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HAND-HELD REMOTE DECISION SUPPORT AID FOR THE NOVICE NURSE

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ABSTRACT

The statement, data rich and information poor, holds for the clinical nursing decision support domain. Modern hospitals are well equipped with monitoring and other data collection devices which provide relatively inexpensive means to collect and store patient data in inter and intra hospital information systems. The problem lies in how this stored data is utilized to support nurses' patient care decisions. In typical environments collected information is used to aid in monitoring patient care for use in billing decisions not to improve patient outcomes. The novice nurse who has frontline responsibility for managing patient symptoms, monitoring complications, and anticipating preventative measures, however, may not have access to this information in a timely manner to aid in patients' outcomes. In addition, traditional evidence-based knowledge and standardized guides, such as clinical algorithms supporting off-line clinical nursing decisions are not available for on-line real-time access. To alter this state, we are developing an integrated hand-held remote patient monitoring, analysis and decision support aid for the novice nurse linked wirelessly to the typical hospitals wealth of patient care data stored on a central server. This paper describes research to develop a prototype Decision Support System (DSS) to guide novice nurses in traversing the nursing diagnostic process without limiting the nurses' choice at all times to perform the most suitable and appropriate and beneficial action towards the patient.

KEYWORDS

data mining, wireless DSS, novice nursing tool

1. INTRODUCTION

Rapid proliferation of new medical and nursing knowledge, expanding operational expectations, and rapidly changing and uncertain practice environments demand new approaches to support nurses' clinical decision making.

The expanding reliance on electronic medical data requires standards for terminology, vocabularies, formats supporting data sharing, standards for interoperability between different sources of data and integration of heterogeneous and legacy data for designing integrated electronic patient records. Most medical environments lack such standards, hindering the use of data-analysis tools on integrated large medical datasets. This problem limits analysis to datasets collected for specific diagnostic, screening, prognostic, monitoring, therapy support or other patient management purposes. Patient records collected for diagnosis and prognosis typically encompass values of anamnestic, clinical and laboratory parameters, as well as results of particular investigations, specific to the given task. Such datasets are characterized by their incompleteness (missing parameter values), incorrectness (systematic or random noise in data), sparseness (few and/or non-representable patient records available) and inexactness (inappropriate selection of parameters for the given task).

1.1 NCODES (Nursing COmputer DEcision Support system) Background

Recently, as hospital patient acuity rises and cost-effective treatment becomes mandatory, nurse clinicians are required to work 'faster and smarter' making complex decisions on an almost continuous basis. Although evidence-based knowledge and standardized guidelines are available in some areas to support clinical decisions, real time access to this information and specific patient information is a major problem inhibiting their use.

Computerized decision support systems within health care have been considered since the mid-1950's however, development in nursing has been limited by a number of factors (Ozbolt & Graves, 1993). Sinclair (1990) cited a lack of understanding of nurses' decision making as well as the fundamental characteristics of nursing knowledge**.** Schutzman (1999) examined hospital environments and concluded that nursing units require complex, portable systems with rapid, seamless connectivity. In addition, the assumptions underlying the original expert systems were often seen as a challenge rather than a support to professional decision-making.

Present nursing decision making processes are driven by "best practice" and experience (Henry, 1995, Dluhy, 1995). Recently a "guideline movement" (Forbes & Griffiths, 2002), emerged highlighting an effort to stimulate evidence-based practice. The NIH Agency for Health Care Policy Research assumed a pivotal role in the development of scientific evidence report guidelines (Guyett, Sacked & Cook, 1993). The intent is to encourage best practice by reducing variability, controlling costs and improving client outcomes. However, research reveals that the mere existence of such guidelines does not necessarily lead to changes in practice. Consensus or expert guidelines tend to be lengthy and complex. While this contributes to their overall value, busy clinicians are frustrated when unable to quickly access information relevant to the presenting client (Kennedy, 1983). Building on this research foundation, a prototype handheld computer, expert system capable of retrieval of patient centric real time point of care clinical decision aid information is being developed to alleviate much of this frustration.

A commercial market exists for error reduction and decision tracking in health care. Nurses have frontline responsibility for symptom management, cost-effective implementation of treatments, surveillance for complications, and anticipatory prevention. A low-cost handheld computer for all staff nurses to reduce errors, track decisions, and maximize client outcomes has commercial appeal.

