTRODUCTION

The Networked Medical Image Database (NMID) system project is the name given to a series of research&development collaborations, between the University of Melbourne, the Austin Hospital and various ICT industry partners including Telstra and Digital Equipment Corporation, conducted over the period ~1992 to the current date.

In this paper, we provide an overview of the project from the perspectives of (i) the areas of discipline knowledge in Computer Science and Information Systems that were engaged in the work (ii) the aspects of industry and university, public and private sector, collaboration and (iii) the benefits that flowed to the participants through the collaboration, especially to the University in terms of postgraduate industry experience and research education, and to the hospital and industry partners in terms of research outputs. We also explore some of the opportunities for similar types of collaboration within New Zealand.

2. OVERVIEW OF THE NMID

Within Australia, there are a few centres, based in public sector hospitals, that specialise in medical imaging and have multiple scanning modalities available such as PET (Positron Emission Tomography), MRI (Magnetic Resonance Imaging) as well as X-Ray images. The acquisition, storage and reticulation of the image data associated with these high-value, high-cost scans places strain on the traditional patient records management systems which were at the time of project initiation (early 1990s), and are still, predominantly paper/hardcopy based both within and between the hospital imaging centres.

The Austin Hospital is a large public teaching hospital with strong education and research links with the University of Melbourne. From the early 1990s, a system of R&D collaborations were entered into between the university, hospital and industry to study the application of emerging technologies to the problems associated with the handling and use of the image data in healthcare. The areas of application ranged broadly from technology evaluations, to information management, to evaluation of use cases, to ethics and then to cost-benefit analyses. The project provided valuable experience of, and lessons in, applying advanced computing technology and systems thinking to industry. It highlighted synergies with research programs and interests of industry stakeholders (Lederman, 1999).

This paper covers, in overview, the three main stages of the NMID project:-

- Technology and systems evaluation
- Prototype deployment and evaluation
- Benefit analysis.

The project is based on a number of distributed database and image processing technologies. A prototype was developed using these and deployed in different areas of the hospital operations where images were accessed (wards, consulting rooms, threates and wards). For the benefits analysis, the workflow and information flows involved in the search for and use of image based data in a hospital department were examined and the possible consequences for both patients and hospitals where information is not available at the point in the workflow process when it is anticipated (as is the case frequently with hardcopy-based systems) was explored. Thus the benefits of automatic delivery using networked databases were highlighted (Lederman, 1999).

The rest of the paper is organized as the follows, Sections 3, 4 and 5 covers the three main stages of the NMID. Section 6 discusses related computing education and Section 7 is about NZ application. Section 8 concludes the paper.

3. TECHNOLOGY PROVING

The NMID project was initialised in 1992. It is a PACS (Picture Archive and Communication) system designed to automatically distribute images from a variety of propriety image acquisition systems associated with each image modality, to enhance patient care by prompt and convenient clinical access to images, to prevent loss of image films and the consequent cost and inconvenience of repeated studies, and to eliminate the need for large radiographic film storage and retrieval facilities. To achieve these goals in an environment where each imaging modality or imaging centre may hold its own image data (that is there may be several geographically dispersed centres holding image data associated with a given patient), distributed database was employed.

The WWW was not widely used at the time the project was commenced so early implementations of the emerging standards for Distributed Search and Retrieval- the ISO10162, 10163 Information Search and Retrieval and ANSI Z39.50 protocols for support of parallel search and retrieval of information (ISO, 1993; ANSI, 1988) - were used. Modality image data was keyed in each database and an associated metadata + report record in text format stored in association. The image could be recovered by key, or via a 'free-text' search by keyword on the associated metadata or report file. This format followed closely the practice in hospitals of radiographers reporting on an image set, and allowed recall of all records associated with a given patient (irrespective of the datastore in which they were maintained) as well as all images with keyword(s) - such as in researching on similar reported artefacts in review. Given the limited number of scanning centres, the search and retrieval process worked effectively. Staff in the scanning centres mapped proprietary image formats from the scanners into canonical formats that could be easily displayed on standard PCs and X-terminals.

Other elements in the technology proving phase of the project included:

- Image compression
- Scene and Artefact extraction from images and image enhancement
- Security/encryption.

For Image Compression, both Lossless and Lossy Compression were evaluated. The theoretical possibility of image compression, no matter if lossless or lossy, is primarily based on the redundancy inside the image. The redundancy is due to the correlation between neighbouring pixels that, their physical values are expected to be near. This assumption is true in most of the part of image, where occasional exceptions only occur at major edges of objects in an image. Based on this assumption, prediction models can be constructed easily for correlating pixels. In other words, if one pixel is given accurately, its surrounding pixels are nearly known. This correlation points out that there is little useful information in pixel values of an image. By representing only this useful information, we should be able to compress the original image to fraction of its size to assist in storage and distribution. In addition to this redundancy in image, lossy image compression can also utilize the characteristics of Human Visual System (HVS). By excluding information irrelevant to the HVS, a better compression performance can be expected. In short, Lossy Compression allows an error in reconstructed image; Lossless Compression does not. Lossy Compression has (much) better compression performance.

