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Proceedings of the Third Australasian Workshop on Health Informatics and Knowledge Management (HIKM 2008), Wellington, New Zealand, January 2009

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Preface

The word is that Barak Obama and Joe Biden will invest US$10 billion a year over the next five years for broad adoption of standards-based electronic health information systems, including electronic health records. The English National Health Service has already invested billions of pounds in recent years on their Connecting for Health Strategy. Australia and New Zealand actually have more and better health IT on the ground than the US, and stand well with respect to the UK, but also have great ambitions for better integration of health information (and thus for better coordination of care). And now the wave of the personal health record (PHR) and IT-enabled 'citizen-centric' care is upon us, with online consumer access to health records the norm for citizens of Denmark and subscribers of Kaiser Permanente in the US, and Microsoft and Google both heaving onto the scene with PHR solutions that cannot be ignored. All of this activity is in response to the recognition that health care is expensive, not adequately reliable, and in ever-increasing demand as we live longer (and fatter) lives.

As such, the domain of Health Informatics (the study of processing of health information) is filled with opportunity, and also under great pressure to deliver. With all the above initiatives (and many more) plunging ahead, we need solutions to information security, creation (and maintenance) of effective clinical decision support systems, systems usability, and interoperability of systems across organisational, vendor and professional boundaries. Moreover, despite the apparent pace of change, computing academics also need to maintain a focus on the long view and deliver the more profound innovations that will yield fundamental, and in some cases unforeseen, improvements in what information systems can do to improve health outcomes and healthcare delivery.

This workshop is a place for computing researchers to share their experiences apropos to the problems of healthcare. Moreover, we hope that this workshop may serve to promote a greater interest in Health Informatics among Computer Science academics to provide much needed capacity for problem-solving in the domain. I'd encourage the Computer Science community to have a careful look at the Health Informatics community, which is reasonably well formalised with a hybrid of IT and biomedical traditions. Health Informatics Society of Australia (HISA) and Health Informatics New Zealand (HINZ) are our member bodies in the International Medical Informatics Association (IMIA). Please consider collaborating with us, or even joining our ranks.

Jim Warren
University of Auckland

HIKM 2009 Programme Chair
January 2009

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Welcome from the Organising Committee

We would like to welcome you to ACSW2009 hosted by Victoria University of Wellington, New Zealand.

Wellington is set on the edge of a stunning harbour and surrounded by rolling hills. The earliest name for Wellington, from Maori legend, is Te Upoko o te Ika a Maui. In Maori it means the head of Maui's fish. Caught and pulled to the surface by the Polynesian navigator Maui, the fish became the North Island. Wellington is the capital city of New Zealand and home to the seat of parliament. But this vibrant and dynamic city also has many other capital claims including Culture capital, Creative capital and Events capital. It is a compact, walkable city waiting to be explored. The conference venue is less than fifteen minutes walk to accommodation, Courtenay Place with its wide range of bars, and the harbour with its restaurants and activities such as sea kayaking. The conference venue itself is in the Museum of New Zealand Te Papa Tongarewa, offering visitors a unique and authentic experience of this country's treasures and stories. Over five floors, you can explore the nation's nature, art, history, and heritage - from the shaping of its land to the spirit of its diverse peoples, from its unique wildlife to its distinctive art and visual culture.

Victoria University of Wellington - Te Whare Wānanga o te Ūpoko o te Ika a Māui - is over a century old. Victoria College was founded through an Act of Parliament in 1897, the year of Queen Victoria's Diamond Jubilee celebrations, and named in her honour. Victoria is a thriving community of almost 25,000 people. Situated in the capital city across four campuses, Victoria can take advantage of connections and values its relationships with iwi, business, government, the judiciary, public and private research organisations, cultural organisations and resources, other universities and tertiary providers and the international community through the diplomatic corps. ACSW2009 coincides with the opening of the new School of Engineering and Computer Science as part of the Faculty of Engineering at Victoria University of Wellington - combining a long history of research and teaching of the software engineering and network engineering in the Computer Science department and computer system engineering and electronic engineering in the Physics department. Professor John Hine, co-chairing ACSW2009, is the current Dean of Engineering and the inaugural Head of School of Engineering and Computer Science.

ACSW2009 consists of the following conferences:

- Australasian Computer Science Conference (ACSC) (Chaired by Bernard Mans),
- Australasian Computing Education Conference (ACE) (Chaired by Margaret Hamilton and Tony Clear),
- Australasian Database Conference (ADC) (Chaired by Athman Bouguettaya and Xuemin Lin),
- Australasian Symposium on Grid Computing and e-Research (AUSGRID) (Chaired by Wayne Kelly and Paul Roe),
- Computing: The Australasian Theory Symposium (CATS) (Chaired by Prabhu Manyem and Rod Downey),
- Asia-Pacific Conference on Conceptual Modelling (APCCM) (Chaired by Markus Kirchberg and Sebastian Link),
- Australasian Information Security Conference (AISC) (Chaired by Ljiljana Brankovic and Willy Susilo),
- Australasian Workshop on Health Informatics and Knowledge Management (HIKM) (Chaired by Jim Warren),
- Australasian User Interface Conference (AUIC) (Chaired by Gerald Weber and Paul Calder),
- Australasian Computing Doctoral Consortium (ACDC) (Chaired by David Pearce and Vladimir Estivill-Castro).

The nature of ACSW requires the co-operation of numerous people. We would like to thank all those who have worked to ensure the success of ACSW2009 including the Organising Committee, the Conference Chairs and Programme Committees, our sponsors, the keynote speakers and the delegates.

Dr Alex Potanin and Professor John Hine
ACSW2009 Co-Chairs
Victoria University of Wellington
January, 2009

CORE - Computing Research & Education

CORE welcomes all delegates to ACSW2009 in Wellington. CORE, the peak body representing academic computer science in Australia and New Zealand, is responsible for the annual ACSW series of meetings, which are a unique opportunity for our community to network and to discuss research and topics of mutual interest. The original component conferences – ACSC, ADC, and CATS, which formed the basis of ACSW in the mid 1990s – now share the week with seven other events, which build on the diversity of the Australasian CS community.

This year, we have chosen to feature a small number of plenary speakers chosen from across the discipline, Ronald Fagin, Ian Foster, Mark Guzdial, and Andy Hopper. I thank them for their contributions to ACSW'09.The efforts of the conference chairs and their program committees have led to strong programs in all the conferences – again, thanks. And thanks are particularly due to Alex Potanin, John Hine, and their colleagues for organising what promises to be a memorable ACSW.

In Australia, 2008 has been a busy year for academia, with the incoming Labor government instituting major reviews in areas such as the higher education sector, research funding, postgraduate study, and national curricula. However, while the reviews have exposed severe shortcomings in the funding of higher education and research, they have not as yet been translated into definite action, and the sector as a whole is shrinking. Although there is a widespread perception of a shortage of IT staff, and graduate salaries remain strong, student interest in ICT continues to be low. Moreover, per-place funding for computer science students has dropped relative to that of other physical and mathematical sciences. Several forums and initiatives involving industry, government, and academia have attempted to address the issue of the ongoing difficulties of attracting students to the discipline, but with little perceptible effect. New initiatives that seek to address the issues of students and funding will be a CORE priority in 2009.

During 2008, CORE continued to work on journal and conference rankings, with much of the activity driven by requests for information from the government. A key aim is now to maintain the rankings, which are widely used overseas as well as in Australia, a challenging process that needs to balance competing special interests as well as addressing the interests of the community as a whole. A new activity in 2008 was a review of computing curriculum, which is still ongoing, with the intention that a CORE curriculum statement be used for accreditation of degrees in computer science, software engineering, and information technology. ACSW'09 includes a forum on computing curriculum to discuss this process.

CORE's existence is due to the support of the member departments in Australia and New Zealand, and I thank them for their ongoing contributions, in commitment and in financial support. Finally, I am grateful to all those who gave their time to CORE in 2008; in particular, I thank Jenny Edwards, Alan Fekete, Tom Gedeon, Leon Sterling, Vanessa Teague, and the members of the executive and of the curriculum and ranking committees.

Justin Zobel
President, CORE
January, 2009

ACSW Conferences and the Australian Computer Science Communications

The Australasian Computer Science Week of conferences has been running in some form continuously since 1978. This makes it one of the longest running conferences in computer science. The proceedings of the week have been published as the *Australian Computer Science Communications* since 1979 (with the 1978 proceedings often referred to as *Volume 0*). Thus the sequence number of the Australasian Computer Science Conference is always one greater than the volume of the Communications. Below is a list of the conferences, their locations and hosts.

2010. Volume 32. Host and Venue - Queensland University of Technology, Brisbane, QLD.

2009. Volume 31. Host and Venue - Victoria University, Wellington, New Zealand.

2008. Volume 30. Host and Venue - University of Wollongong, NSW.
2007. Volume 29. Host and Venue - University of Ballarat, VIC. First running of HDKM.
2006. Volume 28. Host and Venue - University of Tasmania, TAS.
2005. Volume 27. Host - University of Newcastle, NSW. APBC held separately from 2005.
2004. Volume 26. Host and Venue - University of Otago, Dunedin, New Zealand. First running of APCCM.
2003. Volume 25. Hosts - Flinders University, University of Adelaide and University of South Australia. Venue - Adelaide Convention Centre, Adelaide, SA. First running of APBC. Incorporation of ACE. ACSAC held separately from 2003.
2002. Volume 24. Host and Venue - Monash University, Melbourne, VIC.
2001. Volume 23. Hosts - Bond University and Griffith University (Gold Coast). Venue - Gold Coast, QLD.
2000. Volume 22. Hosts - Australian National University and University of Canberra. Venue - ANU, Canberra, ACT. First running of AUIC.
1999. Volume 21. Host and Venue - University of Auckland, New Zealand.
1998. Volume 20. Hosts - University of Western Australia, Murdoch University, Edith Cowan University and Curtin University. Venue - Perth, WA.
1997. Volume 19. Hosts - Macquarie University and University of Technology, Sydney. Venue - Sydney, NSW. ADC held with DASFAA (rather than ACSW) in 1997.
1996. Volume 18. Host - University of Melbourne and RMIT University. Venue - Melbourne, Australia. CATS joins ACSW.
1995. Volume 17. Hosts - Flinders University, University of Adelaide and University of South Australia. Venue - Glenelg, SA.
1994. Volume 16. Host and Venue - University of Canterbury, Christchurch, New Zealand. CATS run for the first time separately in Sydney.
1993. Volume 15. Hosts - Griffith University and Queensland University of Technology. Venue - Nathan, QLD.
1992. Volume 14. Host and Venue - University of Tasmania, TAS. (ADC held separately at La Trobe University).
1991. Volume 13. Host and Venue - University of New South Wales, NSW.
1990. Volume 12. Host and Venue - Monash University, Melbourne, VIC. Joined by Database and Information Systems Conference which in 1992 became ADC (which stayed with ACSW) and ACIS (which now operates independently).
1989. Volume 11. Host and Venue - University of Wollongong, NSW.
1988. Volume 10. Host and Venue - University of Queensland, QLD.
1987. Volume 9. Host and Venue - Deakin University, VIC.
1986. Volume 8. Host and Venue - Australian National University, Canberra, ACT.
1985. Volume 7. Hosts - University of Melbourne and Monash University. Venue - Melbourne, VIC.
1984. Volume 6. Host and Venue - University of Adelaide, SA.
1983. Volume 5. Host and Venue - University of Sydney, NSW.
1982. Volume 4. Host and Venue - University of Western Australia, WA.
1981. Volume 3. Host and Venue - University of Queensland, QLD.
1980. Volume 2. Host and Venue - Australian National University, Canberra, ACT.
1979. Volume 1. Host and Venue - University of Tasmania, TAS.
1978. Volume 0. Host and Venue - University of New South Wales, NSW.

Conference Acronyms

ACE. Australian/Australasian Computing Education Conference.
ACSAC. Asia-Pacific Computer Systems Architecture Conference (previously Australian Computer Architecture Conference (ACAC).
ACSC. Australian/Australasian Computer Science Conference.
ACSW. Australian/Australasian Computer Science Week.
ADC. Australian/Australasian Database Conference.
AISW. Australasian Information Security Workshop.
APBC. Asia-Pacific Bioinformatics Conference.
APCCM. Asia-Pacific Conference on Conceptual Modelling.
AUIC. Australian/Australasian User Interface Conference.
AusGrid. Australasian Workshop on Grid Computing and e-Research.
CATS. Computing - The Australian/Australasian Theory Symposium.
HDKM. Australasian Workshop on Health Data and Knowledge Management.
HIKM. Australasian Workshop on Health Informatics and Knowledge Management (former HDKM).

Note that various name changes have occurred, most notably the change of the names of conferences to reflect a wider geographical area.

ACSW and HIKM 2009 Sponsors

We wish to thank the following sponsors for their contribution towards this conference. For an up-to-date overview of sponsors of ACSW 2009 and HIKM 2009, please see `http://www.mcs.vuw.ac.nz/Events/ACSW2009/Sponsors`.

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Catalyst, New Zealand,
www.catalyst.net.nz

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Keynote

Making 12,000 Healthcare Organisations Interoperate, and Other Challenges

Alan Hesketh
Deputy Director-General
New Zealand Ministry of Health
PO Box 5013, Wellington
New Zealand

Alan Hesketh was appointed to the role of Deputy Director-General Information Directorate in December 2007. Alan's previous role was as Program Manager, Telecommunications for Australia's largest retailer Woolworths Limited. During November 2005 Woolworths acquired Progressive Enterprises Limited (PEL) where Alan was the General Manager for Information Technology. PEL is a New Zealand Supermarket retailer operating the Foodtown, Woolworths and Countdown banners.

Alan held the Chief Information Officer role with the Brisbane City Council from early 2001 through to late 2003 and was responsible for all Information Technology facilities of the Council, the largest local government authority in Australasia employing over 7,000 people, 400 of which were employed in the IT division.

Alan's other roles include Vice President, Global Service Delivery Unilever PLC.

Contributed Papers

Assessing Viewing Pattern Consistency in Mammogram Readers

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Abstract

Breast cancer screening programs typically require very large volumes of x-ray images (mammograms) to be viewed by highly experienced human readers. The readers can recognise a wide range of different visible features indicative of clinically abnormal situations, which they use as a basis to generate a report on their findings. Errors in reporting can occur if the readers fail to identify a particular feature of interest for further visual inspection during the viewing process. This risk is typically reduced by training readers to follow a particular viewing path through an image, which they should be able to apply consistently. Knowledge of the extent of consistency in this viewing behaviour within and between viewers would inform the development of an automated checking approach, based on monitoring of viewer visual attention. This paper presents an analysis of some reader viewing pattern profiles obtained using eye tracking with an infra red computer vision system, as a basis for developing a suitable consistency assessment model.

Keywords: medical image, eye tracking, visual attention.

1 Introduction

Many developed countries have instituted national breast cancer screening programs based on 2D X-ray imaging of the compressed breast, typically available every two years for women between about 40 and 60 years of age. This approach has been shown to be highly cost-effective and efficient at detecting many cancers. In Australia, it is estimated that approximately 1 million women are screened each year, which involves acquisition of at least 4 high resolution X-ray images (or mammograms) per subject. These images are subsequently scrutinised independently by at least 2 and sometimes up to 4 highly skilled human readers, who have been trained specifically for this task and are subject to ongoing quality assurance or training processes to maintain their performance level.

When a reader decides that abnormalities which could indicate the formation of cancers are visible in the mammograms, he or she reports these accordingly and the subject is recalled for further clinical assessment. Readers are trained to follow a particular viewing path through the image, associated with landmark anatomical sites (e.g. armpit, nipple, ductal region, chest wall). Usually the mammograms of both breasts are viewed next to each other, and the reader inspects the same anatomical locations in each image together during the viewing sequence so that asymmetry of features can be used to help detect abnormalities. Readers can recognise a wide range of different visible features indicative of abnormal situations, such as internal lesions in the breast tissue, or microcalcifications in the breast vessels. Whether such features indicate abnormalities or not to the reader, is highly dependent on the "context" provided by the surrounding tissue and the overall breast morphology (e.g. density, texture). Readers may also have access to prior mammograms or previous assessment images from the last screening cycle, to allow them to make visual comparisons and detect changes in tissue characteristics. Consequently, the reader must perform a complex multiple-matching pattern recognition task, based on their expertise acquired from viewing many thousands of mammograms including carefully selected educational examples. Readers are required to find all abnormalities when reporting an image, so they must be wary of a "satisfaction of search" effect which reduces their performance once one feature of interest has been established as yielding a positive result.