2. DEVELOPMENT OF NCODES

To construct NCODES, it was first necessary to understand how novice nurses make decisions and develop clinical reasoning skills (Tabak, Bar & Cohen-Mansfield, 1996). While traditional decision frameworks typically address one finite decision point, nursing practice involves an ongoing series of cascading possibly conflicting decisions.

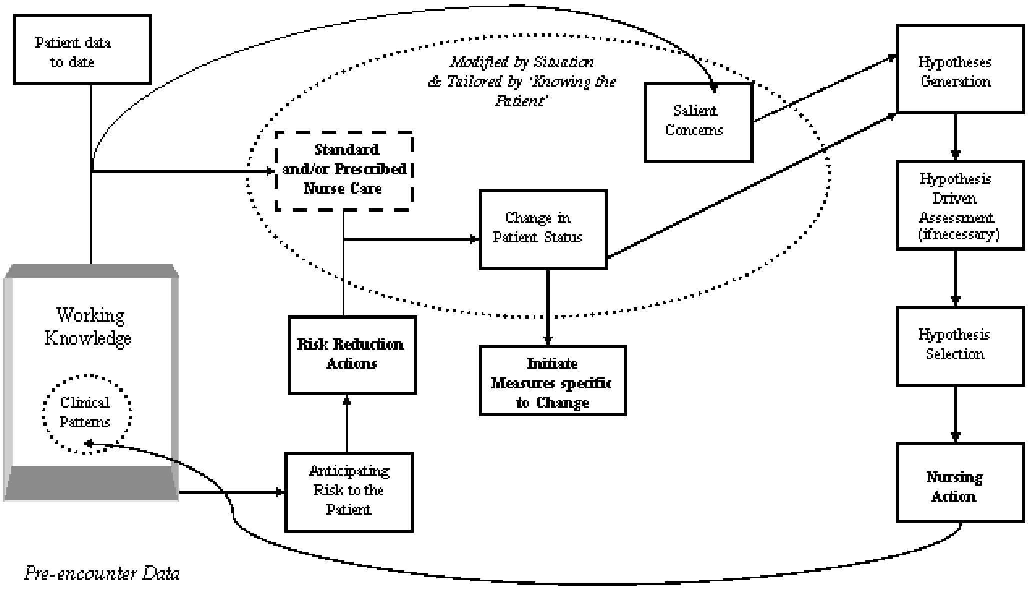

Figure 1. The Clinical Decision Making Model (CDMM)

To systematically examine novice nurses' decision-making events, a theoretical framework was developed. The framework consists of two models, a clinical decision-making model, grounded in information processing theory and a new model of novice's clinical reasoning development. The CDMM (Figure 1) represents the clinical decision making process of the seasoned nurse as multi-dimensional, including pre-encounter data, assessment of risk and risk reduction, the situational features that affect decision-making, salient concerns, and hypothesis generation, hypothesis-driven assessment, hypothesis selection, and then nursing action. The CDMM is a framework for understanding decision-making that occurs in acute care units. It is consistent with recent perspectives on information processing (Custers et al 1996, Charlin et al. 2000, Elstein 2000) and integrates research from several disciplines.

The Novice Clinical Reasoning Model (NCRM) synthesizes theoretical and research thinking in this area (see Figure 2).