Several algorithms were used to test both lossless and lossy compression of images prior to transmission, in order to conserve WAN bandwidth. With lossy techniques, compression of image modalities of over 50-60 could be achieved before noticeable image degradation occurred. With lossless techniques, only factors of ~3 could be achieved. This research and that associated with security/encryption were carried out in the Application Support area of the University's IT Department. In the Computer Science Department, research was conducted within research groups on feature extraction and image enhancement techniques (including Intelligent Databases) using the Digital Massively Parallel system (DECmpp12000) and supported by an R&D grant from Digital. Telstra supported the project through granting of access to its FASTPAC Broadband network linking participating sites.

At the conclusion of this phase, the technologies necessary to put a NMID into place had been developed and evaluated and were ready for deployment in a prototype system.

4. PROTOTYPING/DEPLOYMENT

In 1993/94, the NMID was deployed in a small number of locations: in a ward (for access by nursing staff), in a consultant's room and in an operating theatre.

A GUI had been developed for the system by honours student project teams within the Department of Computer Science, which allowed display and manipulation of the images returned by the Search and Retrieval engine. Using thumbnail images as an intermediate step, consultants could review image slices, cross-compare with other modalities for the same patient, or with image modalities from the other patients with similar reported artefacts. At the same time, procedures and technical processes had been agreed with the hospital ethics committee for the transmission of image data in ways that preserved security of information and patient confidentiality.

During the trials of the prototype, it was found that consultants could not easily differentiate between the images obtained from the Lossy Compression and Lossless Compression. Medical workers however insisted on using Lossless Compression for decision support since the use of Lossy Compression might exacerbate any litigation for misdiagnosis. This is an example where synergies with research program and interests of industry stakeholders are needed.

Several variants of the Graphical User Interfaces were developed to view the image sets: Scan View to display slices from image volumes, Neuroview to display 3D rendered views of an image and Rayview to display large 2D images such as digital X-ray images. All of these were developed by students at the University working with staff (technical and medical) at the Hospital Scanning Centre on industry projects within the overarching project framework. Many tools for feature extraction and image enhancement were developed as aids to consultants in extracting information from the raw image data. These included the use of edge-detection, co-registration of different modalities and 'false-colour'. Again in the initial stages of the prototype deployment, there were mainly familiarity and cultural impediments to the use of other than 'black-and-white' image data representations.

At the conclusion of the prototype stage, there were mixed messages.

On the positive side, the prototype was agreed to work well and be worth deploying on a larger scale, especially to facilitate regional access from GPs to image data and specialist consultants in the centre where the image Compression/Encryption techniques would lower costs and maintain confidentiality on the WAN. Nursing, medical and support staff were enthused and supportive of the extension.

On the negative side there was mainly the cost issue of continuing the project at a time of increased pressure on hospital budgets. The size of the image sets meant that the server used could only manage 2-4 sessions concurrently and this was insufficient for more widespread use. The datastorage was also inadequate as clearly storage of all image data for all patients passing through each centre was desirable for workflow and treatment facilitation. At that time (mid-1990s) the cost of expanded server capacity and also high-resolution desktop PCs was prohibitive for practical deployment in a large public hospital under other pressures on costs/priorities.

Clearly the project had moved through its R&D stages, to prototyping and evaluation. To do more would require an analysis of the costs and benefits of production deployment - a suggestion put forward by senior hospital administrators - sufficient to allow evaluation against alternate funding claims.

5. BENEFITS ANALYSIS

In order to conduct a cost-benefits analysis, it was decided to look at one of two patterns in the hospital involving closely linked information and work flow using image data (i) consultants working with patients and (ii) team case review. In was decided to look at the former as this allowed assessment of benefits and costs falling to the practitioner, the patient and the hospital itself. The falling cost of technology also allowed, through the acquisition of a small RAID disk array, storage of all image modality data for all incoming patients over the normal term of their treatment. In other words complete patient image history would always be available online. The analysis and benefits assessment was carried out by researchers within the Information Systems department at the University of Melbourne.

In the benefits analysis process, two research methods are used:

1. Patient data survey
2. The simulation application.

A patient data survey was used to monitor delays in the receipt of both single and multi-modal patient data sought by a consultant. The patient data survey was divided into three sections. In the first section the consultant was asked to indicate which data was sought, the second section asked whether the data was available at the time of the scheduled consultation, and in the third section, whether a treatment decision was able to be made during a scheduled consultation.