False positive and false negative rates are both important measures for assessing reader performance. False positives cause increased costs and patient inconvenience or discomfort due to the additional assessments, while false negatives prevent cancers from being treated early when there is the greatest chance of success. Viewer behaviour models based on visual saliency (e.g. Itti and Koch 2000) have suggested that readers can be triggered to notice features of interest by both overt gaze fixations and covert peripheral visual attention attraction. The consistency of the viewing path is therefore as important for positioning the gaze of the viewer "in the vicinity" of the feature, as it is for directing the gaze directly at the feature. However, there is little understanding of the mechanisms which cause failure to identify features of interest, once common influences like stress, fatigue and distraction have been excluded. Other factors influencing reader performance are the variations in image appearance due to uncontrolled ambient viewing conditions and different intensity and magnification settings, which readers currently address by using a familiar viewing environment and some optical or mechanical aids attached to the viewing station (e.g. magnifiers, tubes, hoods).

The current international trend to replace film-based mammograms with digital images offers some opportunity to improve both viewer performance and our understanding of the various above factors which influence viewer performance. There is considerable evidence to suggest that use of digital mammograms can increase both the true positive and false positive rates (Pisano et al 2005; Hambly et al 2008). One reason for this effect is that digital images allow standardisation or normalisation of image display characteristics, which can help to remove perturbing effects on viewer performance.

At the same time, the use of digital mammograms allows easier measurement of viewer behaviour including the viewing path and the features attracting viewer interest, by means of eye tracking to determine successive locations of viewer gaze during a period of observation time. This is because the digital images need to be viewed on an electronic display screen rather than a light box as used for films, and the eye tracking hardware can be accurately calibrated in this environment. The work reported here makes use of this capability to investigate an important question related to performance of readers, namely the extent to which reader viewing behaviour follows a similar pattern from image to image, and from reader to reader. A method for assessment of reader consistency using these patterns would allow objective comparisons between readers to be made and thereby predict their absolute performance levels and any variations over time. It could also be used on a continuous monitoring basis, to determine whether viewers were affected by performance-reducing effects such as fatigue or distraction.

2 Method

Observations of reader viewing paths for mammograms have been considered by a number of authors previously. Kundel and Nodine (1983) undertook some pioneering studies which linked behavioural habits of readers with sentinel events in the eye tracking sequence (e.g. faster scanning after the first abnormality was detected). They defined a number of overall key parameters for a viewing session which can be extracted from the eye tracking sequence, which have been used by later authors to measure differences in reader behaviour (e.g. “time to first hit”). This work inspired numerous Receiver Operating Characteristic (ROC) studies to be undertaken based on influencing of these different parameters. Krupinski (1996) investigated the difference between intra and inter reader variability using such parameters and concluded that both types of variability were of similar extent. Mello-Thoms (2006) correlated extracted eye tracking parameters with detection performance and observed low variability across multiple readers. None of these authors attempted to use the full eye tracking sequence, which clearly would provide a richer set of values for comparison of different viewers than the subsets of extracted parameters which are typically used.

The work presented here provides a method which can be used to incorporate more information from the eye tracking sequence. The initial basis for this work was the derivation of characterization formulas based on the sequence of gaze positions identified in an eye tracking session, which could be used to distinguish between different observers in a biometric application (Maeder et al 2004). Subsequent work (Maeder and Fookes 2004) applied these formulas to eye tracking data for mammogram readers and reported that inter observer variability tended to be greater than intra. This work in contrast adopts a more independent analytical approach to dealing with the sequence of gaze positions, which is found to lead to a similar conclusion.

The method applied here involves use of a common feature extraction technique employed for pattern analysis is based on Principal Component Analysis (PCA). This technique was first utilised in a fully automated face recognition system proposed by Turk & Pentland (1991) to derive a set of face representations which were termed eigenFaces. This technique applies eigen-decomposition to the covariance matrix of a set of M vectorised training sequences of gaze. PCA is used to derive a set of eigenvectors which are ranked based on their eigenvalues λ. The D most relevant eigenvectors are retained to form a sub-space ϕ. The eigenvalues represent the variance of each eigenvector and so represent the relative importance of each of the eigenvectors with respect to minimising the reconstruction error in a least squares sense. Once the sub-space ϕ is obtained, a vectorised gaze sequence v_a can be projected into the space to obtain a feature vector $\mathbf{a}$ ($\mathbf{a} = (v_a - \omega)^* \phi$) where ω is the mean gaze vector. This technique is termed “eigenGazes” as each eigenvector is representative of the most variant attributes of the training gaze sequences (similar to eigenFaces as detailed above).

3 Results

The above method was tested on eye tracking data collected from 3 proficient mammogram readers who were presented on 3 separate occasions with the same set of 8 mammograms, each element consisting of paired Medio-Lateral Oblique (MLO) and Cranio-Caudal (CC) projections. 2 of the 8 cases were known positives and the remainder were suspected negatives. The order of the mammograms in each presented set was randomised on each occasion. As only one pair of images could be presented at a time, this test situation is slightly different from the normal reading process, where both MLO and CC images are available for viewing simultaneously. An EyeTech eye tracker (based on infra red computer vision) was used to record the position of the viewer’s point of visual attention on the display screen every 100ms. These points were then scanned to identify successive gaze locations, using a radius of 10 pixels (approximately 2.5 degrees of visual angle) for classifying sequential eye position points as belonging to the same gaze locations. The set of mean positions of all the points for each gaze group provided the gaze location feature values. Figure 1 shows a typical mammogram with the corresponding eye tracker results for a single viewer. For each image, the first 20 gaze locations (including revisits) were extracted and used in the further analysis. Figure 2 shows these results for 5 different sessions with the same viewer.

Principal Component Analysis was then applied to the gaze sequence using the eigenGazes method described above. To find the eigenGazes, each gaze sequence was represented as a vector of clustered fixations, Γn, of length 20. As usual for the construction of a basis set, the mean of the observations is removed and a covariance matrix, C, for the dataset is computed. The eigenGazes then are simply the eigenvectors of C. Using a weighted sum of these eigenGazes, it is possible to reconstruct each gaze location in the dataset. These feature vectors of weights for every gaze sequence were then passed to the classifier to evaluate the how well they match within (intra) and between (inter) individual viewers. The results of the dot products of the resulting eigenGazes (on a scale of 0 to 1, with 1 being a perfect match) are shown in Table 1.

Class	Viewer(s)	Worst match	Best Match
Intra	1	0.82	0.86
Intra	2	0.89	0.94
Intra	3	0.86	0.93
Inter	1 – 2,3	0.74	0.91
Inter	2 – 1,3	0.81	0.91
Inter	3 – 1,2	0.74	0.89

Table 1: PCA based classification of gaze sequences

The intra class results in Table 1 demonstrate that all viewers showed a high degree of "repeatability" in their mammogram viewing behaviour. The match values are high and the ranges between best and worst performance for each viewer are very tight (0.04, 0.05 and 0.07 respectively). Furthermore, the average performance for each viewer is of very small range (0.84 to 0.89). It is interesting to note that the three sets of results are consistent in that a lower worst match implies a lower best match etc. This may be due to other aspects of the viewing process such as speed or concentration, which were not measured during the experiment.

It can also be seen from the above results that the matches for intra classes (in the range 0.82 to 0.94) are slightly higher than those for inter classes (in the range 0.74 to 0.91). At the same time, the average values cover a very small range (0.81 to 0.86) which overlaps strongly with the intra range mentioned above and is of similar size. With data from only 3 viewers it is not reasonable to undertake a confidence analysis of these results, nor to apply conventional methods of statistical comparison (such as kappa), but the considerable overlap suggests that it would not be easy to distinguish an adequate separation between the intra and inter classes.

4 Conclusion

The work reported here provides two outcomes of particular interest for assessment of mammogram reader performance using the eigenGazes approach:

- consistency of gaze sequence performance for a given (intra) reader appears to be sufficiently tight to allow the measurement of deviation from their normal behaviour to be determined;

- consistency of gaze sequence performance between different (inter) readers does not appear to vary substantially, so a common "expected" performance envelope for skilled readers may be able to be determined.

An advantage of the approach adopted here using the eigenGazes PCA assessment method is that a single figure of merit is produced which has intuitive meaning and exhibits monotonic linear characteristics (in a sense similar to a percentage measure).

An immediate extension to this work would be the acquisition of further experimental evidence to increase the validity of the above claims. This work is difficult to perform as access to the time of skilled radiologists for research work is limited. However, national moves towards digital screening mammography in Australia (and elsewhere) and the need to retrain and validate readers in this new environment may offer some opportunity. Some increase in confidence for the results may also be obtainable by comparing them with the behaviour of non-expert viewers, where a greater degree of both intra and inter viewer variability might be anticipated.

The work reported here did not distinguish between gaze sequence behaviour for readers when viewing normal vs abnormal (positive) cases, nor for differing breast morphologies (eg size, texture). Some investigation of the impact on gaze sequence patterns due to attentional attraction in such cases is warranted. This could help improve current computer assisted diagnosis (CAD) software systems for mammogram analysis.

A further matter of interest which could be investigated using the eye tracking data obtained from these experiments, is to consider how to compare macro scale aspects of readers' viewing behaviour (e.g. how much immediate comparison between left and right images they undertake, or whether their overall scanning strategies follow an intended route such as top to bottom). Such aspects will require a more sophisticated clustering approach which extracts information at a higher level of complexity than the individual gaze locations adopted here. This may require the design of specific "signatures" of gaze characteristics which are well suited to the mammogram viewing process rather than to arbitrary image viewing, as those mentioned previously. Nevertheless, the same eigenGazes PCA based method for comparing performance of viewers is a plausible candidate for analysing those situations as well.

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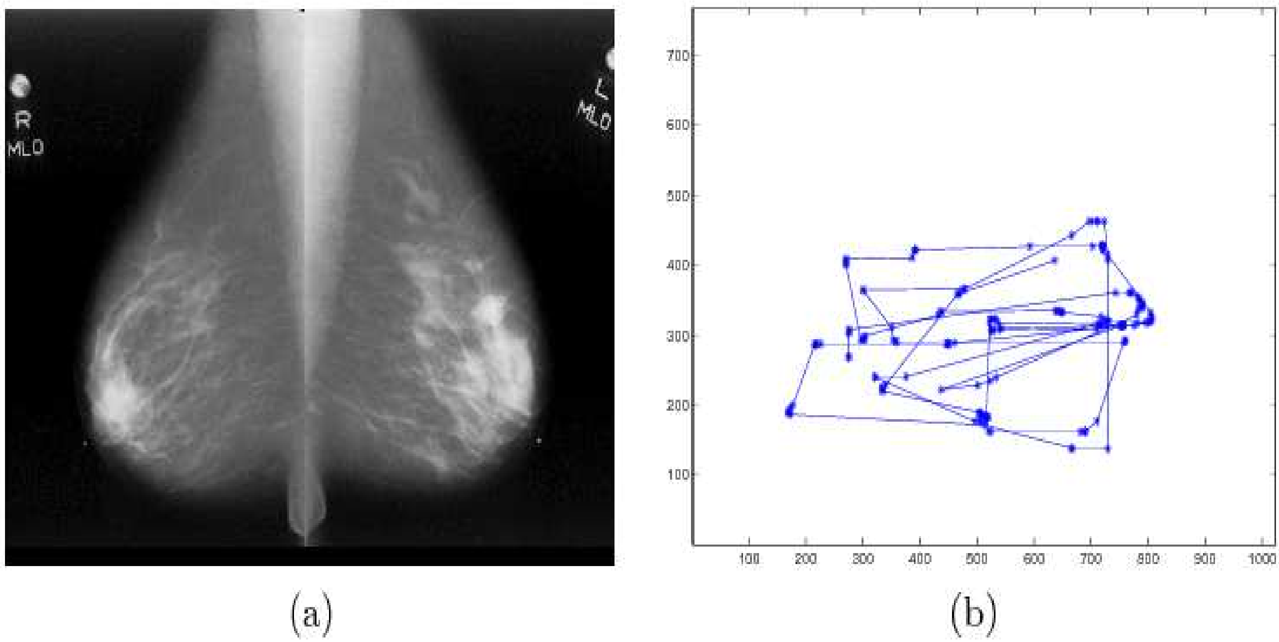

Figure 1: (a) Example of a mammogram (MLO pair) from the test set; (b) one eye tracking sequence for this image.

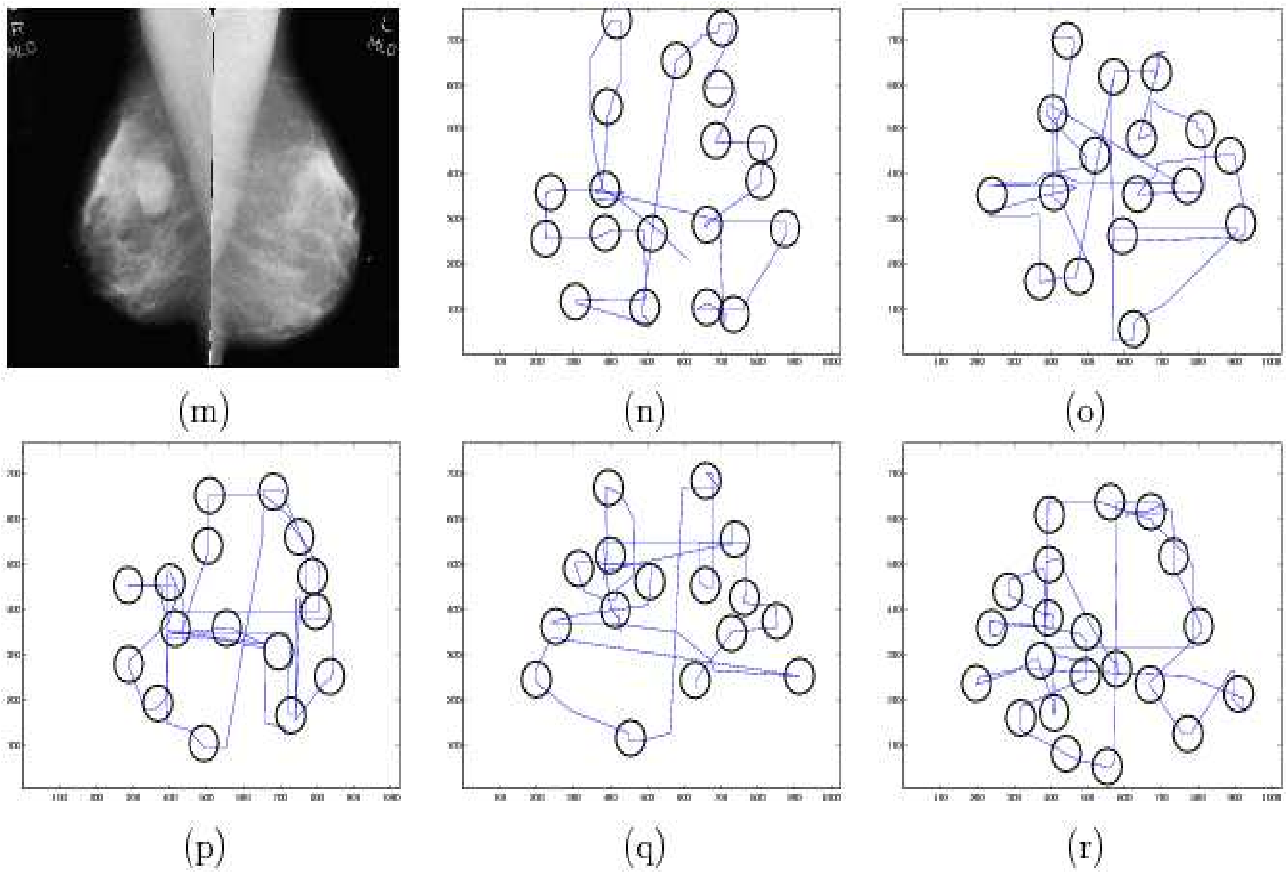

Figure 2: Examples of sets of the first 20 gaze location clusters identified in 5 independent presentations of the image (m) to the same viewer, following our experimental protocol.

A Classification Algorithm that Derives Weighted Sum Scores for Insight into Disease

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Abstract

Data mining is often performed with datasets associated with diseases in order to increase insights that can ultimately lead to improved prevention or treatment. Classification algorithms can achieve high levels of predictive accuracy but have limited application for facilitating the insight that leads to deeper understanding of aspects of the disease. This is because the representation of knowledge that arises from classification algorithms is too opaque, too complex or too sparse to facilitate insight. Clustering, association and visualisation approaches enable greater scope for clinicians to be engaged in a way that leads to insight, however predictive accuracy is compromised or non-existent. This research investigates the practical applications of **A**utomated **W**eighted **Sum**, (AWSum), a classification algorithm that provides accuracy comparable to other techniques whilst providing some insight into the data. This is achieved by calculating a weight for each feature value that represents its influence on the class value. Clinicians are very familiar with weighted sum scoring scales so the internal representation is intuitive and easily understood. This paper presents results from the use of the AWSum approach with data from patients suffering from Cystic Fibrosis.