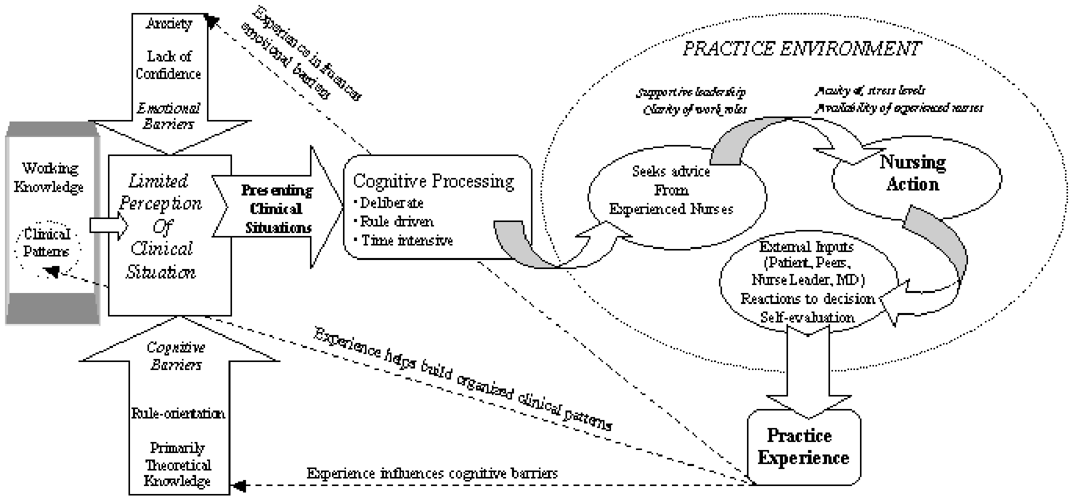

Figure 2. Novice Clinical Reasoning Model (NCRM)

The NCRM describes a process by which the novice nurse develops working clinical knowledge. Due to early anxiety and knowledge limitations the novice initially has a limited perception of the clinical situation. But over time, with repeated practice experiences, the novice begins to develop a complex system of organized clinical patterns, forming the foundation of working knowledge. Our developed model strives to capture this process. The model also includes factors in the practice situation that promote the development of working knowledge such as the availability of experienced nurses and supportive leadership.

2.1 Typology for Development of Practice Maps

After the CDMM and NCRM conceptual models were developed and refined, the next step in NCODES design was to identify a specific knowledge area for knowledge base development. Forbes and Griffiths (2002) point out that this is a critical yet often neglected portion of evidence development. The focus of NCODES is adult hospitalization on an acute (not critical) care unit. O'Neill (2001) indicated that respiratory conditions were commonly encountered in practice and there is little decision support available to help manage these care areas. In addition, nurses involved in the NCODES project have experience in respiratory care allowing them to provide expert evidence for the projects use.

Next, NCODES nursing staff and researchers developed a typology for the major respiratory problems (Figure 3). These are cough, haemopytosis, chest pain, and dyspnoea (Albert et al. 1999). Cough was chosen as the initial symptom to develop since it is considered a universal symptom for respiratory illness. Once this choice was made, the recommendations of the American College of Chest Physicians National Consensus Report (Irwin et al. 1998) were adopted. This report divides cough into acute and chronic, based on a three week episodic duration. Using this partitioning, clinical conditions related to each were determined. For example, under acute cough one category was infection. Acute bronchitis and pneumonia were two of the conditions subsumed under infection.

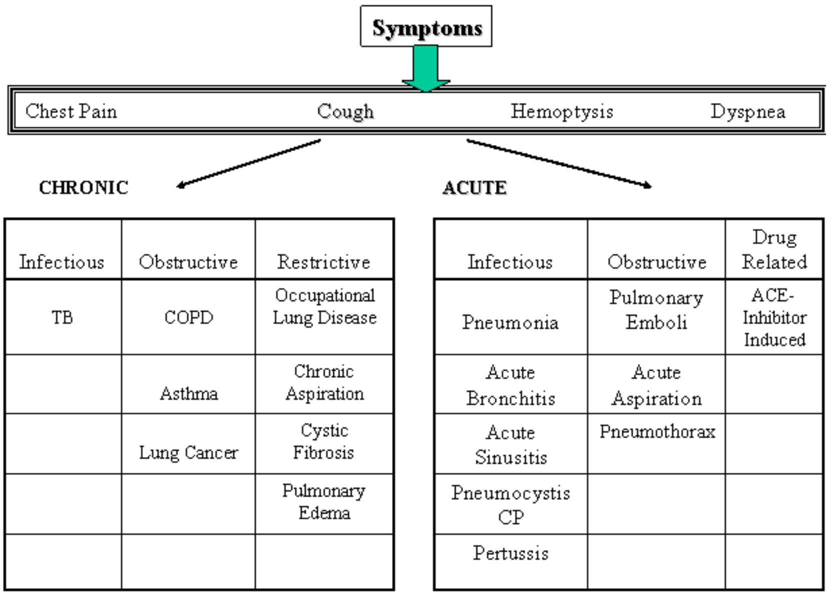

Figure 3. Typology of Respiratory Problems

2.2 Evidence Issues

Early in the NCODES project the nursing team had to confront the issue of what is the "best evidence" supporting clinical nursing diagnoses and interventions (West, et.al., 2002). Is the information found in textbooks, clinical guidelines, does the available information leave no unknowns, is it adequate, is it up to date?