The simulation application was used to model the information flow and time delays in the existing file-based system. Several meetings were held with key imaging, file management and medical staff to model the system. Through these meetings with key staff, a model of the main information flows was iteratively refined and, where these flows intersect with the hospital workflow, a set of simulation and process parameters was developed, which were aimed as accurately reflecting the hospital experience and recreate a valid representation of hospital practice. Using these parameters, a simulation model of the semi-automated process currently in place at the hospital was implemented. Once an initial sample of results was produced meetings were held with staff to validate the model parameters and confirm that the outputs produced were consistent with their real life experience.

The outcomes of the survey and simulation studies showed that there were many hidden costs associated with the existing semi-automated and file-based system (Lederman, 1999). Failure of workflow (patient and consultant and hospital resource scheduling) to intersect with the information flow (file and image data flows) caused disruptions in patient treatment episodes, in consultants' decision making and time management, and in hospital case throughput. All of these increased (hidden) costs and treatment times. With the falling costs of the necessary technology, the research showed that savings against existing processes and costs through adoption of the online system would very quickly recoup initial and ongoing system outlays while offering ongoing treatment and time benefits.

6. RELATED COMPUTING EDUCATION

Throughout the project, there was a wide range of opportunities for:-

- Developing an understanding, through application, of advanced concepts from the undergraduate, honours and Masters programs
- Developing an understanding of industry/client needs, effective team work and 'real-world' project and professional skills

The topics relevant to the project covered those normally seen in a Computer Science curriculum (protocols, compression/encryption, algorithms, parallel systems...) through to Economics and Information Systems (use cases, system and interface design, process modeling and simulation, benefit analyses...).

The project also demonstrated the value of industry/university/application collaboration by exploring innovation and advanced technology development in a 'real-world' context while helping to ensure that relevant skills and knowledge bases are graduated into the workplace. It also exposed participating staff and students to the discipline of Project Management working with consultants and industry. Industry partners gained from the project though development of new algorithms/technologies and the experience/feedback of deploying advanced technologies into a critical work environment.

The NMID project provides good practical motivation for course development on advanced computing topics and in fostering good industry and applications oriented partnerships. For an institution such as UNITEC, it is important both to develop expertise in advanced technologies and to bridge effectively to industry and application areas. Advanced topics in computing are usually theoretical in emphasis. This project gives us a good example of applying advanced computing technology in industry. For students to be capable doing such a project, distributed database, image processing, process modeling and IT Economics elements in the curriculum are essential.

A Distributed Database course provides an introduction to the various models for parallel and distributed computation used in I/O systems and database systems. Algorithmic techniques for processing queries in parallel distributed systems and how these techniques are employed in commercial systems were studied. This type of course also shows the student that there are more to database systems than relational tables! Students can learn the usage of different design strategies for distributed databases, and they can study query processing techniques and algorithms as well as transaction management and concurrency control concepts used in such systems. In the course project work, the class will stress on applying the techniques learned in class to commercial database management systems.

An Image Processing course covers image processing techniques as well as related information theory and coding theory applicable to industry. It should covers main image processing techniques used in NMID project. This includes Paradigm & Definitions, Histograms, Enhancement, Preprocessing, Segmentation Analysis (gray values, color), Image Coding and Compression, Multi-Dimensional Image Analysis, Pattern Recognition, Image Retrieval, Image Displays (Refresh Rate, Interlacing, Resolution).

A process modeling and analysis subject would also teach valuable skills in process mapping and in justification of applications of technology.

7. NZ APPLICATION

There is the potential to conduct an NMID-like project in New Zealand in several ways. One possible way is to extend the work of the NMID, such as further examination of the workflow costs in hospital information management practices and more extensive quantification of the real benefits with regard to patient care of implementing fully automated medical image database systems. Based on the NMID outcomes, deployment of an online image database and redesign of associated work processes can reduce patient treatment episode time and claim a consultants time, enhance decision making and reduce use of hospital resources. All of these can help increase successful patient treatment throughput.

International research suggests that quality problems are not generally caused solely by an individual but by a combination of various actions and decisions from the system level to the individual level. Action to improve quality therefore needs to occur at four levels: individual, team, organisation and system (NHC 2001). We expect the NMID to make contributions on improving healthcare quality by improving system quality.

It is also worth to experiment the NMID benefits analysis method for new IT technologies assessment within one of the health sectors in New Zealand (NHC 2001).

The collaboration model and linkage to the curriculum and recent programs could be used in application areas other than health.

8. CONCLUSIONS

The NMID project provides wide range opportunities for student research projects. The NMID project also highlights synergies with research programs and interests of industry stakeholders. The lessons learned from the NMID project could have relevance for NZ. It would be useful to parallel the activities with a hospital and an industry organisation in a partnership with UNITEC. The NMID benefits analysis method should be helpful for new IT technologies assessment within NZ healthcare system.

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