Keywords: Data mining, cystic fibrosis, Classification algorithm, data visualisation

1 Introduction

Algorithms used in the data mining phase of a knowledge discovery from database exercise can broadly be divided into four categories; classification, clustering, associational and visualisation. Classification algorithms such as supervised neural networks, rule induction or naive Bayes predict a class variable's value given a training set of feature variable values. The potential for an analyst to gain insight toward a deeper understanding of the data varies from algorithm to algorithm. The black box nature of supervised neural networks often results in good prediction accuracies however insight into the data is limited. Decision tree induction algorithms provide more insight by generating an explicit representation of the smallest subset of feature values that lead to good prediction accuracy.

Clustering algorithms group feature values into distinct groups comprising similar items for the analyst to identify as pertinent to the issue. The analyst gains insight by observing like records which suggest new ways to understand the data. However, clustering does not specify ways in which features combine that permits predictive accuracies achievable with classification algorithms. Associational algorithms such as Apriori advanced by Agrawal et al (1996) discover sets of feature values that frequently occur together. Analysts gain a deeper understanding of the data because the associations confirm knowledge they implicitly or intuitively had or because the associations are surprising and suggest new hypothesis to explore. However, typically there are so many associations generated that artificial mechanisms need to be introduced to limit the number that are presented to analysts. Visualisation methods aim to present feature values visually without classifying, clustering or drawing associations. The visual presentation alone can sometimes enable the analyst to glean insights not readily apparent otherwise.

Classification algorithms have limited potential for the facilitation of insight because the representation of knowledge that arises from the algorithms is too opaque, too complex or too sparse. Neural networks inter-node weights do not map directly to any concept or pattern in the data. Decision trees and rules such as those generated by algorithms such c4.5 advanced by Quinlan (1993) present only those features that are useful for achieving high predictive accuracy. Insight into disease causes could conceivably involve features that are not selected for inclusion in the decision tree. Bayesian approaches exemplified by Duda (1973) can also be problematic in that probabilities at many nodes affect the classification requiring some amount of reverse engineering to determine the way in which a feature influences the classification. More recent techniques including Support Vector machines described by Vapnik (1999) actively seek a minimal set of feature values that maximise predictive accuracy. However, as is the case for decision tree induction, understanding often involves features that are not sufficiently prevalent to warrant inclusion in the support vector but are important for suggesting hypotheses or for a deeper appreciation of the disease and its causes.

Further, the representation of knowledge in existing classification algorithms is not easily incorporated into medical practice. For instance, a complex, multi-level decision tree may accurately predict an outcome but it cannot readily be integrated into practice unless embedded and into a decision support system so that the tree is hidden from the clinician. An ideal classifier for use in medical practice is required to be simple and easy to use and interpret.

We claim that a simple and intuitive way to understand how feature values influence a class value is with the concept of a weighted sum. Many medical scales such as the Glasgow Coma Scale (Teasdale and Jennings 1974) associate a weight or score with feature values and a threshold on class values. The Glasgow Coma Scale rates a patient's level of consciousness by providing a score between 3 and 15, from a rating on three variables, eye movement, verbal ability and motor movements. For example, a weight of 1 is assigned toward the total score if eyes do not open. A weight of 2 if the patient makes incomprehensible sounds and a further 2 if the patient reacts to pain. The total score, in this example of 5 results in a classification of severe coma because the total is below the threshold for severe coma of 8. Weighted sum formulas such as the Glasgow Coma Scale are easy to understand. The relative importance or influence of each feature value is provided by the value's score. For example, the ability to obey commands that demand motor movement has a weight of 6 so this feature value itself can be seen to be an influence toward a minor reduction in consciousness as opposed to a severe coma.

In this paper, we present a classification algorithm called AwSum, that demonstrates high predictive accuracy at the same time as engaging the analyst to glean new insights. The AwSum algorithm discovers a weight for each feature value and thresholds on the class variable that minimise misclassification rates. The intuition behind this is that each feature value has an influence on the classification that can be represented as a weight and that combining these influence weights gives an influence score for an example. This score can then be compared to a threshold in order to classify the example. The algorithm for calculating and combining weights, and determining thresholds is briefly described in section 2.

Further, the algorithm discovers weights for pairs of values and uses the pair weight instead of the sum of the component single weights, if the pair weight is appreciably different to the mean of the singles. Interactions between three, four and more feature values are weighted in the same way.

AWSum provides insight into the data that is simple and visual to interpret whist maintaining predictive accuracy comparable with other classifiers. The AWSum algorithm has been applied to parts of The Australian Cystic Fibrosis Data Registry (ACFDR) database and potentially valuable insights have been obtained. Experience with this data set are presented in the next section before a description of the algorithm follows in section 3.

2 Insight into the Cystic Fibrosis dataset

The Cystic Fibrosis dataset consists of 212 records of 23 features associated with a diagnosis of mild, moderate or severe CF. The features relate to patients' antibiotic use, nutritional supplements, gender, body mass, infections, and various breath volume tests. A cystic fibrosis expert clinician was presented with the diagrams generated by the AwSum algorithm depicted in Figure 1. The clinician, a co-author of this paper, had extensive experience with cystic fibrosis. The right hand side of the graph was assigned the value 1 which represents the class value severe for cystic fibrosis. The left side was assigned the value -1 which represents mild cystic fibrosis. We see from the bottom three entries on Figure 1 that being female provides a weight or influence toward mild CF. Testing positive for the yeast infection Candida Albicans provides an influence the other way towards severe CF. Having a breath volume less than 95.85 provides some influence toward severe CF. The influence weight for each feature value including the three above were presented to the expert clinician.

Figure 1 illustrates that the influence for female and Candida together is less than that for Candida alone. This is not surprising given that being female was influential toward mild and Candida presented some influence toward severe CF. However, despite *FVCP less than 95%* being only marginally influential toward severe CF and being female indicative of mild CF, the pair together, paradoxically are far more influential toward severe CF than seems intuitive. Candida and *FVCP less than 95%* is highly influential toward severe CF but the three together, female and Candida and *FVCP less than 95*% are weighted highly toward an assessment of severe CF.

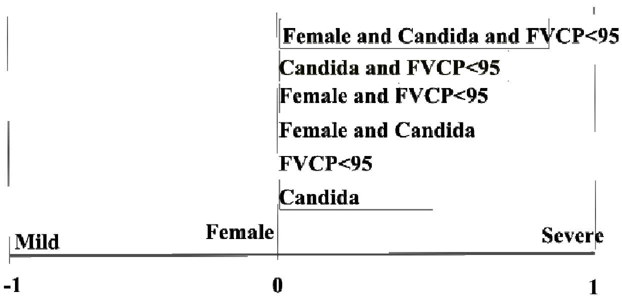

Figure 1: Influence weights for feature values and combinations of feature values

The link between females, Candida and *FVCP less than 95%* and severe CF surprised the expert. His suggestion was that perhaps severe CF caused CA. Sufferers of CF tend to have compromised immune systems that leave them susceptible to infections such as Candida. However, this explanation doesn't fully cover what is seen in the data, as CA seems to compound the CF severity when associated with *FVCP less than 95%*. The explanation for the increase for females may be that females more often have CA. This data has proven interesting enough to the expert that further enquiries are being made of experts in the CA area to try and determine an explanation for the observation. Recent microbiological research by Klotz et al (2007) suggests that Candida may act as a catalyst for the aggregation of bacterial cells which suggests a possible causal link between CA and the severity of CF. While no causal link has been established at this stage and may well never be, the insight provided by AWSum has proved interesting to our expert and prompted him to expand his domain knowledge by consulting other related experts.

Despite the simplicity of scoring systems such as the Glasgow Coma Scale and ease with which they can be applied in clinical practice, (Wyatt and Altman 1995) note that the most scoring systems advanced are in fact, rarely used by clinicians. They attribute the lack of uptake of diagnostic models by clinicians to a lack of adequate evidence for the scale's credibility, accuracy, generality and effectiveness. The approach advanced here could feasibly engender clinicians to trust the scoring system that emerges from the AwSum algorithm more readily because the influence weights are readily seen to be derived from data analyse with minimal assumptions.

Various forms of linear regression are currently used in many medical applications. Although these have solid theoretical underpinnings (Wyatt and Altman 1995) found that in as many as one in five statistical models the underlying assumptions such as normally distributed variables were violated affecting the integrity of the approach.

The AwSum approach draws inspiration from two elements of logistic regression; the avoidance of assumptions and the centrality of relating one class value against another. Logistic regression does not assume that values are distributed normally and, through its use of the odds ratio, directly relates one class value to its opposite: (Pr(Class|Feature_value)/1-Pr(Other class|Feature value). The logistic regression approach differs from that presented here in its derivation of parameters of a logistic function are derived from actual data, for use in classifying new examples. The AwSum algorithm is described in the next section.

2.1 The AwSum Algorithm

The first phase of the AWSum approach lays the foundations for classification by calculating influence weights for each feature value. A feature value's influence weight, **W,** represents its influence on each class value and so it needs to simultaneously represent the feature value's association with a class value and its alternate. The AWSum approach extends beyond binary classes but the simpler binary case will be described here. We arbitrarily specify a range for the influence weight for a feature value to be between -1 to 1 , where a certainty of one class value produces a weight of -1 and a certainty of the other class value a weight of 1. We arrive at an influence weight for a feature value that represents the feature value's influence on one class value relative to its opposite. Equation 1 demonstrates this calculation and Figure 2 shows an example where:

Pr(Class_value_1 | Feature_value_1) = 0.2 and
Pr(Class_value_2 | Feature_value_1) = 0.8
These conditional probabilities are calculated as:
n(Class_value ∩ Feature_value) / n(Feature_values)

The influence weight for a feature value, W_{Fv1} is:

$$W_{Fv} = pr(O1 \mid Fv1) - pr(O2 \mid Fv1)$$

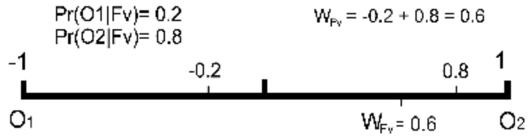

Figure 2 Binary class example

Classification of an example is achieved by combining the influence weights for each of the example's feature values into a single score. By summing and averaging influence weights we are able to arrive at a scaled score that represents a combination of the evidence that the example belongs to one class and not to another. The use of a scale from -1 to 1 is somewhat counter-intuitive because of the suggestion of negative probabilities. To avoid this, a mapping function is used to scale influence weights to be non-negative. The same mapping function is used to determine influence weights where there are more than two class variable values.

Performing the combination by summing and averaging assumes each feature value's influence is equally comparable. Although this is a relatively naive approach, it is quite robust as described later in this section. It also leaves open the possibility of using other functions for the combining of influence weights, much the same as different kernel functions can be used in support vector machines.

The influence score for an example is compared to threshold values that divide the influence range into as many segments as there are class values. For instance, a single threshold value is required for a binary classification problem so that examples with an influence score above the threshold are classified as one class value, and those with a score below the threshold are classified as the other class value. Each threshold value is calculated from the training set by ordering the examples by their influence weight and deploying a search algorithm based on minimising the number of incorrect classifications. For instance, the examples with total influence scores that fall to the left of the threshold in Figure 3 are classified as class outcome, **A** This however includes two examples that belong to class **B** in the training set and so these two examples are misclassified but the number of misclassifications has been minimised. Two examples to the right of the threshold are misclassified as class **B** when they are **A**'s. In cases where there are equal numbers of correctly and incorrectly classified examples the threshold is placed at the mid-point under the assumption that misclassification of class **A** and **B** is of equal cost. New examples can be classified by comparing the example's influence score to the thresholds. The example belongs to the class in which its influence score falls.

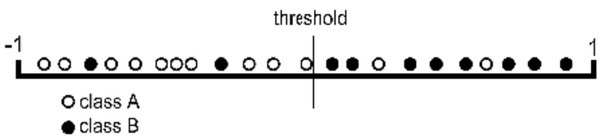

Figure 3 Threshold optimisation

AWSum is suited to nominal feature values and class outcomes although it is not necessary that they are ordinal. Continuous numeric features require discretisation before use in AWSum. As a consequence there is a risk of information loss due to the discretisation however studies to ascertain the impact of this have not yet been performed. While there is a potential for developing a distinct method of discretisation in AWSum the research to date has used the MDL method by (Fayyad and Irani 1993).

The combining of influence weights for single feature values into a total influence score for an example and using this to classify is intuitively based however, it is plausible that feature values may not individually be strong influences on a class outcome but when they occur together the combination is a strong influence. For example, both *drug A* and *drug B* may individually be influential toward low blood pressure but taken together lead to an adverse reaction that results in exceedingly high blood pressure.

The influence weights for each feature value combination can be calculated in the same way as they were for the single feature values. These combinations of feature values can contribute to an increase in accuracy and provide insight. Analysts can use them to identify feature values that have interesting interactions. This is achieved by comparing the influence weights of the individual component feature values of the combination to the influence weight of the combination. If they are markedly different this indicates a level of interaction between the feature values. This is useful, for example, in identifying things such as adverse drug reactions.

2.2 Model Selection

AWSum calculates an influence weight for each feature value and all combination's of feature values and so a comparison of the influence of the feature value combination to its parents is possible. By this we mean that a feature value combination containing two feature values can be compared with the feature value weight of each of the components that make it up. In doing so the difference between the influence weight of the parent and child can be calculated. If the influence can be attributed to a parent, or if the weight of the combination is not significantly different to the influence calculated for combining the two single feature influence weights using AWSum's averaging method then there is be no need to include the child in the classification model. This also leads to an ability to identify combinations of feature values that interact strongly in a way different to their constituent features which can provide insight into the data as discussed above with the Candida example in the Cystic Fibrosis data.

3 Classification accuracy

Four datasets were sourced from the UCI Repository maintained by Blake et al (1988) in addition to the Cystic Fibrosis dataset (ACFR 1999), for the comparative evaluation of the AWSum approach:

- Cleveland Heart - 14 numeric features, 2 classes, 303 instances, 6 missing values
- Iris- 5 numeric, continuous features, 3 classes - 1 linearly inseparable, 150 instances, 0 missing values
- Mushroom - 22 nominal features, 2 classes, 8124 instances, 2480 missing values
- Vote - 17 Boolean features, 2 classes, 435 instances, 0 missing values
- Cystic Fibrosis - 17 categorical features, 6 continuous feature, 3 classes, 212 instances, missing values

Classification accuracy has been assessed using 10 fold stratified cross validation. Table 1 shows the classification accuracy of other techniques using the Weka suite Witten (2000) alongside results from AWSum. AS1 refers to AWSum using single feature values independently, without considering any interaction between feature values. AS3 shows the classification accuracies achieved with AwSum including the influence weights for combinations of feature values up to a combination of three feature values. Naive Bayes (NB), TAN, C4.5, Support Vector Machine (SVM) and Logistic Regression (LG). Table 1 illustrates that AWSum performs comparably on all datasets, particularly when interaction effects with three features are adopted.

	AS1	**AS3**	**NB**	**TAN**	**C45**	**SVM**	**LG**
Heart	**83**	**90**	84	82	79	84	84
Iris	**94**	**97**	94	94	96	97	93
Mush	**96**	**99**	96	100	100	100	100
Vote	**86**	**97**	90	94	96	96	95
CF	**48**	**64**	60	60	61	56	61

Table 1. Classifier comparison

4 Conclusion

AWSum demonstrates that classification accuracy can be maintained whist providing insight into the problem domain. The insights into the CF data have been shown to confirm domain knowledge. It has also been shown that AWSum can elicit non trivial insights that can be of interest to domain experts. Given the ease of use and interpretation of insights stimulated by the AWSum algorithm, it would seem that it would be of use in real world data mining situations. Future work involves redesigning the algorithm for the streaming of data.

The AWSum algorithm lends itself to time series problems. The counts of the weights and combinations of weights can be incremented example by example as they arrive in the data stream and each influence weight updated accordingly. Preliminary studies on a Diabetes dataset of 80 features and 1930 records have shown promise.

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Characterizing Image Properties for Digital Mammograms

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Abstract

Adoption of computed radiology (CR) and direct radiology (DR) imaging for screening mammograms in many countries alongside digitally scanned film mammograms has resulted in a wide range of different intrinsic (physical) characteristics of images becoming commonplace. It is sometimes conjectured that viewer performance could be adversely affected by this wider variability, as compared with the variability that was formerly experienced with film only. This paper identifies several aspects of the image characteristics relevant to viewer perception, including intensity properties (such as contrast), spatial properties (such as texture) and structure properties (such as breast density). We then provide quantitative descriptions of the variability of these properties over a test set of 12 screening mammograms drawn from three different modalities and containing a typical mix of screening cases.

Keywords: Digital mammogram, Image properties.