In response to these concerns, a comprehensive framework for nursing knowledge acquisition, validation, and synthesis as well as a knowledge-mapping framework was developed (O'Neill et al. 2004). The framework outlines types of evidence, levels of confidence in different types of evidence, and a tracking grid to determine the value of collective evidence. It also includes the use of clinical experts and a network of acute care nurses to incorporate recent and regional practice patterns. An example of questions developed by the NCODES nursing team to evaluate qualitative studies is presented in figure 4.

Each developed data rule has evidence rankings of strong, sufficient or marginal. Nursing knowledge is represented as a set of data rules (e.g. *If high probability PE, then consider adequate hydration*) and associated linkages (also called meta rules, e.g. *if pneumonia, then monitor for complications*) forming classical clinical cases (e.g. pneumonia detection and care). The process of accessing knowledge to support the evidence base, codifying, and evaluating the quality of this knowledge has led to new insights into evidence-based practice. Additionally, the process has exposed gaps in our knowledge, which has required creative strategies to bridge. As data rule construction proceeds, the nursing team is continually refining the method.

-There is a clear statement of the aims of the research
- The sampling strategy is clearly justified and linked to the target population
- The description of the data collection and data analysis process is clear
- The categories and themes are logical
- The findings are clearly delineated
- The studies findings are transferable
- The results will assist in the care of patients

Figure 4. Judging the quality of qualitative research reports

2.3 Practice Maps

Clinical problems chosen by decision support developers often do not reflect what clinicians find most difficult (O'Neill & Dluhy, 2000). To avoid this mistake the nursing team examined previous research and discussed with clinicians their most frequent and difficult decisions. Based on this data, respiratory problems were chosen as the content focus for the NCODES prototype. The nursing team then developed a typology to identify the acute and chronic respiratory problems that needed to be mapped. Over the course of the first two years, practice maps for acute care respiratory problems have been developed.

A practice map is a template of the IF … THEN … data rules laid out to mimic a nurse's decision making process. These data rules are then linked together by procedural rules that connect distinct states together within a map. The procedural rules follow the model of *If condition X, is true, Then do Y*. The 'If' part of the procedural rule relates to the state (domain of knowledge) constructed using a collection of related data rules comprising a state. The 'Then' part of the procedural rule invokes or moves the nurse to performance of another new state.

To date the nursing team has created seven practice maps, which contain the data and meta rules for a given clinical condition. Each map represents a collection of data rules and paths through the map representing the knowledge regarding an acute clinical condition and nursing treatments. These rules mimic how the nurse moves from one line of reasoning to another.

During the first year the nursing team approached practice map development using the CDMM and NCRM theoretical frameworks by listing rules under categories such as risk assessment and interventions. Next the rules were laid out on a large board and the team discussed each rule, each category, and the meta rules to move between categories. Currently the team is experimenting with a new approach using nursing diagnostic language as a guide (McClosky et al. 2004, Moorhead et al. 2004). Figure 5 depicts a section of the practice map for pneumonia. The nursing team has discovered that knowledge mapping is a laborious process involving interaction between knowledge engineers and domain experts in the transfer of knowledge (O'Neill, 1995, O'Neill, 1999).

