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Peter F. Summons
The University of Newcastle University Drive, Callaghan, NSW 2308, Australi, Peter.Summons@newcastle.edu.au

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Clinical Guideline Audit and Knowledge Elicitation Using the MDS Tool and Techniques

Peter F. Summons
The University of Newcastle
University Drive, Callaghan, NSW 2308, Australia
Peter.Summons@newcastle.edu.au

Abstract

This paper outlines a study, utilising the MDS methodology and tool to create a knowledge model based on clinical experts' interpreted knowledge of clinical guidelines. The study demonstrated the elicitation of tacit expert knowledge when the formalised processes of the MDS were applied to model a clinical expert's interpretation of the knowledge content of a clinical guideline onto the specialised MDS architecture.

Keywords
Knowledge acquisition; Knowledge model; Clinical guideline; Ontology

INTRODUCTION

The application and acceptance of clinical guidelines remains problematic in many health and medical settings. Many reasons may be posited for this. One is that guidelines are not globally applicable - there is often a requirement for local adaptation of a guideline (SANPIS 2003). Other reasons are that guidelines tend to be static but medical and health knowledge evolves, and that guidelines have limitations in their ability to be maintained and updated in light of local best practice decisions and current clinical findings (Sanders, 1998). A further reason is that much of the expertise in medical and health areas is regarded as coming from experience – it is seen as a learned behaviour that is dependent on the local environment and that may become tacit over time.

Pusic and Ansermino (2004) proposed that clinical Decision Support Systems (DSS) could be classified according to the nature of their interaction with a clinician. The types of systems, however, possessed the common element in that they all tried to support the actions of the clinician in a specific clinical situation. To this extent a clinical guideline is accepted in this paper as a decision support tool for a clinician.

MDS is acronym for a system proposed for Medical Decision Support. It represents a combined tool, architecture and a methodology lifecycle (Summons, 2005). Knowledge Acquisition referred to by Feigenbaum (Feigenbaum and McCorduck, 1983) as the critical bottleneck in the Knowledge-Based System development process, is a well-researched area and is still regarded as a problem today (Turban et al, 2005, p578). Many forms of solution have been proposed, ranging from the ad-hoc interview approach to more structured, formalised methodologies. The MDS was proposed partly to answer problems in knowledge elicitation, specifically tacit knowledge, from medical experts. Games (ETHO, 2008), a successor of the knowledge based system (KBS) development methodology CommonKADS, was intended to develop KBS specific ally for the medical domain. Whilst the knowledge acquisition tool Protégé (Protege 2000, 2005) could be applied within GAMES for the Knowledge Acquisition task, there was no structured methodology specifically intended to help make expert medical knowledge explicit and to identify differences in interpretations as part of the Knowledge Acquisition process. The MDS attempts to do this without requiring the knowledge engineer to become an expert in the domain.

The MDS architecture is an artefact representing the medical domain, with constraints believed to hold in the domain. The architecture is based on concepts used in existing Knowledge Acquisition tools, such as Protégé and RDR, Ripple-Down-Rules (Compton, 1993; Martinez-Bejar et al, 2001). Existing theory, such as Allen's Interval algebra (Allen, 1984) was modified to form the basis for MDS temporal modelling in the medical domain. The architecture is based on the Object-Oriented paradigm to model the constructs that occur in the domain, due to its natural correspondence with reality. The MDS architecture is aligned more towards Protégé than to RDR. It has features of a fixed architecture, with the causal mechanisms and inter-relationships of its meta-classes; however the adoption of the object-oriented paradigm, using objects for its basic constructs, enables it to retain the flexibility of Protégé.