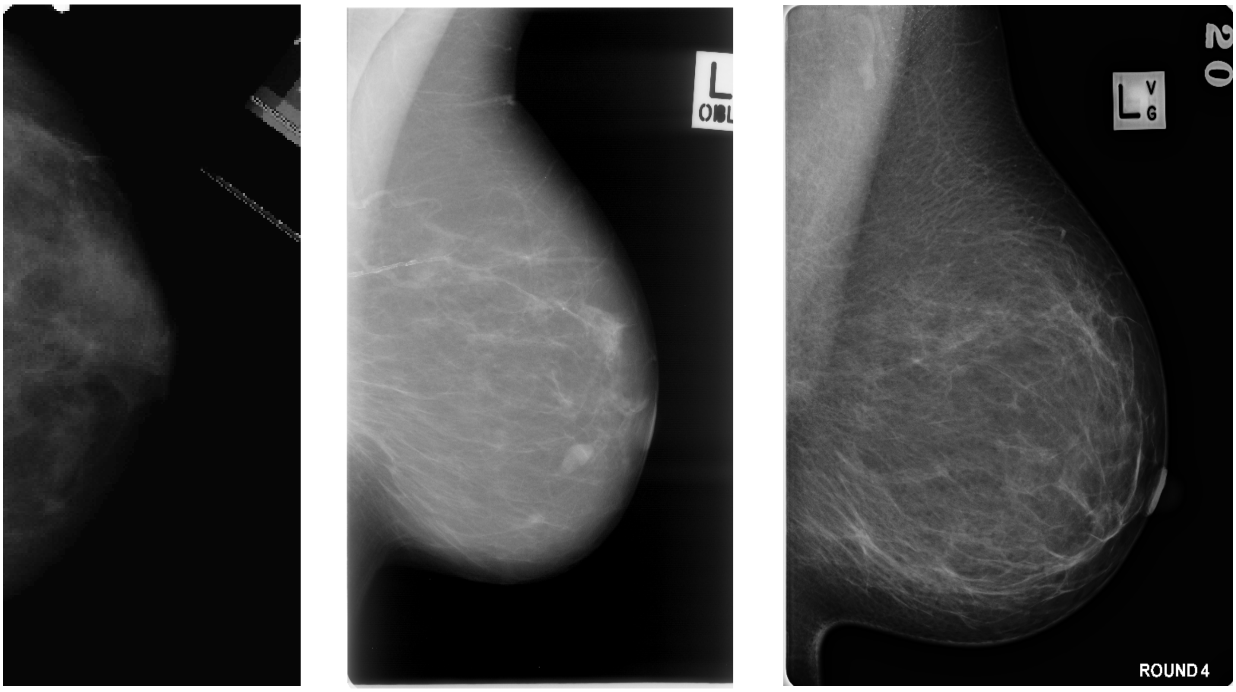
1 Introduction

Digital mammography is becoming widely adopted for national government-funded screening programs in many countries, and consequently diverse local choices of imaging equipment and local guidelines for image acquisition are being established. For example, in Australia each State is conducting its own project for conversion of their screening program from film to digital, resulting in use of imaging equipment from several different vendors, while the Australian and New Zealand College of Radiologists (ANZCR) and Australasian College of Physical Scientists and Engineers in Medicine (ACPSEM) are developing national guidelines for image quality and acquisition processes which may nevertheless be interpreted or customised differently at state level.

A major consequence of the conversion to digital is a disruption of the established envelope of "typical" image visual characteristics (such as brightness and contrast) to which readers have become accustomed in their previous film-based environments. While readers are generally tolerant of some variation in image appearance, there will inevitably be differences between digital images acquired on different vendor equipment both computed radiology (CR) and direct radiology (DR) (and potentially with variations in setup e.g. due to automatic dose adjustment), and also differences between these new digital screening images and prior film images now scanned to digital.

The definitive work on comparing the effectiveness of digital mammograms against films in a screening scenario was conducted by Pisano *et al* (2005) and showed no significant differences in reader performance. Use of different acquisition equipment has been the subject of some studies on variability (e.g. Young *et al*, 2008) which however generally relate to image formation and signal-to-noise characteristics. Some work has also considered impacts on readers of variable image quality (e.g. Astley *et al*, 2008) mainly from the perspective of receiver operating characteristic (ROC) performance rather than subjective opinions. Generally, variations in image characteristics have been ignored due to the adoption of image acquisition calibration standards such as CDMAM (van Engen *et al*, 2006) which it is argued will produce highly consistent source images. Unfortunately this does not help in situations where longitudinal sets of images acquired from different sources must be considered, such as in screening cases where only priors from a different modality are available, or in long term longitudinal cohort studies using images from multiple historical sources.

It is sometimes conjectured that viewer perception (and consequently reading performance) could be adversely affected by this wider variability, as compared with the variability that was formerly experienced with film only. However, no standard metric for characterization of such image variability has emerged, although some quantitative analysis of variability for particular modalities has been reported (e.g. Davies, 1993). Also, there is little commentary in the literature on the variability of images across data collections used for experimental work, in terms of their intrinsic (physical) image characteristics. This paper takes a step towards addressing this gap, noting that variability in



USF **Lumisys** **Sectra**

Figure 1: Screening mammograms obtained from USF, Lumisys and Sectra

characteristics determined by quantitative analysis should be correlated with viewer subjective performance studies.

2 Method

The characterization work reported here was intended to be applied only to the interior of the breast region in mammograms, as the background variability is arguably not relevant to reader performance. First we need to consider the choice of a range of appropriate image characteristics, which will give a broad indication of the types of image variability differences arising from the different modalities. We elected to choose simple measures that would be easy to compute, were not biased by any assumption of models of image or observer characteristics, and were well known so as to be readily reproducible. We also sought to use measures that would characterize different levels of perceptual complexity, to offer more complete coverage of the effects of image variability than if we were to concentrate on only one level.

The most obvious visible changes that might be expected are those arising from overall image appearance, in particular related to *image intensity* properties in the overall region-of-interest. These can be derived most easily from image histogram information. The next level at which perceptual effects may occur is in subtle *local intensity relationships* within a group of pixels, such as those related to texture and small scale tissue structures. The final level we identified was that of *major structures* within the breast tissue, related to actual pathology such as lesions or masses. To represent these three levels, we selected the *mean* for a sub-image block of pixels,

$$m = \sum_{i=0}^{G-1} r_i \, p(r_i)$$

the *single pixel entropy*,

$$\Re = \sum_{i=0}^{G-1} p(r_i) \log_2 p(r_i)$$

and *uniformity* computed using the well established moment formula,

$$U = \sum_{i=0}^{G-1} p^2(r_i)$$

where *G* is the number of possible intensity values ranging from 0 to *G*-1, r_i is the intensity value, and $p(r_k)$ is the normalized histogram obtained by dividing all the histogram elements of an image by its total number of pixels (Tjondronegoro *et al*, 2006).

Here, the block statistics mean (*m*), entropy ($\Re$) and uniformity (*U*) constitute rough indicators of some typical variations in image intensity characteristics of the three levels of complexity, which image readers would easily notice. The mean is an approximation for the overall brightness of the image, which influences how well subtleties in the texture within the breast tissue can be

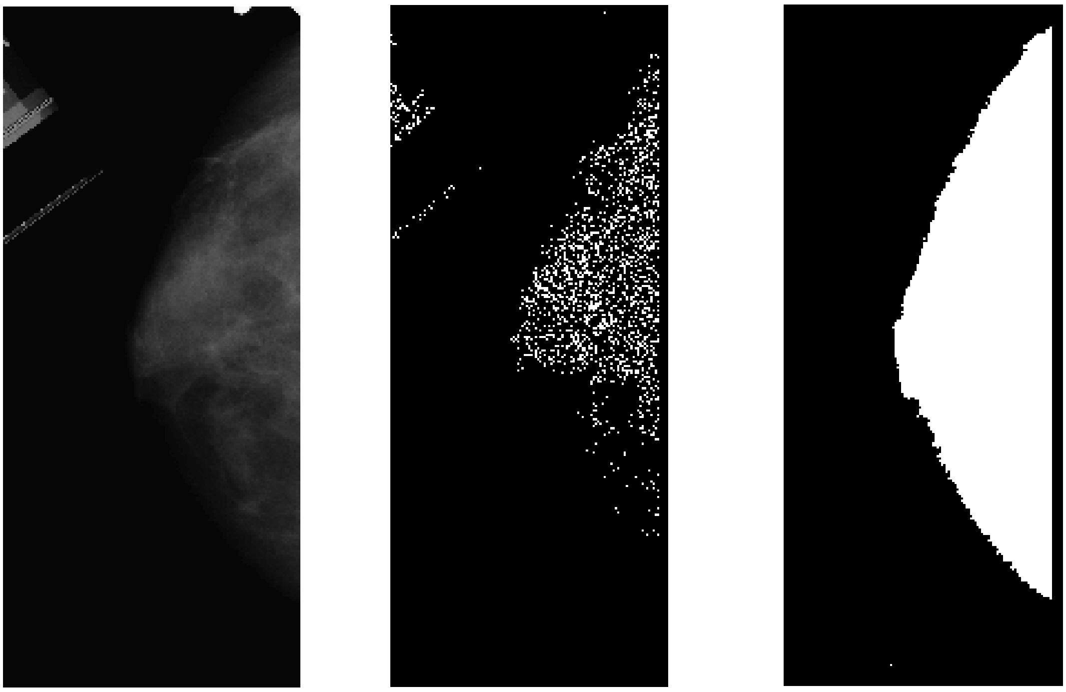


Figure 2: Binarization of a digital mammogram using a Sobel filter and morphological operations to segment the breast ROI

Table 1: Mean (standard deviation) results for individual image property measures

Mean Intensity	USF	Lumisys	Sectra
Image 1	21278 (3826)	65077 (175)	6189 (3235)
Image 2	41091 (4702)	65145 (64)	3921 (952)
Image 3	39969 (4166)	64797 (92)	4095 (3594)
Image 4	31223 (2344)	64794 (96)	1380 (290)
Entropy	**USF**	**Lumisys**	**Sectra**
Image 1	8.74 (0.43)	6.83 (0.45)	11.68 (0.71)
Image 2	9.05 (0.39)	6.35 (0.33)	11.20 (0.39)
Image 3	8.76 (0.38)	5.88 (0.62)	11.40 (0.99)
Image 4	8.98 (0.25)	5.69 (0.45)	9.93 (0.35)
Uniformity	**USF**	**Lumisys**	**Sectra**
Image 1	0.0028 (8.16E-04)	0.0105 (3.27E-03)	0.0004 (2.70E-04)
Image 2	0.0023 (5.97E-04)	0.0148 (3.72E-03)	0.0005 (1.49E-04)
Image 3	0.0027 (7.19E-04)	0.0219 (9.85E-03)	0.0006 (5.29E-04)
Image 4	0.0023 (4.13E-04)	0.0236 (7.71E-03)	0.0013 (3.15E-04)

discerned. Entropy indicates the amount of high local variation in the image, which is related to overall image contrast and also the amount and visibility of fine detail features (such as calcifications). Uniformity gives an indication of the extent of typical "smooth" intensity regions within the breast tissue, given the choice of block size.

3 Results

A test collection consisting of three cohorts of 4 screening mammograms from each of three different modalities was constructed, using the following sources:

- University of Southern Florida dataset of digitised film (USF using DBA @ 42 micron) (Heath *et al*, 2001)

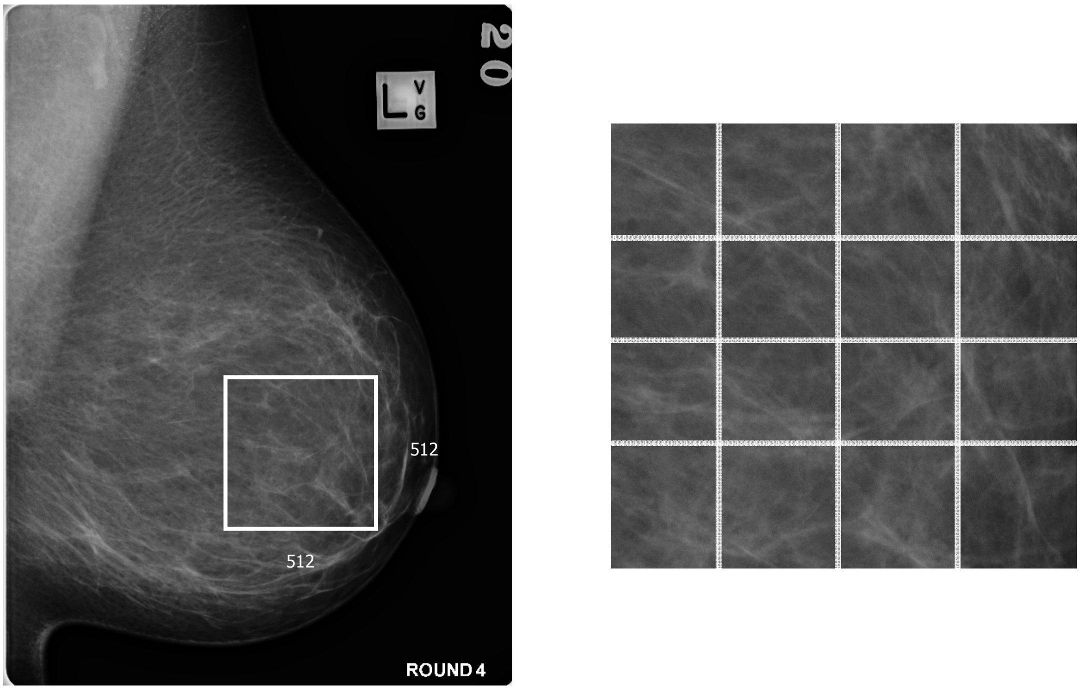


Figure 3: A 512x512 block obtained for analysis

Table 2: Summary of cohort image property measures

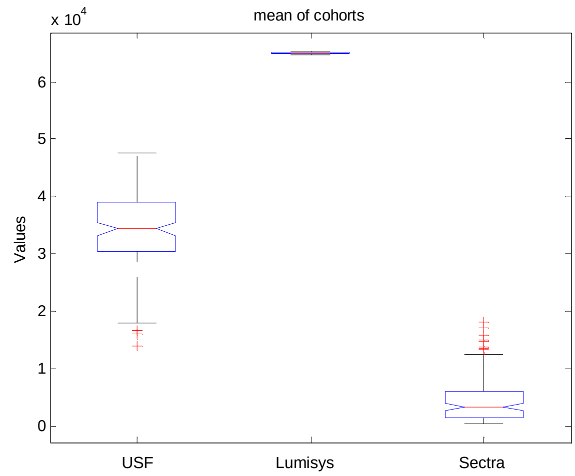
	Mean intensity	Entropy	Uniformity
USF mean	33390	8.88	0.0025
USF standard deviation	8871	0.385	6.91E-04
Lumisys mean	64953	6.19	0.0177
Lumisys standard deviation	196	0.642	8.46E-03
Sectra mean	3896	11.05	0.0007
Sectra standard deviation	2959	0.936	4.72E-04

- Local university supplied dataset of digitised film (LUMISYS @ 50 micron)
- Vendor-supplied dataset of digital CR and DR images (SECTRA).

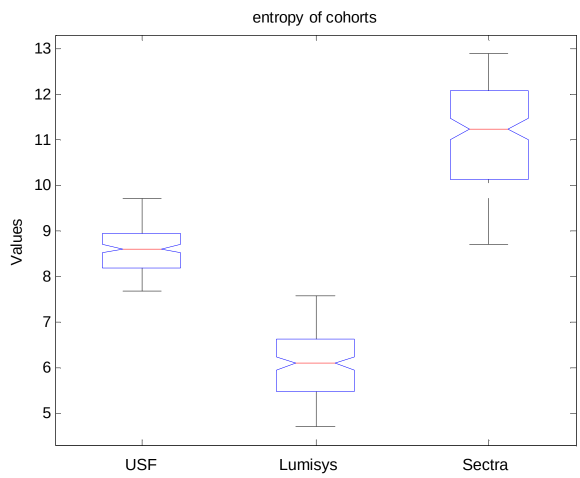
Each source contained high resolution screening mammograms encoded using 16 bits per pixel. Figure 1 shows example screening mammograms from each of the three sources).

The breast interior part of each image was obtained using binarization and region extraction tools in MATLAB. More specifically, the Sobel filter in combination with MATLAB morphological operations such as image dilation (imdilate) using a vertical and horizontal line structuring element of length 3, filling in image regions and holes (imfill) and image opening to remove small objects (bwareaopen) was used to define the breast ROI (see Figure 2). A 512x512 pixel block was then located behind the nipple area within the whole of breast region-of-interest. This 512x512 block was further divided so that 16 128x128 sub-images represented the textured areas to be analysed for each mammogram image (see Figure 3).