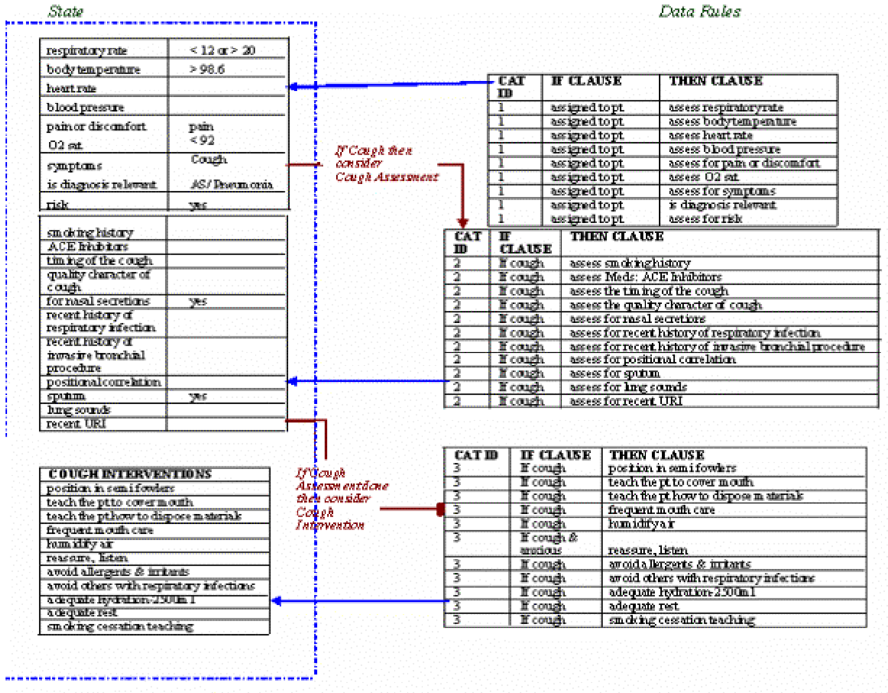

Figure 5. Sample Practice Map

2.4 Nursing Knowledge Extraction, Translation and Integration

A major problem is in how to combine an expert's fundamental nursing knowledge granules (or simple nursing practice facts (e.g. if fever, sputum and . . . then Pneumonia)) and the ordering of applying these knowledge rules (e.g. if state 1 and input set 2, Then State 5) in decision making with a computerized inductive learning algorithm. The algorithm automatically derives ordered decision trees/rules following patterns infused by interrogation of an expert's knowledge rules and process rules presented. The derived tree/rules graphs are then presented to the domain expert in the context of a specific scenario (e.g. pneumonia assessment and treatment) to judge if the constructed decisions and decision flows are sound. And if not, provides a means to edit and rebuild the tree. In doing so the tool provides a means to investigate new derived knowledge fragments (outliers) to allow the expert to judge if they have potential value (e.g. constitute new nursing knowledge).

To construct the trees/rules our algorithm uses information provided by the domain knowledge expert as a component of our data collection process. Information about the class (patient case, e.g. raspy lung sounds) a data rule is associated with along with information concerning other cases that this data rule may also be a component of (e.g. cold, pneumonia, etc.) with a weighting (metric of importance) to associated cases is collected. This information is then used to determine the strength of all such rules in relation to each other. These rules, associated cases and strengths are then utilized to construct an initial case decision tree by grouping rules with cases based on their strongest return of "related information strength"

(Madiraju, 2005). This grouping is done working from the root to the leaf nodes of an associated case.

The constructed initial decision tree is then presented to the knowledge domain expert for review, possible augmentation and validation. This review and augmentation may take the form of altering a rules strength, pruning a rule, providing a different traversal method for a set of rules to allow for refined training and construction of the case rule set. The resulting trees are then used as means to index into the case data sets to aid in assessment of a new supplied case within our rule / case based DSS, Figure 6.

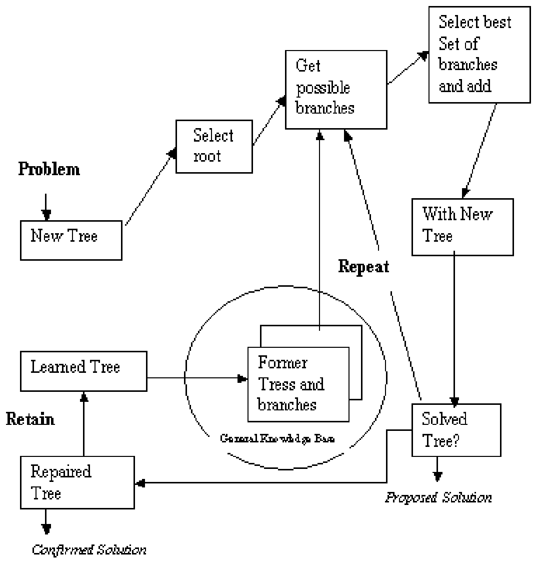

Figure 6. Concept for Automated Decision Tree Construction

2.5 NCODES Knowledge Processing Engine

The operational concept for the NCODES architecture, Figure 7, is based on a generalized state based processing algorithm. The multi-tiered algorithm (Figure 8) operates by using knowledge of the present state of the system along with processing of new inputted rules, to determine the next best possible state to transition to using a mixture of rule base processing and case based comparisons (Figure 9). The set of all possible traversals is limited and controlled by the prior knowledge of similar cases which are used as exemplars in determining which of possibly multiple plausible next state(s) is the most appropriate to fire (i.e. transition to) (Figure 10, Figure 11). The background rule engine however can be instructed to traverse all paths simultaneous and to check if the system indeed selected the most optimum path for the inputted set of rules and the given prior state.