The MDS uses a structured Lifecycle for model formulation and the prototype approach of contemporary KBS development methods such as CommonKADS, as well as accepted Software Engineering principles. It employs a software tool (the environment uses Visual Basic and Microsoft Office) to provide support for mapping knowledge from normal clinical textual documents, such as Clinical Guidelines or interview transcripts, into an

abstracted ontology. The tool maintains the mapping between the data and the abstracted model, and is used to help develop the ontology as a knowledge model capable of storing the structure and behaviour of the domain, in such a way that the model can be transferred into a an operational KBS environment, such as Visual Rule Studio (2005), or CLIPS, which has been used in medical applications (Barth et al, 2003). Although Visual Basic has been used successfully in a specific-purpose decision-support application for a hypertension guideline (Persson et al, 2000), its use in the development of the MDS tool was a pragmatic one at the time.

This paper outlines the application of the MDS in a research study to elicit and model the interpreted knowledge of a clinical guideline for Patient Controlled Analgesia (PCA) by four clinical domain experts in the Hunter Integrated Pain Service at the John Hunter Hospital, Newcastle. The study applied the MDS lifecycle to the modelling of expert knowledge of the four experts independently. It was done to evaluate the suitability of the MDS architecture and methodology lifecycle in producing a knowledge model that was representative of an expert's interpretation of the knowledge contained in a medical guideline. It also evaluated the MDS lifecycle as a technique for eliciting tacit medical knowledge. The results of the study indicated that the MDS is suitable for use in elicitation of individual tacit expert experience which may allow guidelines to be improved so they reflect and model the experience and expertise of the local expert clinical practitioners.

CLINICAL GUIDELINE INTERPRETATION

Clinical guidelines come in numerous formats and levels of complexity. Clinical Guidelines are typically presented in text form, with a description of the procedure and supporting information (such as evidence from clinical studies), or in algorithmic form, indicating the procedure that is to be followed and the conditions for divergences between procedures (Patel et al, 2001).

The creation and implementation of clinical guidelines is still a difficult task in even the most simple of medical procedures, due to the variety and expertise of staff in the many disciplines. Problems caused by multiple interpretations of the terminology used between different grades and disciplines in as simple an activity as hand-hygiene activities was reported by Bisset (2003), who described an audit of personal definitions of handwashing, hygienic handwashing, and hygienic handrub in different grades and disciplines of staff who came in contact with patients. A difference was found to exist and the study cautioned that different compliance could occur in protocols or guidelines that included them.

Patel et al (1998) indicated that different recommendations would be given for the treatment of a patient using computerised guideline representations that were created by different individuals. Patel's study also indicated that computer scientists (knowledge engineers) and clinicians produce different computerised representations of a guideline, and that both have deficiencies. The clinician's representations had content that was missing in the computer scientist's model, but had ambiguities and lacked the definition of the computer scientist's representations, especially in temporal definitions. These authors concluded that a guideline representation would need a combined representation, which was more than the sum of the parts.

Patel et al (2001) noted the possibility of tacit expert knowledge being excluded from Clinical Guidelines and of subsequent interpretation problems. They stated that "guidelines are generally written by a team of experts in the medical area covered by the guideline since experts approach the guideline with a more highly organised knowledge base, as writers, they may inadvertently expect the reader to have the same knowledge base, and be able to make the inference is required fully comprehend the guideline. A non-expert may not be able to correctly make these inferences, leading to errors or frustration"

The identification of different clinical practitioners' expertise levels is accepted in Health and Medicine. Patel et al (ibid) also identified different categories of clinical expertise and indicated that these groups display different patterns of reasoning, different organisation of their knowledge bases, and different approaches to a clinical problem. Experts approach a problem by generating a small set of hypotheses at a high level of abstraction and use rules of thumb derived from the previous experience to quickly arrive at an approximately correct solution, while non-experts generate a potentially larger set of hypotheses, take longer to reach a solution and have to rely more on empirical evidence.

Benner (1984) indicated a potential problem for practitioners at the lower levels of proficiency who rely on rules or directions for their actions. Such practitioners lack the experience and the holistic understanding needed to recognise what aspects of rules may be the most important in a problem, and cannot modify the rules to suit new or unusual situations.