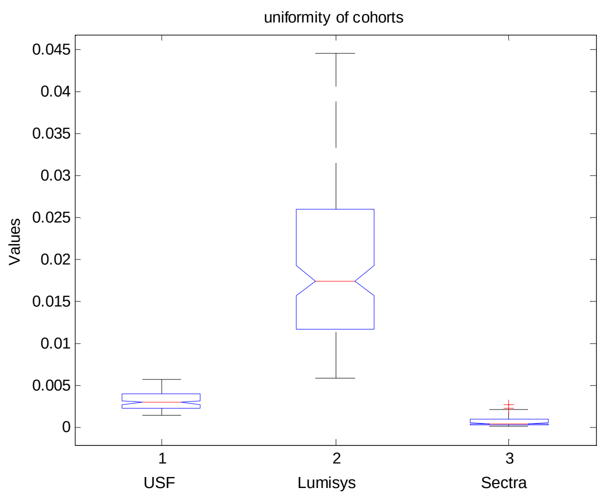
Each of the sub-image blocks within an image were analysed for average intensity, uniformity and entropy. The mean and standard deviation for each measure was computed over all sub-image blocks for a given image and image source, showing measurements over all 16 blocks in an image (Table 1) and 64 blocks in each cohort (see Table 2 and Figure 4), respectively. On each box plot the central mark shown is the median and the edges of the box indicate the 25th and 75th percentiles. The whiskers of the box show the extent of the most extreme



(a) Mean intensity measure



(b) Entropy measure



(c) Uniformity measure

Figure 4: Image property variability between cohorts

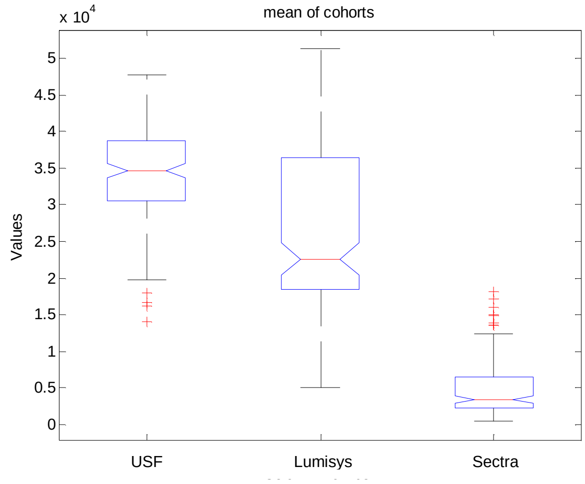


Figure 5: Image property (mean intensity) variability between normalised (linear stretch over the full dynamic range) cohorts

data points which are not considered outliers, while outliers are plotted individually as plus signs (+).

4 Discussion

The results indicate surprisingly large differences between the inherent intensity properties for the three image cohorts, with less variability within image than between image (and indeed between modality). The differences between cohorts statistically could easily be shown to be representative of three different distributions with a very high level of confidence.

In practice these differences are usually masked by display transformations which linearise the perceived values, and optimise the contrast and brightness. Applying a simple linear stretch over the full dynamic range (16 bits) associated with the data, to mimic the display transformation, the box plot diagram in Figure 5 was generated. It can be seen that there is still sufficient apparent variability to suggest that perceptual performance may be affected, if indeed it depends on the characteristics represented by these measures.

While more statistically significant results could be obtained by repeating this analysis over a larger sample size or using sample groupings within the cohorts to allow analysis of variance, we feel there is enough *prima facie* evidence here to justify further investigation of the perceptual effects which might be encountered, either through observer modelling or subjective testing.

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Privacy and Security in Open and Trusted Health Information Systems

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Abstract

The Open and Trusted Health Information Systems (OTHIS) Research Group has formed in response to the health sector's privacy and security requirements for contemporary Health Information Systems (HIS). Due to recent research developments in trusted computing concepts, it is now both timely and desirable to move electronic HIS towards privacy-aware and security-aware applications. We introduce the OTHIS architecture in this paper. This scheme proposes a feasible and sustainable solution to meeting real-world application security demands using commercial off-the-shelf systems and commodity hardware and software products.

Keywords: architecture of health information systems, privacy protection, security for health systems, access control, network security in e-health, application security for health applications. .

1 Background

The OTHIS Research Group at the Information Security Institute (ISI) in the Queensland University of Technology (QUT) has been recently formed in response to industry need for systems expertise in contemporary Health Information Systems (HIS). The Group's vision is to bring together system and network researchers, application domain specialists, and security specialists to contribute to the design, development and enhancement of a trusted framework for the protection of sensitive health data in HIS. Currently the OTHIS Research Group is chaired by Emeritus Professor William (Bill) Caelli, AO. The Group has already been successful in defining and developing an overall trust architecture based around identification of the separate domains of concern. Preliminary results have been published (Liu, Caelli and May 2006; Croll, Henricksen, Caelli and Liu 2007; Henricksen, Caelli and Croll 2007; Liu, Caelli, May and Croll 2007; Liu, Caelli, May, Croll and Henricksen 2007; Franco, Sahama and Croll 2008; Liu, Caelli, May and Croll 2008b; Liu, Caelli, May and Croll 2008a).

2 Paper Structure

Section 3 introduces the concepts of privacy and security in HIS and aligns security requirements for HIS with more general goals and initiatives. The authors' proposal for a secure and open e-health architecture is overviewed in Section 4. Sections 5, 6 and 7 discuss the components of this architecture. Future work is outlined in Section 8.

3 Introduction

As a general principle privacy and security of individual patient data is paramount. In the real world the challenge is to carry this principle through to HIS implementations. The primary goal of the OTHIS Research Group, therefore, is to promote an architecture that provides guidance for technical and security design appropriate to the development and implementation of trusted HIS. This research provides a sufficiently rich set of security controls that satisfy the breadth and depth of security requirements for HIS whilst simultaneously offering guidance to ongoing research projects. In order to meet real-world application security demands that are understandable, implementable and usable, our research themes embrace reasonable security strategies against economic realities using commercial off-the-shelf systems and commodity hardware and software products. Our research team continues to focus on architectural implementation activities around the OTHIS scheme in order to address security requirements at all levels in HIS. The team's future research work will implement and verify the practicality of the OTHIS scheme to a real HIS in partnership with a number of medical institutes.

3.1 The Need for Trusted HIS

Social, political and legal imperatives are emerging worldwide for the enhancement of privacy and security in health information systems. A high level of "information assurance" is now accepted as the necessary baseline for the establishment and maintenance of both current and future HIS. A security violation in HIS, such as an unauthorised disclosure or unauthorised alteration of individual health information, has the potential for disaster among healthcare providers and consumers. In a separate paper (Liu et al., 2007) three such real-world scenarios (from Australia, UK and the USA) are identified and analysed from a security and sustainability perspective. Although the concept of Electronic Health Records has much potential for improving the processing of health data, electronic health records may inadvertently pose new threats for compromising sensitive personal health data if not designed and managed effectively.

Indeed malevolent motivations could feasibly disclose confidential personal health information on a more widespread scale (potentially massive) and at a higher speed than possible with traditional paper-based medical records. There is also the factor of the healthcare service providers' willingness to accept and adopt a new technology that does not always facilitate efficient working practices. To encourage healthcare service consumers and providers to use electronic health records, it is crucial to instil confidence that the electronic health information is well protected and that consumers' privacy is assured.

3.2 General Health Information Systems

A generic modern HIS architecture normally consists of a number of structures at various levels in computer hardware, firmware, operating system design and facilities, network management system, middleware, database management system and healthcare applications as shown in Figure 1.

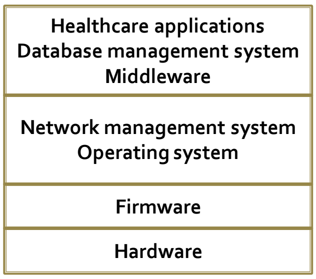

Figure 1: General HIS Structure

Unfortunately, many application users wrongly believe that they have sophisticated security at that particular level since their applications provide a form of message level protection or equivalent. It should be understood that no matter what security measures are supported at the application level they are only ever going to be superficial to the knowledgeable adversary or malicious insider. A significant limitation in this scenario is that the overall application system can be no more secure than the software libraries invoked and incorporated into it, as well as the underlying Web Services upon which the applications depend through such internal actions as systems calls, dynamic library activation, use of intermediate code interpreters such as "JavaScript" or "just-in-time" compilers, etc. The Web Services itself can be no more secure than the firmware and hardware facilities of the computer on which it operates. Likewise, any other software component set, such as "middleware", database management system, network interface structure or "stack", is constructed above the Web Services and so totally depends upon security functions provided by the Web Services as well as the robustness of that Web Services against attack. Healthcare applications can be secure and trusted only when the underlying operating system is secure and trusted.

3.3 Australian national e-health initiatives

The National E-health Transition Authority (NEHTA) gives direction on developing e-health implementations for the Australian environment. NEHTA recommends a Service Oriented Architecture and Web Services approach to healthcare application systems (NEHTA 2005). This is recognised as best practice for scalable distributed systems today.

NEHTA work programs for an e-health interoperability framework include Clinical Information, Medicine Product Directory, Supply Chain Efficiency, e-Health Policy, Clinical Terminologies, Individual Healthcare Identifiers, Healthcare Provider Identifiers, Secure Messaging, User Authentication and Shared Electronic Health Record Specifications.

NEHTA focuses on exchanging clinical information by electronic means securely and reliably at the HIS application level. A limitation of this Web Services approach is that security is restricted to the application level only. This is the highest level depicted in Figure 1. Three real-world scenarios, where privacy and security breaches and weaknesses occur external to the application level, are given in Liu et al. (2007). A complete architecture is needed, therefore, and not one that involves just a secure messaging system alone. OTHIS addresses the privacy protection and security for health systems in a holistic and "end-to-end" manner. This incorporates more than just the high-level application layer. The OTHIS architecture also complements existing work already evident in related HIS security areas.

4 Proposed Architecture - OTHIS

In order to achieve a high level of information assurance in HIS, we propose a new approach to a more trusted scheme, the Open and Trusted Health Information Systems (OTHIS). The goal of OTHIS is to address privacy and security requirements at each level within a modern HIS architecture to ensure the protection of data from both internal and external threats. OTHIS also has the capability of providing conformance of any HIS to appropriate regulatory and legal requirements. Its primary emphasis in this paper is on the Australian health sector.

4.1 OTHIS is an Open Approach

In line with contemporary information technology concepts of open source and open architecture, OTHIS incorporates the term "open". In order to embrace emerging open architecture, standard and open source technologies are used rather than proprietary technologies. This allows the architecture to be publicly accessible, providing a platform for interoperability. Normally HIS are based around open and distributed network systems. It is therefore entirely appropriate to relate OTHIS to international standards such as Open Systems Interconnection (OSI) security architecture (ISO 7498-2 and ISO/IEO7498-4). This research adopts the broad architectural concepts as proposed in those standards and as adopted for some time by national governments via "Government OSI Profiles".

4.2 OTHIS Builds upon Trusted Systems

Aligned with the concept of trust in information systems, OTHIS also incorporates the term "trusted system". Any information system depends upon its basic architecture for its general operation. Any trusted information system depends, therefore, upon a trusted base for safe and reliable operation, commonly referred to as a "trusted computing-base". Without a trusted computing base any system is subject to compromise. In particular, data security at the application level can be assured only when the healthcare application is operating on top of the trusted computing base platform. Threats to the security of healthcare applications can be either externally or internally sourced. In the case of an external threat, an adversary can exploit illicit means to perform actions that bypass or disable the security features of healthcare applications or that grant inappropriate access privileges. In the case of an internal threat, if the HIS is not internally robust authorised users can inadvertently compromise the system. This is a commonplace scenario. Inevitably healthcare applications or databases must be executed upon a trusted platform in order to achieve adequate information assurance. For this reason OTHIS aims at running on top of trusted firmware and hardware bases.

4.3 OTHIS is a Modularised Structure

Appropriate data security management involves the protection of data in storage, during processing, and during transmission. The proposed OTHIS structure (Figure 2) addresses all these areas. It consists of three distinct modules:

- Health Informatics Access Control (HIAC),
- Health Informatics Application Security (HIAS), and
- Health Informatics Network Security (HINS).

OTHIS is a modularised architecture for HIS. It is divided into separate and achievable function-based modules. The advantage of the modularisation is that each module is easier to manage and maintain. One module can be changed without affecting the other module. OTHIS is, thus, a broad architecture covering those requirements and parts that may be selected as required to meet particular circumstances. Although there is some overlap across the modules, each module has a specific focus area. HIAC is data-centric dealing with information at rest. HIAS is process-centric dealing with information under processing. HINS is transfer-centric dealing with information under transfer. Trust in network operations through HINS rests completely upon trust in HIAS and HIAC, otherwise the security of messaging becomes futile.

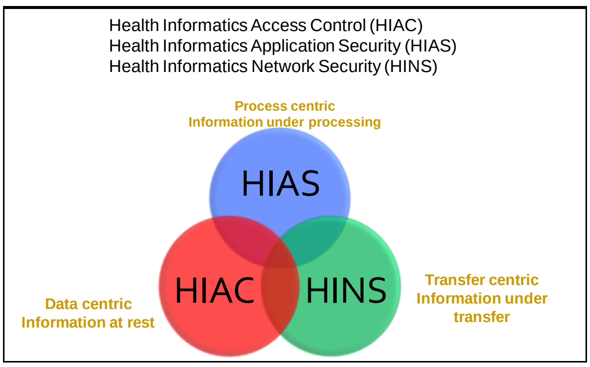

Figure 2: Modularised Structure of OTHIS

5 Health Informatics Access Control (HIAC)

"Access control" simply refers to a set of rules that specify which users can access what resources with particular types of access restrictions. Various Web Services, network management systems and database management system can employ a choice of access control mechanisms to grant users access to protected resources of the system. Controlling appropriate access to data in any information system is a major security issue. Many instances of poor access control management practices leading to security and privacy violations are reported on a regular basis (Liu, Caelli, May and Croll 2007).

5.1 Access Control Models

Discretionary access control essentially assigns responsibility for all security parameters of a data resource to the "owner" (user), usually the data resource creator, who can pass on such parameters to others and perform functions as desired in an unrestricted manner. Role based access control refines the concept to allow for users to be grouped into defined functions or "roles" enabling easier management of overall system security policy particularly in dynamic business environments. Mandatory access control (MAC), in principle, enforces security policy as set out by the overall enterprise and not set up by the data resource "owner". The traditional MAC policy was originally designed for a military environment. It was based on the multi-level security policy hierarchical structure and was quite rigid in its application. More recent research has modernised the traditional MAC approach to a flexible form of MAC (Flexible MAC) that overcomes traditional MAC limitations. Flexible MAC provides a balance of security needs and flexibility of implementation that allows the security policy to be modified, customised and extended as required in line with normal application and system requirements. The OTHIS/HIAC model is Flexible MAC-based accompanied by Role Based Access Control administration properties for flexibility and a refined level of granularity. This degree of simultaneous control and flexibility is not achievable with Discretionary Access Control, Role Based Access Control or MAC individually.

OTHIS/HIAC proposes a viable solution to provide appropriate levels of secure access control for the protection of sensitive health data. Increasingly, HIS are being developed and deployed based upon commercial, commodity-level information and communications technology products and systems. Such general-purpose systems have been created over the last twenty-five years, often with only minimal security functionality and verification. In particular access control, a vital security function in any Web Services that forms the basis for application packages, has been founded upon earlier designs based on Discretionary Access Control. Discretionary Access Control systems were defined around an environment where data and program resources were developed and deployed within a single enterprise, assuming implicit trust amongst users. This environmental model is no longer valid for modern HIS. In some commercial systems, for example, even the addition of a simple single printer unit has the capacity to seriously undermine the overall integrity of the information system.

5.2 Granularity in the HIAC Model

While privacy and security requirements directly relate to identifiable data and information, a far finer level of granularity is needed for security and control management requirements of a real HIS. Not only does HIAC enforce access controls on data files and file directories within the trusted Web Services level, it also provides access control at the {data element, database table}, {row/column}, and cell level views. This can reduce the maintenance cost of managing security at the application level.

5.3 Viability of an HIAC model

To determine the practical viability of an HIAC model for HIS a demonstrator, based on a "Security Enhanced Linux (SELinux)" computer platform ("Red Hat Enterprise Linux version 4"), was built (Henricksen, Caelli and Croll 2007). This work was carried out at the primitive stage of SELinux project development. As SELinux continues to advance and evolve, our research to date has modernised our HIAC demonstrator (Martin Franco 2008). Preliminary results of this research indicate that the broad philosophy of Flexible MAC appears ideally suited to the protection of the healthcare information systems environment.

6 Health Informatics Application Security (HIAS)

The overall aim of the OTHIS/HIAS model is to address the data protection requirements at the application level in HIS. HIAS is located at the OSI's "Application Layer", Layer 7, to provide security features which are often required by a healthcare application at a data element level through to a service level. While privacy and security requirements directly relate to identifiable data and information, those HIS elements sitting at higher level information system layers cannot be ignored.

6.1 HIAS Legal Compliance

HIAS addresses enterprise policies, and legislative and regulatory requirements, as well as growing social and political demands relevant to the implementation of security controls in HIS with a primary emphasis on the Australian health sector. Based on a Flexible MAC-based concept, OTHIS/HIAS proposes a feasible and reliable solution for the protection of sensitive health data. It satisfies legislative, regulatory and organisational policy requirements for both healthcare providers and healthcare consumers, as well as providing the flexibility to meet operational demands in HIS. This concept is entirely pertinent to the recent e-health privacy blueprint (Australian Government Office of the Privacy Commissioner 2008) proposed by the Australian Government Office of the Privacy Commissioner, which requests specific enabling legislation in order to protect sensitive health data. Such legislative support is crucial for the proposed national Individual Electronic Health Record systems to be a successful implementation. The objective of the legislation is to gain the trust and confidence of individuals in the Individual Electronic Health Record system.