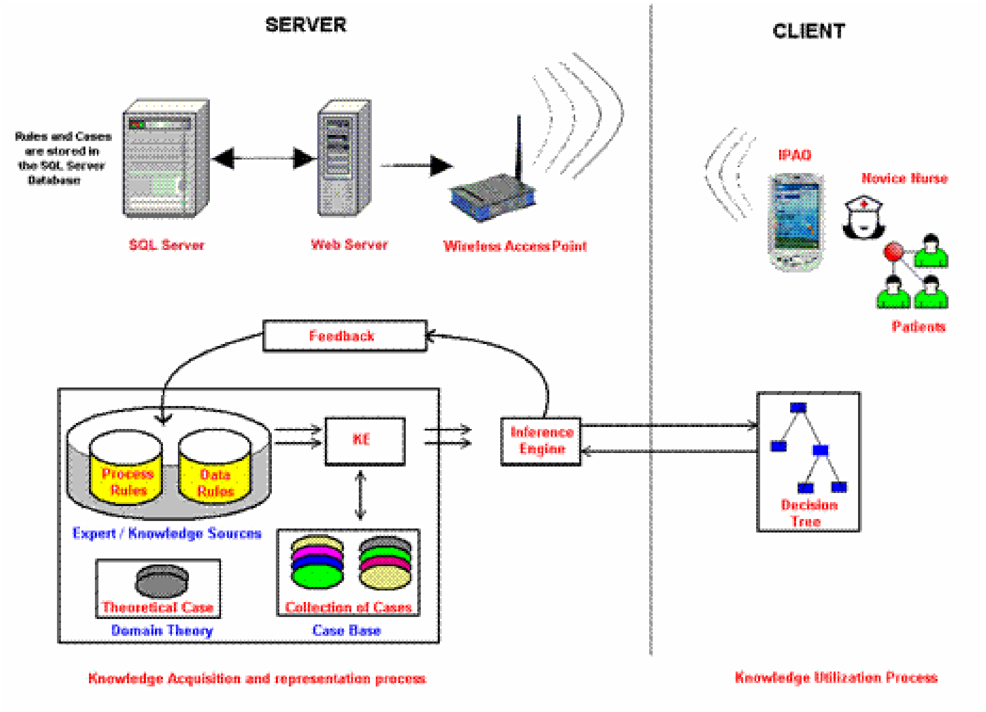

Figure 7. NCODES Conceptual Architecture

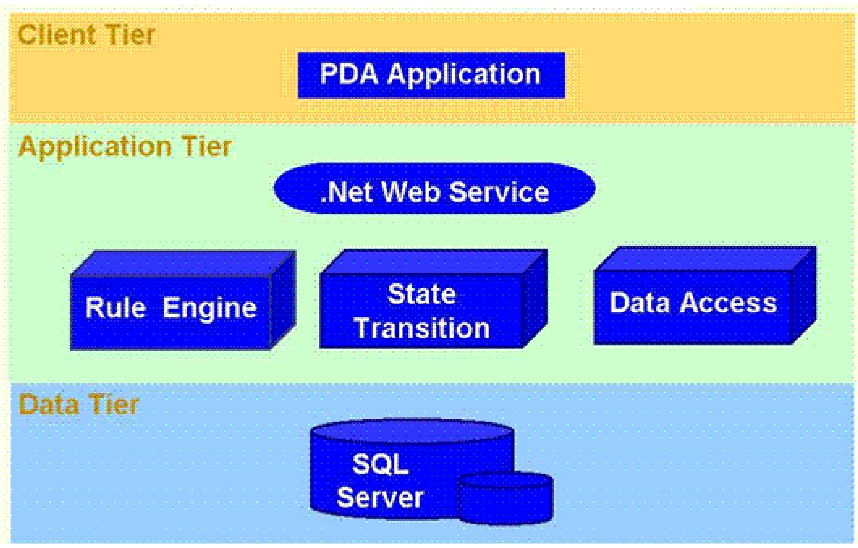

Figure 8. NCODES Conceptual Multi-Layered Architecture

Once the system has traversed to a leaf state (e.g. intervention) the set of traversed states represents the decision process the nurse used to determine the present outcome and would map to a classical nursing patient care decision tree. What makes ours different is the generality of possible tradeoffs and the multiple concurrent methods used to fire a transition (move from one state to another) and to test if the resulting traversal is a valid new state, representing the most appropriate state to be in for this unique patients' conditions. We use mappings of a set of terminal historical patient case histories and their partial predecessor cases (intervening states) used in constructing these prior cases to test for this sense of correctness (Sarangarajan, 2004).

2.6 NCODES DSS Interface and Operations

The major e-component of this project is the hand held DSS aid for the clinical novice nurse, seamlessly linked to the server DSS and data mining system. The hand-held device provides the real-time link for the novice nurses to collect infuse and process patient information leading to directed nursing actions to perform based on an individual patients status (Figure 7). The main function of the hand-held DSS is three fold. The first function is to allow a nurse to download a set of assigned patient information from the server at the start of a nursing shift to the PDA. The second, function is to support the continual use of the patients' information stored on the PDA throughout the course of their shift and to support