The MDS is an architecture and methodology that was designed to provide a mechanism to model medical scenarios, specifically a clinical expert's interpretation of the knowledge (in terms of objects, behaviours and processes) contained in a clinical guideline. It supports a methodology that builds such a knowledge model, and then validates it with the expert using best-practice data. The knowledge model is initially equivalent to that of

Benner's novice level of expertise. The validation process also allows tacit expert knowledge, which may not have been contained explicitly in the guideline, to be elicited.

MDS METHODOLOGY

MDS was intended as an Object-Oriented (OO) architecture and methodology that is suitable for modelling medical domain knowledge and that can support acquisition and change of knowledge (Summons, 2005). The objects have formalised behaviour and support formal definitions of temporal aspects and relationships that are normally required for modelling time in medical knowledge–based systems (Summons and Colloc, 2006).

The generalised MDS architecture (Figure 1) can be broadly interpreted as having three major meta-classes. Clinical experts categorise objects in the clinical domain into these meta-classes. To facilitate this, the meta-classes are described to the clinical domain experts in terms of the clinical domain. The meta-classes are:

- the Temporal Object class, described to clinicians as being Patient Properties consisting of physical things in the system that exist through time (such as Patient, Right Lung, Circulatory System); This class also has an associated History, representative of a past states of an instantiated Temporal Object;
- the Action Object class, described to clinicians as being Staff Interventions consisting of things or actions that staff would either perform, or have others (ward nurses etc) perform in relation to the system under consideration (such as tests, measurements, observations or signs);
- the Association Object class, described to clinicians as being Diagnoses consisting of labels given to the possibility of a Disease or a Pathological Process being present in an instantiation of a Temporal Object (such as Hypertension or Pain).

In the study an additional category considered domain objects falling outside these three meta classes. Referred to as System Objects (the "Other" category), this class described the general environment and captured clinician's references to people, places, instruments, and policy.

The MDS architecture supports a methodology to assist in knowledge acquisition, particularly tacit knowledge of an expert clinician (Summons, 2005). Tacit knowledge may be used in the interpretation of medical guidelines by an expert and not be explicit in the guidelines, such as when an expert uses a shortcut. By comparing the differences of a model of an expert's interpretation of the knowledge held in a guideline created using the MDS with, say, a novice's interpretation model, it can help to identify tacit expert knowledge.

Typically in the development of a knowledge-based system (KBS) a knowledge engineer works with a domain expert to produce a Knowledge Model of the domain. This consists of a domain Ontology, describing the objects and structures of the domain, and also Rules for the domain indicating the system relationships and behaviours of domain objects.

Knowledge engineers may base their design on incorrect knowledge interpretations from the expert, or they may not know that they have missed knowledge from the expert. The interpretation differences of a system by stakeholders is referred to as cognitive dissonance (Cleal and Heaton, 1988). KBS developed for clinical applications also have an added problem in that the domain itself is very complex and specialised.

The MDS methodology addresses the interpretation problems associated with the elicitation of domain knowledge. The major stages of the methodology are:

- Knowledge acquisition is initially based on an interpretation of the expert's understanding of content in a clinical guideline;
- The domain expert and the knowledge engineer then refine the interpretation into a knowledge model of the content. The formulation of the ontology requires the identification of objects, which are then classified into categories prescribed by a supporting architecture. It is at this stage that object states are defined, causal relationships between objects are determined and temporal aspects of the domain are identified;
- System behaviour rules (existence rules, association rules and internal behaviour rules) are identified;
- The knowledge model, which is now fitted to the supporting MDS architecture, is used as a prototype knowledge-based system with the expert;
- Iterations of the knowledge based model using best practice clinical test cases continue until expert validation or agreement is reached. The knowledge model is updated at each iteration. It is during this stage that the tacit expertise of the domain expert is elicited.