It must be noted, however, that not all individuals have trust and confidence in the overall management of their health records or in the associated information systems used by healthcare providers. To instil an individual's trust and confidence, it is critical to ensure that electronic health information is maintained appropriately, and that any such security measures are understood and accepted by an individual and by society at large. OTHIS/HIAS proposes a Flexible MAC-based scheme for the development of a reliable and sustainable Individual Electronic Health Record system against misuse, disclosure and unauthorised access. This is reinforced by the assertion of the Office of the Privacy Commissioner (Australian Government Office of the Privacy Commissioner 2008) and NEHTA[1] (2008). They argue that it is necessary to have the "sensitivity label" mechanism in place in the design of a national approach to Individual Electronic Health Record in order to enable individuals and their health providers to have the appropriate level of access they are permitted to have on sensitive health data.

6.2 Web Services Security in the HIAS Model

Web Services and Service-Oriented Architecture concepts and implementations are proliferating. The Web Services application model promises to add functional and assessment complexities to the overall information assurance problem by weaving separate components together over the Internet to deliver application services through such methodologies as software "mashups" and the like. These techniques place full trust in the underlying components that are combined into the overall system in a situation where the provenance of those underlying components may not be known.

NEHTA recommends using an Service Oriented Architecture approach to the design of healthcare application systems and the use of "Web Services" as the technology standards for implementing secure messaging systems (NEHTA 2005). NEHTA argues that development of information systems around Web Services technology is the direction in which the information and communications technology industry is heading as well as being accepted as best practice for the design of scalable distributed systems today. The Service Oriented Architecture approach is claimed to lead to more reusable, adaptable and extensible systems over other techniques. In particular, NEHTA supports the concept that Web Services technology has gained notable attention within the information and communications technology industry and its use is extending in both popularity and market penetration.

The Web Services technology can incorporate security features in the application layer, for example the label "WS-Security" in the header of a "Simple Object Access

[1] The National E-Health Transition Authority (NEHTA) has been established to accelerate the adoption of e-health by supporting the process of reform in the Australian health sector.

Protocol" XML message. WS-Security provides a set of mechanisms to maintain finer granular levels of security services such as authentication, confidentiality, integrity and non-repudiation at an element level. For example, WS-security defines how to use XML Encryption and XML Signature processes in the Simple Object Access Protocol to secure message exchanges. Moreover, Web Services is a series of open standards intended to support interoperability in an environment where separate applications need to share information over an open network. As such, any healthcare security architecture must be capable of handling the Web Services paradigm in a trusted, secure and efficient manner.

OTHIS/HIAS also addresses the situation where Web Services structures are being used as the major health informatics information transport methodology. OTHIS recognises that the Service Oriented Architecture approach, implemented through a Web Services structure, has become a major information architecture paradigm. As such, any healthcare security architecture must be capable of handling the Web Services paradigm in a trusted, secure and efficient manner. This, however, provides end-to-end security for data and messages in transit but depends upon an underlying trusted system that supports Flexible MAC principles.

6.3 Health Level 7 in the HIAS Model

In developing a trusted system architecture for an HIS, it is important to understand the philosophy of Health Level 7 for medical data transfer. Health Level 7, an American National Standards Institute accredited standard, has been developed to enable disparate healthcare applications to exchange key sets of clinical and administrative data. With respect to the Health Level 7 structure, HIAS depends upon the use of cryptographic subsystems as its security mechanism. Future research programs under OTHIS will elucidate the relationships between the broad Health Level 7 structure and that of OTHIS from an information assurance perspective. In particular, the focus is on the use of Health Level 7 for both communication and application security and privacy services as needed.

It is necessary to determine which parts of the Health Level 7 standards set belong to either of, or both, HINS and HIAS. The problem of secure messaging structures, however, belongs to the HINS component (as will be described in a forthcoming paper). For example, Health Level 7 requires the use of "digital signatures". Reliable digital signatures are expected to be created from subsystems within the computer Web Services, and also possibly specific computer hardware under which the HIS works. Without a trusted foundation, the data security of any health applications is inherently vulnerable.

7 Health Informatics Network Security (HINS)

HINS consists of the appropriate network level security structure within an underlying HIS. HINS is aimed at the provision of services and mechanisms to authenticate claims of identity, to provide appropriate authorisations (least privileges) following authentication, to prevent unauthorised access to shared health data, to protect the network from attacks, and to provide secure communications health data transmission over the associated data networks. The major function of HINS is the authentication of claimed identities throughout HIS. This includes not only all personnel but also all computing, data storage and computer peripherals such as printers, scanners and network interfaces. OTHIS/HINS involves the vital integration of network security protocols and associated data formats with the access control structures contained within an operating system and allied generic application systems of individual computer nodes.

At the same time the OSI Presentation Layer, as envisaged in the HINS project, will enable cryptographically secured trusted paths to be created between applications at client and server levels in any Service Oriented Architecture environment. The combination of the SELinux/Flexible MAC structures with a clear identification of a new "Layer 6" structure stands at the centre of the HINS project to enable protection of health systems on an end-to-end basis. Under the HINS scheme, the new Layer 6 will also be managed in the usual way via the creation of essential Flexible MAC user authorisation "profiles" that will be introduced into a running system in a dynamic way in order to be enforced by the new layer. Users will be authenticated into a stated profile at the network level; that is, without connection to any specific health information server host. In this sense, an authenticated user will be able to present an authorisation vector to any allowed host in the approved network in such a way that the separation of such hosts will not be obvious to the end-user.

The OTHIS/HINS project is currently under development. The broad system architecture is nearing completion. The connection of Flexible MAC "compliant" servers and network elements into the overall structure is being defined against stated health information system requirements. Progress so far has demonstrated the basic concept of a "presentation layer" style "stub" structure for use by common application packages.

8 Conclusion and Future Work

The concepts of privacy and security in HIS were introduced in Section 3 along with the alignment of security requirements for HIS with more general goals and initiatives. Section 4 overviewed the authors' proposal for a secure and open e-health architecture. Components of this architecture are further detailed in Sections 5, 6 and 7.

Our research indicates that an overall trusted HIS should implement security at all levels of its architecture to ensure the protection of personal privacy and security of electronic health information. From an information security perspective, we propose OTHIS for the overall HIS architecture. This comprises a set of complementary security architectures consisting of HIAC, HIAS and HINS. This proposed OTHIS scheme will be tested through experimental structures created on trusted Web Services. Key research questions to be answered include those concerning both system efficiency and availability aspects of the proposed architecture. Preliminary results of this research indicate that the broad philosophy of

Flexible MAC appears ideally suited to the protection of the healthcare information systems environment.

We contend that it is both timely and desirable to move electronic HIS towards privacy-aware and security-aware applications that reside atop a trusted computing-based Web Services. Such systems have the real-world potential to satisfy all stakeholder requirements including modern information structures, organisational policies, legislative and regulatory requirements for both healthcare providers and healthcare consumers (privacy and security), and flexible operational demands in HIS. This paper emphasises the need for well-directed research into the application of inherent privacy- and security-enhanced operating systems to provide viable, real-world trusted HIS. The OTHIS scheme has the potential to fulfil these requirements. Future work continues on the development of the other modules within the proposed OTHIS structure with the ultimate goals of maximum sustainability, flexibility, performance, manageability, ease-of-use and understanding, scalability and legal compliance in the healthcare environment.

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Understanding the Implementation of an Electronic Hospital Information System in a Developing Country: A Case Study from Pakistan

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Abstract

Literature on implementation of hospital information systems is scarce, especially with regard to developing countries. Pakistan Institute of Medical Sciences (PIMS) is a large public sector hospital in Pakistan that successfully implemented a hospital information system (HIS). This article studies how this success was achieved and examines the hurdles faced in the implementation of the HIS and how they were overcome. The article aims to provide a better understanding of implementing HIS in a developing country setting, to add to academic knowledge in the area as well as to serve as a guide to anyone wishing to implement an HIS in such a setting.

Keywords: health informatics, hospital information systems, system implementation, developing countries, Pakistan.

1. Introduction

Hospitals are the main healthcare providers in developing countries (Clifford, Blaya et al. 2008). For this reason hospitals ought to be the primary target institutions when aiming to improve health information systems in developing countries. However electronic information systems in hospitals in developing countries are "rare to nonexistent" (Rotich, Hannan et al. 2003). In an environment where the awareness and appreciation of electronic hospital information systems (HIS) does not exist, implementing[a] an HIS would be a serious challenge (Idowu, Cornford et al. 2008). Against all odds, if a hospital in a developing country did decide to transform its information system and implement an HIS, there would be surprisingly sparse literature on useful experiences to guide that hospital through the transformation. This is because literature on "implementation" [a] of hospital information systems is extremely limited (Ovretveit, Scott et al. 2007), and whatever literature is available is predominantly from developed countries where the circumstances, systems, processes, and cultures are different from that of developing countries.

This paper attempts to improve the understanding of HIS implementation in a developing country setting firstly by reviewing the literature on HIS implementation, and then by presenting a case study of HIS implementation in a large tertiary public-sector teaching hospital at the Pakistan Institute of Medical Sciences (PIMS) in Islamabad, Pakistan.

2. Methodology

The literature reviewed included papers that directly or indirectly presented information on HIS implementation with a special but not exclusive focus on developing countries. The case study was a qualitative study carried out in PIMS from August to September 2007. PIMS was selected for the study because it is the only public sector hospital in Pakistan that has successfully implemented a fully functional HIS. "Successful"

[a] Implementation here is taken in the broad sense that includes development and deployment of the electronic information system

implementation was defined as the system installed institution-wide, with users routinely using and being satisfied with the system. PIMS was also selected because it's HIS was developed wholly within and for that particular institute, making it a very developing-country-oriented system. Otherwise the general trend in developing countries is for HIS projects to be "funded through various sources from international donor and aid agencies to local non-governmental organizations"(ITG 2001). Finally, PIMS was chosen because it presented a success case, as opposed to a failure case, which is thought to be more informative for an implementer rather than a failure case. Success cases also highlight challenges and barriers and learning how these are overcome increases the understanding about the challenges and barriers. Failures are however more commonly seen in the domain of health informatics (Berg, Aarts et al. 2003; Heeks 2006).

The methods of the case study included in-depth interviews of five key informants and twenty users, informal conversations, study of documentation and observations carried out over the study period. The selection criterion for the key informants was that they have been involved with the project from its initiation to the present. Notes were taken during interviews and reviewed on a daily basis. Contradictions were clarified with the informants the following day. Validity of information was determined through comparative analysis of data from the different sources. Data analysis was carried out by studying and mapping emerging themes.

3. Literature review: experiences of implementing HIS

The classic works documenting experiences of implementing ICT projects are "Leading Change" (Kotter 1996) and "Crash" (Collins and Bicknell 1998). Kotter lists the sense of urgency, powerful coalition, creating a vision, communicating the vision, empowering others, planning for short-term wins, consolidating improvements and institutionalizing new approaches as key factors leading to successful implementation. Kochers on the other hand focuses on failure factors and identifies over ambition, complacency, over-rating computer technology, over reliance on ICT professionals and ICT consultants, undue confidence in the power of the contract to penalize an underperforming ICT company, and trust in costly custom built software as key factors.

From the literature accessed for this study, social factors were identified to be more critical that the technical factors when determining the success of implementation. The most common factor observed in the literature that influenced the success of HIS implementation related directly or indirectly to change management, pointing out the necessity of formal managerial skills to manage the transformation, the need for effective communication channels, and the importance of a vision for change (Berg, Aarts et al. 2003; Lorenzi and Riley 2003; Alvarez 2004; Kensing, Sigurdardottir et al. 2007; Ovretveit, Scott et al. 2007). Extensive upfront planning (IT 2007; Frame, Watson et al. 2008), securing political support (Cassels 1995; Alvarez 2004), and implementation from the top (Ovretveit, Scott et al. 2007b) were also identified as important success factors. Associated with these factors was mention of the characteristics of leaders (Berg, Aarts et al. 2003; Lorenzi and Riley 2003; McGrath 2006; Frame, Watson et al. 2008). These included beneficial characteristics that led to success (e.g. transformational type, physician-champion, senior), and detrimental characteristics that predisposed an implementation to failure (e.g. over committed and emotionally involved leader).

Consideration of the end user was the next most commonly identified factor. Raising users' understanding of the requirements and benefits of change, as well as ensuring user participation in the design and development of the system were identified (Kuhn and Giuse 2001; Meijden, Tange et al. 2001; Ball 2003; Alvarez 2004; Igira, Titlestad et al. 2007; Kensing, Sigurdardottir et al. 2007; Kyhlback and Sutter 2007; Ovretveit, Scott et al. 2007; Soriyan, Ajayi et al. 2007; Frame, Watson et al. 2008). Regarding user involvement it was pointed out that the difference between genuine user involvement and users being mere informants should be borne in mind.

In failures, as opposed to successes, software emerged as a ubiquitous factor. Over ambitious projects, complexity of the project, scope creep, poor user-interface design, lack of clarity on the functionality required, and lack of sensitivity to the local systems were identified as important failure factors (Cassels 1995; Collins and Bicknell 1998; Lorenzi and Riley 2003; Heeks 2006; Kyhlback and Sutter 2007; Lucas 2008). One paper (Sicotte, Denis et al. 1998) described the inappropriateness of a normative approach adopted in the project whereby new realities were imposed through the HIS. This forced uniformity and predictability in care delivery and consequently the system did not get accepted by the physicians because that was not how physicians thought or worked. Furthermore, tried and tested systems that were intuitive and required little or no training were said to reduce failure rates (Ovretveit, Scott et al. 2007a).

The articles from developing countries, in addition to touching on some of the factors listed above, identified other issues more fundamental in nature. These included the lack of adequate electricity supply, lack of computer infrastructure, lack of funding, unsustainable funding, and the low level of educational of the technical staff who, rather than the clinicians, tend to be the primary users of the system in developing countries (Chandrasekhar and Ghosh 2001; Rotich, Hannan et al. 2003; Gordon and Hinson 2007). Idowu, Cornford and colleagues (2008) identified the government's lack of appreciation of the value of IT in healthcare, cost, Internet connectivity, and lack of maintenance culture as further obstacles.

4. Study results: experience of implementing the HIS at PIMS

When the idea of an electronic hospital information system was first conceived in PIMS in 1996, the foremost implementation barrier was the lack of interest in such an initiative. There was no mechanism at the hospital by which to formally seek internal or external advice on this issue. This initiative therefore had to become the personal effort of an enthusiastic physician, who championed its initiation, development and deployment.

In terms of infrastructure, there was a complete lack of information technology (IT) hardware in the hospital. The pathology department was the only department that had one old computer. The initiation of the HIS at PIMS was based on small donations. One old Pentium II computer was purchased which was setup as a makeshift server while the older existing computer was placed as a terminal at the registration counter of the pathology department.

When it came to identifying software, there was no off-the-shelf software available in the local market. At that time open source software was not much developed and PIMS could not afford the commercially available software that would have required significant customization. Furthermore, these were untested for local conditions, and too sophisticated and complex for the level of IT expertise available at PIMS. Through personal networks of the physician champion however, a software vendor was identified who agreed to deploy eight programmers in the hospital who would develop the HIS software application in house free of cost. Being an IT company, the vendor had expert knowledge and skills in application development. Basic HIS knowledge was gained from the Internet. Initial development focused only on the registration function of the pathology department that was installed on two nodes, one of which was placed in the office of the head of department (HOD) of pathology. After the HIS was developed and deployed successfully, it demonstrated its value as well as the potential for expansion to other functions of the department. With this expansion there was need for more hardware, so more hardware donations were sought from companies, particularly those that regularly upgraded their systems. This led to the acquisition of additional second hand computers and one old server.

The expansion of the system in the pathology department however meant that it would require other staff and not just the already enthusiastic HOD of pathology to use the system. This was the greatest challenge as it meant changing the perceptions (and in many cases misperceptions) and attitudes of the staff to this "alien" technology. It also meant changing work routines and work practices, which the technical staff was so used to and comfortable with. The technical staff (who typically run departments in developing country settings) of the pathology department were to be the main users of this system. These technicians however, typically coming from the lesser educated background had either never or very rarely come across a computer. Many were intimidated by the thought of having to work with a computer because it was either perceived as a threat to monitor and penalize them, or because they thought that exposing their lack of computer abilities might mean they would lose their jobs. How this change was led merits an independent paper in itself, but very briefly the main strategy for this was holding countless formal and informal discussions. Many assurances and much support had to be given so much so that the IT people developing the software had to at times sit as computer operators entering the data.