collection of additional patient vital signs, and other pertinent patient assessment and care information. The third function uses this stored and real-time collected information, to act as a stand-alone nursing coach, assisting the nurse in making the appropriate assessments and interventions based on the patients' historical and present state of health.

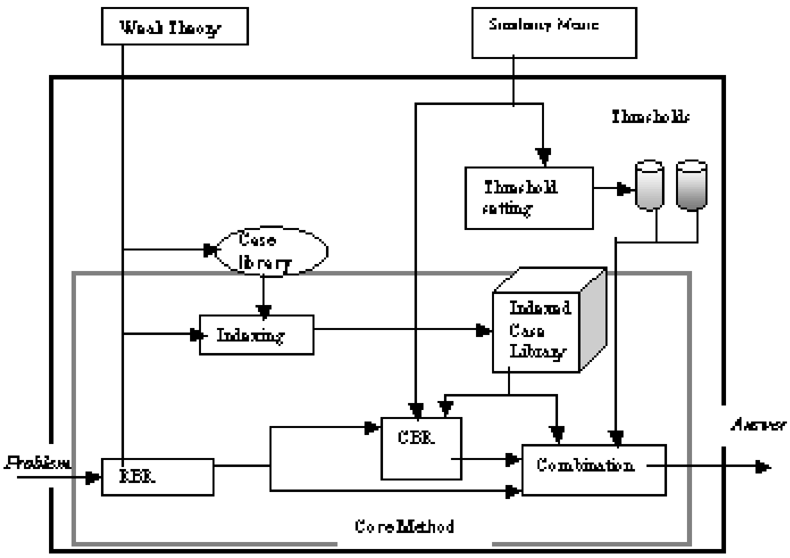

Figure 9. NCODES Integrated Rule / Case System Architecture

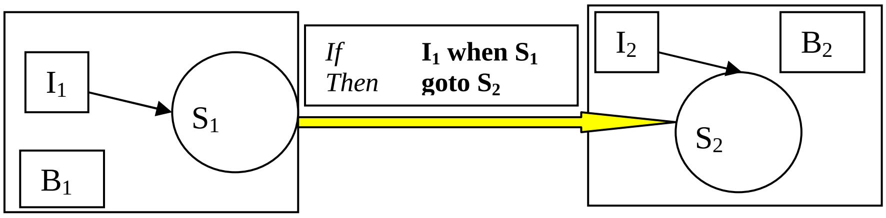

Figure 10. Concept for State Transition using Process Rules

The methods applied in realizing this system utilize efficient remote database access protocols to access appropriate rule sets and case sets for comparison to presented information. The three processes residing on the hand-held computer performing these tasks are the transmission and reception process, the inference engine and the presentation engine. Each of these processes has a specific function they perform for the nurse. The transmission and reception process has the function of initiating and keeping a conduit open for the continuous upload and download of data as needed by the nurse once they have initiated a session. The interface process has the function of providing relevant output information consistent with the state of patient assessment or care review the nurse is operating within. This process also has the function of providing the novice nurse with relevant input operators consistent with the actions he/she is being coached through in the present state. For example within base line assessment the nurse will be presented a visual representation of items they can measure and fill in to form the baseline assessment for this patient.