MDS METHODOLOGY LIFECYCLE

The MDS methodology has a lifecycle consisting of iterative Phases and Stages. These are applied by a knowledge engineer to a group of clinical experts to model their interpretation of a textual clinical guideline. The main Phases and stages of the MDS are:

Phase One: Class Identification

Initial Text Classification: Process the Clinical Document text.
Concept Identification and Abstraction: Perform concept abstraction from the guideline text
Temporal Dimension Definition: Identify temporal domain concepts and references such as temporal scales, intervals and time reference points.
Internal Structure Definition: Identify hierarchical Taxonomies to specify Class inheritance, and define Class Composition.
Class State Specification: Identify class states and define Temporal Object's characteristic state.

Phase Two: Behaviour and Relationship Identification

Existence Criteria Definition for States: Identify behaviour due change in class state, and behaviour that causes class state change.
Existence Criteria Definitions for Class Instances: Identify Creation and Destruction Criteria for identified classes as Production Rules.
System Relationship Specification: Define causal relationships (use *related* predicate for associations) system rule definition.
Consistency Checks: Perform a general consistency check of the identified relationships.

Phase Three: Knowledge Acquisition using the MDS Knowledge Model Prototype

Ontology Model to Knowledge Base Mapping: Develop pragmatic and operational considerations of the domain suitable to implement the MDS Knowledge Model as a prototype decision support system in the clinical scenario being described.
Ontology Model Iteration: Establish system meta-knowledge; Elicit and document the clinical expert's tacit knowledge by comparing discrepancies when representative clinical case data is applied to the prototype DSS and the clinical expert.
Maintenance: Schedule and perform ongoing maintenance tasks for the Clinical Guideline knowledge model.

CLINICAL GUIDELINE STUDY

The clinical domain modelled is the management of complications for patient controlled analgesia (PCA). The study looked at the respective interpretations of the PCA clinical guideline by four expert clinical nurse consultants from the Hunter Integrated Pain Service who are consultants in both acute and chronic pain for the state hospital service in the Hunter Area of New South Wales, Australia. These experts are involved in the production of clinical pain guidelines.

In the study of the PCA guideline four separate models, associated with four clinical experts using the MDS independently, were constructed. A software tool was developed to semi-automate this process. These were used to compare the commonalities and differences between each expert's model.

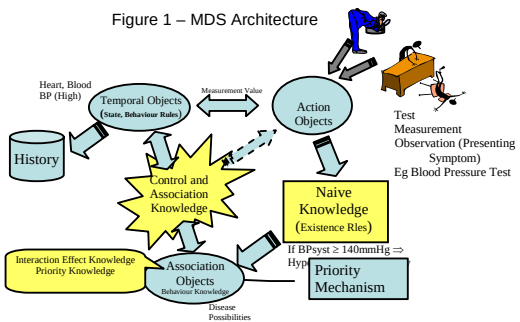
The experimental task was to acquire the interpreted knowledge of different experts about a common clinical guideline using the MDS methodology and to then produce knowledge models of the interpreted guideline knowledge in the MDS architecture. The participants identified domain objects as instances of MDS Classes, and their relationships in terms of production rules (IF...THEN... type rules) such as

- IF the Sedation Score > 2 THEN Administer 12 L/minute O2 via mask
- IF the Sedation Score > 2 THEN
  Contact Anaesthetist or Medical Officer

The production rules were associated with internal class behaviour, or with system event behaviour due to causal class interactions, or with system behaviour involving inter-class associations.

While the use of production rules in KBS is not new, the MDS architecture is based on specified meta-Classes and their instantiated objects, and the production rules model the behaviour of instantiated objects in response to an event (both internal to the object and external to it), and also provide a mechanism

Figure 1 – MDS Architecture



for an instantiated object to generate future events. The MDS architecture requires the antecedents and consequents of its production rules consist only of identified meta-class instantiations, where a future event can be represented in a rule consequent by instantiating an Action Object that may schedule a test, or alert that a symptom has been recognised A negation of the existence of class instantiations is also allowed. As the study was intended to research the use of the MDS tools and techniques, the knowledge engineer played a passive role in the clinical experts' object categorisation, although in a normal clinical setting the knowledge engineer and the experts would be in a common group setting, and the knowledge engineer would validate classified objects more interactively.