Round the clock support was offered with the HOD himself always on-call to attend any failing of the system, ranging from the simplest problems like changing paper rolls in the dot matrix printer to more serious issues like the database crashing or the physical breakdown of the exposed network of Ethernet cable. The physical breakdown of the network sometimes happened as a result of deliberate action to sabotage the progress of the system development. It is important to note that pursuit of the offender was considered counterproductive so was never undertaken. Instead, based on the experience of each incident, the system was made more secure.

For a long time both the computer and paper based systems ran in parallel. Staff started inputting data into the electronic system during off-peak times, initially with the IT "staff" sitting next to them or even doing it for them. This was seen to significantly encourage the technical staff to use the system. Later IT "staff" only helped during peak-times. Only when the staff started using the system were they able to appreciate its benefits. They began to feel ownership of the system, the proof of which was that they themselves ensured that whenever there was a failing, it was promptly reported and restored. Using the system also resulted in many suggestions of improvements coming from the technical staff, which led to its refinement and improvement. Only after the staff became fully confident at inputting data electronically was the paper-based system discontinued. Training of new staff, ongoing staff training and refresher courses became an important ongoing part of the system.

While developments were happening in the pathology department, the championing physician also started having discussions with other departments. Radiology was the next most willing department that showed an interest in implementing the HIS. So development of software for the radiology department commenced. At this time it was realized that the main registration counter of the hospital was collecting the same information that the pathology and radiology registration desks were collecting. To avoid this redundancy, registration was unified and centralized between the main registration counter, pathology and radiology departments by connecting a couple of computers of these departments.

In the expansion of HIS to other departments and wards, disinterested and skeptical medical doctors, nurses and technical staff were constant barriers. Doctors and nurses had not been exposed to any electronic health system through past training or working environments, and because of their lack of awareness they became indifferent to the implementation of this system and showed no encouragement, support, or commitment. However, when the pathology and radiology information systems were up and running, the other departments of the hospital started to receive pathology and radiology reports in electronic format. These outputs led to a decrease in the skepticism of HIS by the clinicians and an increased interest in the electronic system as they could visibly see outputs and realize the benefits. This paved the way for discussion to further expand the information system by developing software modules for other departments.

Gaining political support at the senior management level was an insurmountable challenge, at least at the outset. As the department of pathology initiated the project, there was no institutional ownership and interest in the system. Constant dialogue and demonstration of the value of the system to the stakeholders through seminars and meetings was undertaken to resolve this problem. Changing management which, like other developing countries, is not infrequent in Pakistan, brought in different personalities with different ideas, some of them reluctant on HIS and others keen (or at least not reluctant). However the championing physician was very committed which helped in tackling the lack of political support in the early stages. Once the implementation process had reached a stage where stopping the systems running in pathology and radiology would have lead to chaos, the system became viable against political barriers. Further development and expansion of the system however had to be undertaken in a stealth and low-key manner.

5. Discussion and conclusions

There are many similarities between the PIMS experience and what is seen in the literature. However there are key differences as well which need to be highlighted.

From the literature, formal upfront detailed planning and management that includes forming strong coalitions emerge as key factors to drive the implementation, institutionalization and acceptance of a system. In the case of PIMS no detailed planning was carried out beforehand and there was no formal management of the project. Detailed planning would have necessitated thinking at an institutional level. However, the departmental-level small-gains focus adopted in PIMS is thought to have been a key factor in the successful implementation of the system through a step-wise approach to meet every emerging need. Each step was taken to successful completion before proceeding to the next step. This did not indicate a lack of institutional vision; it was important for the champion to have the greater vision in order not to miss valuable opportunities of development and expansion when they arose. The departmental-level small-gains approach meant that emerging needs shaped the institutional vision rather than some preconceived inflexible grand institutional vision driving the change.

Also relevant to this point is the lesson learnt from the study that a strong and visible coalition at senior management level is not mandatory for the success of HIS implementation. Because there was no buy-in from the senior management or other departments initially, institutional recognition and acceptance did not exist and a single-person driven, stealth and low key approach had to be adopted. This strategy worked successfully in PIMS. The fact that the champion was a senior, well-connected and well-respected clinician, who was passionately dedicated to establishing the system, was also a key factor in its success. However, it is also important to note that the champion (and his "team") worked very closely, at a personal level, with the primary users to "convert", train, and support them. So while coalitions to drive the system implementation from the top were not formed, strong networks of users were formed at the grass-root level that progressively expanded. Training of the users was carried out on a one-to-one, on-site and hands-on basis rather than in the more theory-based traditional "class-room" style. This seemed to have been better accepted by the users.

The key factor that led to user acceptance was the practical usage of the system. It seems to have worked well to "release" the system in its infantile stage of development thereby engaging the users early in the development process leading to their "real" involvement. Only when the technical staff experienced using the system did they realise its value. They were then able to identify how it could be improved, which was critical in the development of a system that was suited to the local requirements. Early involvement also put the users at the leading end. enabling them to help develop the system, rather than being at the receiving end where the end users are imposed an "externally" developed system. All this worked in favour of user acceptance.

The factors leading to institutional acceptance were similar to those of user acceptance. When the stakeholders saw the outputs of the PIMS system, e.g. pathology and radiology reports, they were able to realize its benefits. This eventually led to the institutionalization of the system.

It is important to note that an "evolutionary" approach was taken throughout the implementation process where both staff and the system evolved and matured together. Software development and changing people's attitudes were interrelated and required time but, contrary to evidence from the literature, no sense of urgency was introduced. Had it been introduced, it might have been detrimental; by not letting the change "sink in" slowly there would not have been enough time for the users to understand, appreciate, and accept the system. It is equally important to note that a "revolutionary" approach was avoided, particularly in software development. The initial design was kept as similar in layout as possible to the paper-based forms. This helped to initiate the implementation process without unnecessary conflicts.

Evidently, successful implementation of HIS in a developing country setting is very possible. The implementation of HIS in PIMS is an example of the successful implementation of an institution-wide information system against all odds, in a hospital in a developing country where no prior electronic information systems existed. It is however important to realize that the circumstances in developing countries are different from those in developed countries, which is where most of the experience of, and guidance for, implementing HIS comes from. When implementing HIS in developing countries, context-specific circumstances, barriers, and needs must be taken into account. System implementation should be seen in the wider context of organizational change, of which software development is but one part.

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GP Attitudes towards Using HI Systems in Their Professional Role

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Abstract

This paper reports on a qualitative study of South Australian General Practitioner (GP) attitudes towards adopting Health Informatics (HI) technology. The study suggests attitudes are determined by GP perceptions of competing managerial, technological and political factors. Findings indicate increased exposure to HI use in performance of their role influences GP perceptions of the importance and certainty of implementation outcomes. However the prospect of such technologically facilitated change tends to manifest in resistance if perceived as uncertain, involuntary or not of demonstrable benefit to patients. The findings highlight the desirability of HI technology use being associated with benefits to GP patients and practices rather than with change to the GP's professional role and value.

Keywords: Change management, Social-technical change, Resisting change, Professionals.

1 Introduction

This paper explores 23 South Australian General Medical Practitioner (GP) reactions to the potential adoption of an unspecified data amalgamating Health Informatics (HI) system. The research was undertaken in order to gather more detailed and in-depth information on why GPs tend to resist (or not) HI systems.

Data is the basis for the information and generation of knowledge that healthcare relies on to support its delivery (Conrick, Hovenga, Cook, Laracuaente and Morgan, 2004; Georgiou, 2002; Yasnoff, O'Carroll, Koo, Linkins and Kilbourne, 2000). While information management is seen as a major activity of the healthcare professional, their work can also be characterised as complex and requiring contingent interpretations of physical signs, diagnostic tests, regulations, guidelines and patient needs (Ash, Berg and Coiera, 2004; Greenes and Shortliffe, 1990). Hence the ability to standardise unique diagnostic and therapeutic care paths of individuals is seen by Ash et al. (2004) to be the healthcare professional's true skill. However, having to respond simultaneously in multiple dimensions under continuous time pressure is also seen by Ash et al. (2004) to both create and hide errors. So while HI systems include decision support and expert applications to potentially assist the medical practitioner in their tasks (Jones and Craig, 2000), practitioner autonomy is traditionally regarded as a cornerstone of healthcare (den Hertog, Groen and Weehuizen, 2005)

Health Informatics is an emergent interdisciplinary label for the '…application of computers to assist the gathering, storage, processing and use of information to improve the procedures or outcomes of health care…' (Sullivan, 2001). HI systems look to reflect the principles, aims and tasks of evidence-based medicine in a specialised approach to the collection, storage, retrieval, communication and optimal use of health related data (Georgiou, 2002; IMIA, 2002). Aimed at improving the efficiency and effectiveness of healthcare management, implementing such HI technology is seen to have the potential to reduce the cost of chronic care while significantly raising the overall level of public health (Kelly, 2000; Warren, Noone, Smith, Ruffin, Frith, Van der Zwaag, Beliakov, Frankel and McElroy, 2001). Yet while Friedman (2006) opines developed nations are '…adopting health information technology as a tool for rationalising complicated healthcare systems, improving the quality of patient care, moderating healthcare costs, and reducing the incidence of adverse events…', investment in Information and Communication Technology (ICT) by the healthcare industry globally has historically tended be proportionately less than in other industries (Wanless 2004).

Accelerating the adoption of technology aimed at improving the overall management and quality of healthcare has become a priority for successive Commonwealth Governments in Australia (Commonwealth of Australia, 2001a). Yet despite the ongoing growth of technologically supported health-related activities in industrialised nations, there is a growing recognition that the diffusion process of HI technology is multifaceted in nature with no single tactic that will successfully address all the barriers to adoption (Fernandopulle, Ferris, Epstein, McNeil, Newhouse, Pisano and Blumenthal, 2003; Takahashi, 2001).

Estimated to see 85 percent of healthcare consumers annually, Australian GPs are seen as gatekeepers to the wider health system and integral to delivering any comprehensive, coordinated and continuing healthcare strategy (Weller and Dunbar, 2005). In order to facilitate GP use of such technology, the Commonwealth Government has targeted them with funding initiatives such as Practice Incentive Payments (PIPs) (AMWAC Report, 2005). This is seen to have contributed to the substantially higher degree of computerisation in general practice than for other healthcare entities, with 86 percent of GP practices estimated to have at least one computer in 2001 rising to 94 percent in 2005 (Didham and Martin, 2004; Henderson, Britt and Miller, 2006). On the other hand, increasing computerisation has also crystallised concerns about GP individuality, privacy considerations, migrating existing systems and systems reliability capability and connectivity (AMWAC Report, 2005). Technological initiatives aimed at interoperability also need Internet connectivity and GPs in remote/regional populations are arguably affected by a decreased Internet access for minority groups, rural populations, and those with low socioeconomic status (Chang, Bakken, Brown, Houston, Kreps, Kukafka, Safran and Stavri, 2004).

However facilitating technological interoperability between entities within a healthcare system also requires the adoption of standardised electronic patient records and can therefore be seen to potentially disrupt an entity's existing business and clinical processes (Ford, Menachemi and Phillips, 2006; Miller and Sim, 2004). Early research in New South Wales (NSW) by Bomba (1997) indicated that despite awareness of the possible advantages and benefits offered, GPs were unhurried about computerised patient records adoption decision making. Later research by Henderson et al. (2006) concluded that despite the rapid increase in availability, GPs continue to remain reluctant to embrace such technology. With almost all practices having at least one computer, some are nonetheless seen to have increased the use of technologically supported systems in order to increase practice income (Powell-Davies and Fry, 2005; Rudd and Watts, 2005). Yet a study of Australian GPs between 2003 and 2005 found some who had access to computers and clinical software chose not to use them, and only a third kept all patient data in an electronic format (Henderson et al., 2006). Other findings indicate HI systems that can reproduce accepted models of clinical reasoning or provide immediate patient benefit have generally been adopted whereas systems aimed at improving the overall efficiency and effectiveness of healthcare appear to have been resisted (Arroll, Pandit, Kerins, Tracey and Kerse, 2002; Bolton, Mira, Kennedy and Lahra, 1998; Walsh, 2004).

The need to identify factors affecting practitioner decision making is not only underscored by the push by governments and the rapid development of such systems, but also estimates that 76 percent of unintended events that could or did 'harm a patient' in Australian General Practice are preventable with such technology (Bhalsale, Miller, Reid and Britt, 1999; Chau and Hu, 2002a). Yet successful implementation of such technology is dependent on traditional functional structures of highly skilled and high status professionals in health organisations being committed to the project (Alsene, 1999). Since it does seem possible albeit increasingly difficult to continue operating a viable general practice without a computer, it would seem reasonable to judge such technical solutions in healthcare by the perceived usefulness to the user or organisation (Georgiou, 2002).

Even so, understanding why people accept (or not) innovation, particularly in information systems research, remains one of the most challenging and complex issues (Davis, Bagozzi and Warshaw, 1989; Frambach and Schillerwaett, 2002). Medical practitioners have additionally been cited as classic examples of 'professional' populations where understanding decisions of what innovations are adopted and when has been especially problematic (Greenhalgh, Glenn, McFarlane, Bate and Kyriakidou, 2004; Mintzberg, 1979).

Understanding technology acceptance behaviour has largely drawn on application of research models such as Innovation Diffusion Theory (IDT) or Behavioural Intention (BI) constructs (see for example Rogers, 1995; Venkatesh, Morris, Davis and Davis, 2003). IDT views innovation adoption as a process of reducing uncertainty about outcomes rather than as a single event while BI models posit determinants of both intention to use technology and technology usage behaviour. However traditional frameworks are not necessarily seen to reflect the reality of innovation diffusion and BI studies in healthcare contexts have been criticised for lacking consistency with studies using non-professionals (Chau and Hu, 2002; Gallivan, 2001). Earlier studies have also tended to take place within large and complex organisations, whereas General Practice in South Australia mostly averages 2.5 GPs each (AMWAC Report, 2005). While Gatignon and Robertson (1989) identify technology rejection is not simply the mirror image of adoption, limited relevant information systems research literature does attribute resistance to technological, individual, organisational and external factors (see for example Enns, Huff and Golden, 2001). In particular, key inhibitors have been identified as uncertainty about future business models and inadequate technical, legal and policy infrastructure (Debreceny, Putterill, Tung and Gilbert, 2002).

Rather than in system or setting terms, Markus (1983) believes resistance is more precisely explicable in terms of 'interaction' between characteristics of the people and the system, yet there is little diffusion research that examines the impact of context (Larsen, 2003). The 'sociotechnical' (distribution of responsibility) and political (distribution of power) variants of the interaction theory hold that resistance is the outcome of different political interests and power distributions. Thus decentralised structures are seen to resist change towards centralised control, and systems seen to potentially change the balance of power will be resisted by those who lose power. Hence the greater the perceived potential for such change, the more the change would be resisted. It seems reasonable to argue that technology adoption within General Practice may be influenced by structural and cultural complexities different even from other healthcare settings, while technology adoption models have arguably been generalised to a commonality of factors that lacks regard for contexts and settings (Aarts et al., 2004; Kaplan, 2001).

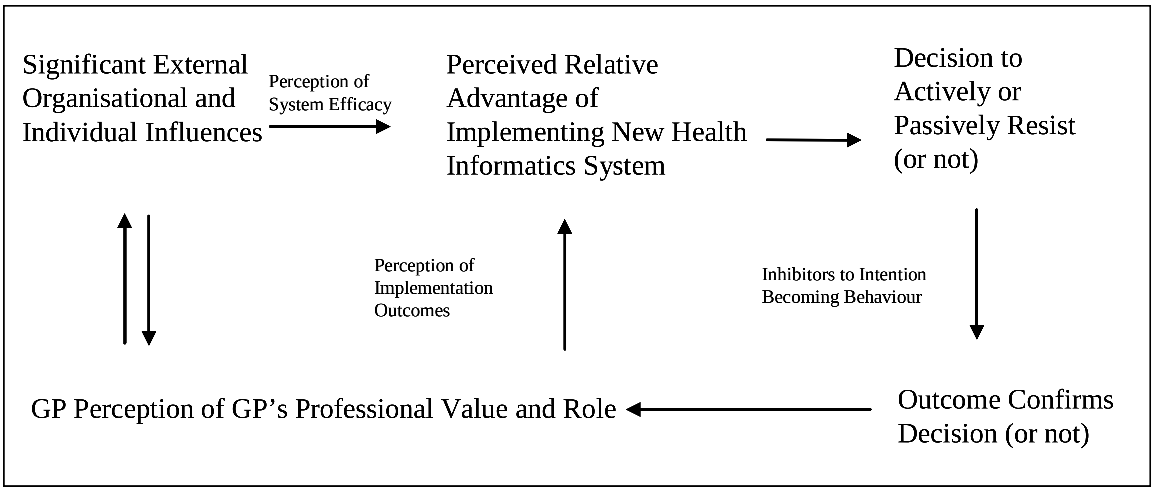

Figure 1: Research Model of Influences on GP Attitude towards a new Health Informatics System

Previous technology acceptance research has only made limited use of the literature from professional groups yet Mintzberg (1979) suggests change perceived as an assault on a professional's autonomy (such as making their skills programmable) triggers resistance, as this not only impinges on their autonomy but also drives a change in the organisational form. Findings do indicate technological innovations are likely to be resisted if the change process, change agent, risks or outcomes are perceived to be incompatible with the professional's values, goals, skills or ways of working (Bayless, 1996; Edwards, Kornacki and Silversin, 2002; Swan and Newell, 1996). Thus the perceived efficacy of the technological innovation may not guarantee widespread adoption as perceptions of anticipated implementation outcomes could still lead to resistance, rejection or non-adoption (Fitzgerald, Ferlie, Wood and Hawkins, 2002). This research therefore explores the question: -

'What do South Australian GPs perceive as barriers to implementing and adopting HI systems that can potentially routinely collect, analyse and redistribute information?'