The models were constructed by having a knowledge engineer conduct weekly sessions with each expert (separately). In Phase One of the MDS Lifecycle, experts identified concepts from the guideline text, and classified their "labelled" concept into categories of the MDS meta-classes. These were added to the knowledge model as items in a relational database. Using the MDS tool, the concept labels were merged, deleted, or added to until all the guideline text had been covered.

In Phase 2 of the MDS lifecycle associations between the identified objects were identified and stored as production rules. Behaviour, heuristics and rules were identified and categorised. Heuristics and "rules" categorised from the guideline text were validated using the MDS tool. This highlighted missing objects that should have been categorised as they were involved in "behaviour" rules, or the examination of identified Action Objects indicated the need for a rule.

In Phase 3, various examples of best-case data (in the form of clinical scenario data prepared by a clinical expert not involved in the study) were applied to the model for each expert. The models were tested through iterations of case-based application data presented to each of the clinical experts participating in the experiment, and changes in their models produced from application of the MDS over the iterations were measured. As the MDS tool had not been fully developed to be a KBS, the expert's response and the model's response were investigated in a semi-structured interview style. In this phase discrepancies between the responses indicated new, or modified, objects and/or rules.

The models for each expert were compared over time to study the development process, and crude metrics were developed that indicated the types and rates of change of the models, in terms of new, deleted and modified production rules and/or object class instantiations (mainly involving the major meta-classes). These measured differences in the same clinical domain expert's interpreted knowledge model (at two different times) and also differences between different expert's knowledge models. The former reflects either change in an expert's interpretation, or in the extent to which their interpretation has been iteratively captured by the MDS methodology. Differences between knowledge models at similar capture stages can indicate differences between domain experts' interpretations of a guideline due to differences in their expertise; disagreement in their opinions; or ambiguity in the guideline.

The suitability or completeness of the knowledge model is reflected in the amount of change in the knowledge model (that is required to accommodate new cases). Here 'change' is measured in terms of new objects required, incorrect or redundant objects deleted or updated, new antecedents or pre-conditions added, incorrect or redundant antecedents or pre-conditions either removed or updated, new rule outcomes added and incorrect or redundant rule outcomes either deleted or updated.

Software was developed to implement some of the metrics by examining the underlying expert's knowledge models where objects and attributes were represented in a relational database. Comparison between several experts' knowledge models was done by merging identified objects in their knowledge models into a single combined database, and then applying SQL queries to indicate commonalities and differences between individual models and the combined model. The objects in the combined data model formed a standard, or normalised, dataset of identified concepts for the clinical domain.

The results of the study showed that a consistent process was being carried out by all experts using the MDS methodology. Table 1 shows the correlation of objects identified longitudinally as MDS meta-classes in the knowledge models produced over time, and separately, by the four clinical experts. The process of identification of objects was well correlated between participants, consistent with the claim that each participant is conducting a similar process of class identification. While the MDS provides a consistent process for the formulation of a knowledge model, this does not imply that it will produce exactly the same knowledge model for each participant, but that the processes of the MDS are consistent between participants in producing a knowledge model and also that a knowledge model will be produced.

Results also indicated both the expected common core of knowledge and also differences in knowledge between the experts (Summons and Colloc, 2007). The common core of knowledge was indicated by a significant common identification of objects and rules by all the expert clinicians. The difference in knowledge was shown by each clinician identifying objects and rules that were completely different from other experts (indicating their

prior experience differences). The different interpretations were also seen in different text labels being applied to concepts between experts, and different concepts being associated with the same text label or "tag".

Table 1 - Correlation of Clinician Models

Correlation - Action Objects

	D1	D2	D3	D4
D1	1.00			
D2	0.95	1.00		
D3	0.94	1.00	1.00	
D4	0.86	0.91	0.94	1

Correlation - Association Objects

	D1	D2	D3	D4
D1	1.00			
D2	0.92	1.00		
D3	0.91	0.79	1.00	
D4	0.68	0.86	0.64	1.00

Correlation - Temporal Objects

	D1	D2	D3	D4
D1	1.00			
D2	0.42	1.00		
D3	0.93	0.51	1.00	
D4	0.86	0.59	0.97	1.00

DISCUSSION

The use of the MDS highlighted that different hospitals had PCA guidelines that contained different instructions for the same condition, sometimes requiring clinical staff to let patients reach different levels of pain before assistance was requested. This would have been confusing to casual nurses who worked at all of those hospitals, which is a common occurrence. The clinical experts indicated that they would not expect novices to be aware of all the implications of these instructions. Some instructions considered people who may not have the depth of experience to want to take responsibility for some actions, as indicated by instructions in one guideline to prepare to administer a medication rather than to administer it.

Different interpretations of common events by experts were also identified by the MDS. It indicated that different rationales for actions and clinical interventions were held by different clinical experts. Important goals for the guideline were identified as being absent from the guideline after application of the MDS – this was tacit knowledge of the experts who constructed the guideline. The successful goal of the guideline was to minimise pain and to mantain and manage comfort. The measure for this was that a patient could deep-breath, cough and move easily. These measurable objectives of the treatment were missing from both the clinical treatment document and the background guideline document on which the clinical practice document was based. New guideline documents have been created that rectify the anomalies found.

The MDS also highlighted different interpretations by the clinical experts for the rationale behind common actions. One expert indicated that the reason for a requirement to have two registered nurses present when programming and loading the PCA, and also when disposing of the opioids was that it was legislative due to the nature of the drug. This would be the view of a novice also. However, a deeper rationale was found when the MDS was used with other experts – the requirement for the presence of two registered nurses when programming the PCA was due to this being the point at which most mistakes had occurred.

CONCLUSIONS

Problems in the interpretation of clinical guidelines were examined. The MDS system was presented in the form of a tool, a methodology and architecture that can be used to create a knowledge model of a clinical experts' interpretation of a clinical guideline. This was demonstrated through the application of the MDS to building expert's interpreted knowledge models for a clinical guideline for Patient Controlled Analgesia.

The results of the study indicated that the MDS was being used in a consistent manner by all experts to construct a model representative of the clinical guideline knowledge. This process both identified the common knowledge shared between the experts and highlighted the differences in their interpretation of the guideline knowledge. The differences formed the basis for further clarification.

The application of the MDS in the study demonstrated the elicitation of important tacit expert knowledge that was not explicitly contained in the clinical guideline. The potential for the structured validation of guideline knowledge content using the MDS was also briefly examined.

The application of metrics may allow clinical guidelines to be reviewed to identify the information they actually contain compared to the information they are intended to contain (and which domain novices might need to interpret). This would help in auditing the effectiveness and interpretation ability of specific guidelines for novices, where the MDS process is applied (using the novice in place of the expert) to gauge their interpretation of the guideline by building successive knowledge models. The metrics discussed would be allow comparison of the completeness of the novice's model compared to a previously completed expert's, and would also provide an indication of the evolution of the effectiveness of the novice's "learning".

The indication of the amount of commonality and difference in interpreted knowledge could also be used to audit a guideline that has been altered from a national guideline to reflect local demographics. This may allow guidelines to be improved so they reflect and model the experience and expertise of the local clinical practitioners. It may also help new practitioners in their familiarisation with local practices and expertise.

The MDS system will be used in future auditing and development of clinical algorithms and guidelines for Pain Management in the Acute Care Setting, and also for Pain Management in the elderly in Residential Care.

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