Drawing from the paradigms and studies cited above (Markus, 1983; Rogers, 1995; Venkatesh et al., 2003), the authors developed a model to frame the research (see Figure 1). The model illustrates the process by which theory suggests GPs develop a perception of the relative advantage of adopting a particular HI system. This can be seen as the emergent outcome of individual and environmental characteristics and a perceived potential for change if the innovation is adopted. The model posits that the perceived relative advantage, behavioural intention and subsequent behaviour of a GP are influenced by perceptions of environmental antecedents and the value and role of the GP professional. There is a loop where the perceived advantage leads to a decision to resist or not. Subsequently the outcomes of the decision confirm or disconfirm the decision and flows back to GP perceptions.

2 Research Methodology

Interviews for this study were conducted between January and October 2007 with GPs in member practices of South Australian Divisions of General Practice. All member GPs of three Divisions sponsoring this research were offered the opportunity to participate in the study. Follow up by the researcher accounted for thirteen of the GP sample who primarily belonged to one of two divisions. Although much redundancy after preliminary analysis of these interviews indicated the data size was sufficient, Miles and Huberman (1994) suggest a sampling strategy that challenges existing understanding by seeking out the typical case, the negative case and the exceptional case. To ensure that the full range of potential beliefs was adequately canvassed, ten practitioners perceived by other interviewees to represent substantially different views to GPs generally were therefore purposively added to the initial sample. When interpretation of these interviews revealed no significant new insights (data saturation), interviewing was stopped (Bowen, 2008).

Eventually 22 GPs from seven Divisions and one full-time locum were represented in the sample. Although categories of questions had been formulated to identify issues potentially relevant to GP concerns, GP answers determined how further questions were asked. Hence rather than asking pre-formulated questions, a funnel sequence of questions was utilised to uncover information not as yet available from prior research (Cavana, Delahaye and Sekaran, 2001).

Interviews lasting between 30 and 90 minutes were used to increase the likelihood of identifying the seemingly diverse yet interrelated communication, care, context and control causes for potential barriers to HI system adoption (see for example the conceptual model of Greenhalgh et al., 2004). The potential technology was described as able to record patient data as an electronic record within the practice, but also able to potentially facilitate the routine amalgamation and exchange of data outside their organisational boundary. Questions began with GP reaction to the topic and subsequent questions were specifically designed to probe deeply held attitudinal information and associated underlying tacit or informal knowledge (Sternberg and Horvath, 1999). In particular the questions focused on GP perceptions of the system design and implementation process, the 'readiness' of the practice to implement such technology, external influences and the potential for the technology to encroach on the professional value, role, relationships and autonomy of the GP. Whenever concern was expressed, follow up questions centred on what mechanisms the system would need to include to rebut GP concerns. The GP interviews delivered transcripts of more than 29 hours of talk which served as the unit of analysis.

The transcriptions were analysed by manual content coding followed by NVIVO (computerised text-based analysis) to arrive at the key concerns and themes expressed (Bazeley and Richards, 2000). While the semi-structured interview question categories were suggested by literature, analysis of the interview data was approached from a logic of discovery with no advance hypotheses or a priori categories (Strauss and Corbin, 1998).

3 Results

The results for this study may be limited because Practice Managers generally negotiated an interview with the GP and their choice was often ascribed to the technology champion status of the GP within that practice. Also the results reflect the views of GPs from just 23 of 1785 practitioners from 22 of 700 practices in South Australia and do not necessarily reflect the profile of General Practitioners in Australia (Britt, Miller, Charles, Pan, Valenti, Henderson, Bayram, O'Halloran and Knox, 2007; Sims and Bolton, 2005). For example, GPs in solo practice (13% in the sample compared to 13% nationally), female (17.4% c.f. 34.0%), full time (78.3% c.f. 63.3%) and non-metropolitan (39.1% c.f. 27.1%).

While specific demographic data were not collected to ensure participant confidentiality, multiple attributes of the practice and the GP were revealed through interviews with practice managers or GPs. Although not reported in this paper, such data were used to populate a 'casebook' of practice and GP attributes. Practices varied in billing practices (gap charged over Medicare rebate), specific experience of National Primary Care Collaboratives (NPCC) or Practice Health Atlas (PHA) as examples of data amalgamation and analysis technology, accreditation, capability (for medical service provision), designation, size, structure and choice of billing and clinical software. However all practices used billing technology and only one practice had no clinical software, GP computer, broadband connection or electronic pathology result capability.

GPs (19 male) varied in experience as a GP and qualifications ranged from overseas trained Doctor awaiting Australian recognition to post graduate qualifications in areas of medicine as well as in computer systems analysis, agriculture, music and Doctorate of Philosophy. GPs also varied in their practice role, use of software and 'champion' status concerning technology use within the practice. All 22 GPs with access used clinical software to some extent for tasks such as generating scripts, storing electronic pathology reports or recording quantitative patient data, however 4 routinely chose to not record all their clinical consultation notes electronically. The 6 interviewees who did not regard themselves as organisational innovation decision makers tended to support existing technology strategies and expressed overall satisfaction with their current usage. Nonetheless, all interviewees were readily able to identify opportunities and weaknesses with aspects of organisational technology in use. Many attributed slow HI system take up rate to be in part the result of little available time for GPs to spend addressing 'non-medical' issues. Recent graduates had not been introduced to clinical software as part of their university medical training, however continuing GP education was generally focused on '…saving lives rather than learning about computer programmes…' The perceived need for electronic interaction with external entities varied with context, but all interviewees identified electronic interaction with specialists and receiving discharge information from hospitals electronically as important drivers. Such technologically facilitated innovations as HI systems were generally recognised as an integral part of contemporary healthcare provision, however the lack of appreciation for the secondary use of amalgamated data for public health management was suggested by an attitude of '…no conceivable need for access to de-identified amalgamated data…' Yet a desire to improve the holistic and longitudinal outcomes of patient healthcare was always expressed and all interviewees, regardless of context, recognised potential benefits from being able to access consolidated longitudinal patient records. But a diverse range of barriers was also perceived, including conflicting perceptions of the need to standardise processes and share clinical notes, the potential for competitive disadvantage, the resolution of ethical moral and legal issues, the availability of appropriate technology and the motivation for political and policy decision making. A consistent theme was the nature of the work had greater appeal to the GP than effective organisational use of technology. This was seen to be maintainable because the GP practice organisations were traditionally structured in order to underpin the GP performing their role.

Analysis of the manual content coding was undertaken iteratively in four phases, with each phase informing the next. The first phase of analysis sought to reduce the data into manageable groupings by identifying recurrent 'issues' that GPs raised as relevant to their attitude formation. Common themes of the 80 'issues' identified were categorised in order of source frequency of coding. Issues related to practicing medicine as a General Practitioner were characterised as 'Profession'. 'Internal' related to GP practice competitiveness, processes and personnel; 'External' related to the policies, strategies and systems in environments beyond the GP's practice boundary; 'Data' related to the collection, use and control of data in GP medicine; 'Patient' related to the patient relationship with the GP and other entities in the Healthcare delivery System.

The second phase of analysis recoded the grouped issues for their apparent influence on GP attitudes. In this way data coding led to themes emerging from the data.

Key sources of 'influence' seen to stimulate or engender GP resistance were associated with GP perceptions or attitudes toward unwanted functionality of Data (e.g. don't want/need), a perceived inadequacy of Practice organisation attitude, structure and resources (e.g. flexibility, capability, receptivity and strategic alignment), or undesirable impact on the GP's Role (e.g. on GP autonomy, status, control or workflow). Whereas the 'issues' raised identified potentially relevant concerns, no issue, theme or construct was found to be an exclusively positive 'influence', and only one an exclusively negative influence (i.e. unremunerated practice cost) on emergent GP attitude.

The third phase of analysis sought to refine thematic patterns between perceptions of relevant issues and their apparent influence on GP attitude formation. Hence the number of times a theme was indicated, particularly by different interviewees, was considered. Yet different and even the same GP could raise different concerns about the same issue from different contexts. An emergent positive attitude towards the potential value of amalgamating a patient's longitudinal electronic Health Data for example, was legitimised by the potential for improving the functionality of patient health data (and thus GP patient health and well-being outcomes). However this was constrained (or not) by concern for the generation and/or accessibility of such data, and whether this was in the context of the GP Practice or not. Hence the legitimacy of implementing and adopting such technology was seen to be mediated by the GP's perception of their 'professional' and 'managerial' roles. That is, whether adoption was seen to be primarily aimed at improving GP generated data for primary (e.g. GP patient) or secondary (e.g. population health or GP performance management) use. Similarly change in the socio-political, system of healthcare delivery or Profession context was generally perceived as outside the immediate control of the GP, while the impact of such change to their practice or role was generally perceived to be in some measure within their control. Thus perceptions of the implementation aim and its voluntariness were seen to influence GP intention to adopt. Hence, perception of undesirable technologically facilitated change to their practice or role perceived to be beyond their control can be seen as a major inhibitor to the GP adopting a positive attitude towards that change. By inference, not adopting such technology could forestall such change. So even if the GP acknowledged the potential of the technology to improve patient outcomes it may still not be implemented, or implemented and not adopted. So incentives promoting the use of such technology (e.g. PIPs) can still manifest in GPs consciously forgoing increased revenue by not adopting the change.

The fourth phase of analysis sought to associate the nature of common themes of influence arising from identified issues with individual GP and practice attributes. This suggested that where positive sources of influence on GP attitude formation were lacking (such as current GP use of HI) this compounded uncertainty regarding outcomes and that impacted negatively on GP support, planning and commitment to organisational implementation and GP adoption of such technology.

4 Discussion

Although interview content allowed for identifying discrete GP attitudes towards HI technology, they are not mutually exclusive and more appropriately seen as a series of developmental and co-existing perspectives determined by GP perceptions of competing contextual factors. Four of these attitudes are further discussed below.

4.1 Passive or Active Resistance

This attitude was identified from a diverse range of technologically aware practices where a GP might readily acknowledge a clear and certain advantage to the performance of their role and practice by adopting such technology, but this was inhibited by resultant change in patient outcomes not being clearly perceived as a relative advantage. Thus the primary inhibitor to adoption is seen to manifest as unwanted change in the GP's ways of working. Despite recognition for the potential and even advocacy of the technology, the utilisation of such technologies is seen to be a process too far removed from that GP's 'style' of 'thinking', 'reflecting', 'observing' or 'recording.' In this instance, a weak appreciation of technological and managerial factors is arguably overwhelmed by a strongly perceived need to protect political interest. Thus having little to no desire to behave in such a way as to facilitate the sharing of in-house patient data outside the practice can manifest as passive GP resistance to adoption.

On the other hand there are repeated incidences where the potential for sharing data is deliberately constrained by the database being overtly maintained for only specific data. GP behaviour reflected concern for trust in other healthcare entities, the paucity of sanctioned software, the apparent indifference of software vendors and a perceived onus to use in-house resources to provide '…different solutions to the same problem…' Major barriers to implementation and adoption articulated included unresolved, changing or ambiguous policy issues (e.g. legal, ethical and data control) and in particular the 'top down' yet 'piecemeal' approach of governments to HI technology use. In this case a strong appreciation of managerial and technological factors in multiple healthcare delivery contexts is arguably countered by a strongly perceived need to protect political interest into the (uncertain) future. This attitude manifests in the need for a practice structure able to support both electronic and manual processes for the same task. Thus controlling any future need for sharing of in-house data can manifest as active GP resistance to adoption despite undermining ongoing practice efficiency and effectiveness.

4.2 Attitude toward HIS technology as a tool to support individual processes

In this case the benefits of such technology are mostly perceived in terms of a business case for organisational advantage. Fundamental to this attitude is costs are perceived in terms of changing organisational processes and not as changes to individual GP workflow or autonomy. Interview content for example, identifies repeated incidences where the potential benefit of implementing such technology is constrained by the data that the GP subsequently generates electronically. A consistent outcome is similarly the need for a practice structure able to support both electronic and manual processes for the same task. However the non-strategic implementation of different vendor systems increased the likelihood of new software being perceived as less intuitive, with incompatibility between different operating systems leading to overall system instability reinforcing a poor opinion of such technology. In this instance appreciation of managerial factors is arguably constrained by a weak appreciation of technological factors and a strong albeit covert need to protect, or subconscious need to exercise, political interests within the practice context.

4.3 Attitude toward HIS technology as a tool to integrate current processes

This attitude manifests as the strategic acquisition of hardware and systematic upgrading to more integrative clinical and billing software. The adoption of more complex, less understood, less available and potentially more integrative systems was aligned with appreciation of the need for change in the organisational ways of working by autonomous members and existing system migration, reliability and capability. Adopting this attitude was generally associated with GPs that had access to experience of technology use inside and outside the practice. Hence the GP primarily perceives benefits of technology adoption in the practice context more holistically in terms of the potential for improved individual workflow or organisational process leading to improved practice patient outcomes, and costs in financial terms. This attitude could be identified in most practices already utilising such technology to some degree. Those who had recently changed existing clinical software were generally looking to integrate billing and clinical software for ‘greater system stability’. However this was also seen to create tension with GPs reluctant to consider changing vendors or existing ways of software use. In this instance a strong appreciation of technological and managerial factors is arguably not inhibited by a weakly perceived need to protect political interest within the practice.

4.4 Attitude toward HIS technology as a tool to transform processes

This attitude tended to manifest in practices with GPs active in activities outside of the practice such as professional and/or political organisations. Interviewees associated with this attitude identified for example, the need for multiple activities to be duplicated in order to satisfy the requirements of all stakeholders in healthcare delivery. This attitude was generally associated with GPs that had access to detailed experience of technology use in similar environments and who perceived themselves or their organisation to be capable technologically and administratively. In this instance the GP arguably adopts a less isolationist perspective of the quality and management of healthcare delivery, yet change is primarily perceived in terms of the need to transform external entities. Also interoperability is complex and difficult and generates the least immediate concern for GPs and the Healthcare delivery system in general. Hence, the constraint of a need to protect political interest on a strong GP appreciation of technological and managerial factors is not necessarily tested.

5 Conclusion

While all GPs interviewed represented their role to some degree as dispensers of complex health knowledge that was irreplaceable by technology or other disciplines in medicine, data indicates the majority of the sample understood the potential financial and time cost, task performance, patient outcomes and organisational revenue advantage of implementing such technological innovations. Interview content identifies adoption is positively influenced if GPs are convinced of positive consequences that are closely aligned to improvement in their patient outcomes and their own workflow, there is a clear and certain potential to advantage their practice and GP interaction with outside entities would be streamlined. Intention to adopt can thus be seen to stem from the potential for direct (e.g. ‘technologically’ improved health data functionality) and indirect (e.g. improved ‘management’ of healthcare processes) benefit to patient outcomes. Yet such support is constrained by a perceived need to defend against any threat to the GP role, value and patient ‘wellbeing’. While a potential for involuntary and/or undesirable change in the GP role and patient wellbeing is seen to be the primary inhibitor to adoption, context and appreciation of managerial and technological factors are seen to both diminish and reinforce emergent attitude favouring adoption. Despite consensus on the inevitable increase in such technology use to deliver healthcare in a General Practice context, any immediacy to implement technology was influenced by the contextual perspective of potential implementation outcomes. Hence any manifestation of resistance to such technology can be similarly characterised and resistance in a particular context can be seen as an emergent outcome of negative perceptions of the technology’s ability to provide functional data, to be readily assimilated by the practice and to produce desirable outcomes for the GP’s role. This is seen to be influenced by GP perception of their role and value, need for self-validation of existing processes, and exposure to utilising HI systems as part of their workflow. The findings also highlight the desirability of ensuring the importance and certainty of potential HI system implementation outcomes are associated with benefits to the practice and the patient while addressing any perceived need for the practitioner to protect their political interest in an individual, practice, profession and healthcare system context.

6 Further Research

This paper reports on analysis of exploratory interviews conducted between January and October, 2007 and set the foundation for a more comprehensive and broader study currently being undertaken. Recurrent themes and concerns identified from this study were used to develop a ‘concern’ dictionary for a confirmatory survey which also explores strategies to reduce apparent resistance.

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