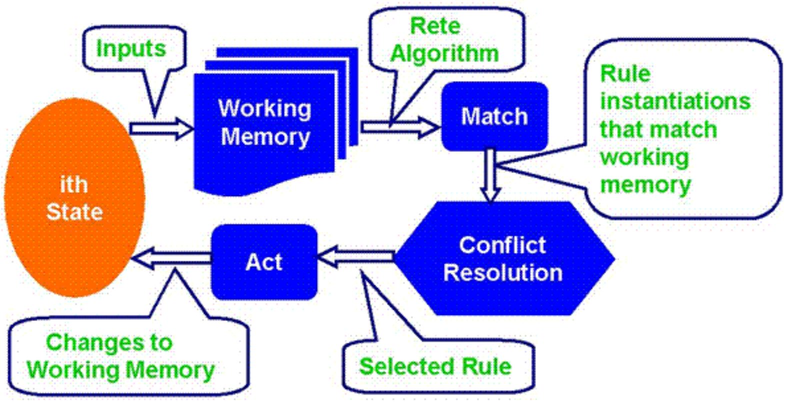

Figure 11. Concept for State Transition Flow

This may include items such as heart rate, body temperature, blood pressure, respiratory rate, and other pertinent initial measurements. The interface process must also provide mechanisms for the nurse to be able to seamlessly move between states already visited to re-look at any pertinent patient information collected or

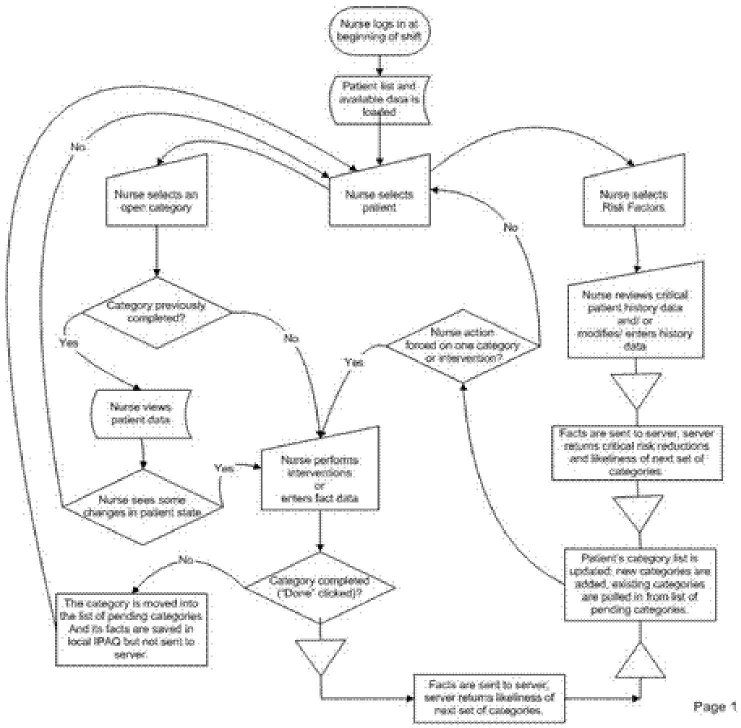

Figure 12. NCODES DSS Concept of Operation for Nursing Use

retrieved within their shift or to allow for the nurse to alter items erroneously entered. The inference process is the main component of the hand-held device and holds the most unique aspects of our system at this level. This process has the function of formulating an initial state (patient baseline) and using this to compute which possible next state is the most likely next best candidate state from a given set of valid next states using only the input parameters, process rules and past similar case histories' exemplars (extracted from the server knowledge base). For example from a baseline assessment do we proceed to pain assessment, cough assessment, or some other possible state?

We use the server side stored case histories to provide a means to "validate" the highest valued state transition derived from the valid process rules triggered (activated) during the decision processing cycle (Figure 12).

3. SUMMARY AND CONCLUSION

The NCODES project is in the 3rd year of a proposed 4-year project supported by a grant from the National Science Foundation (EIA 0218909). The project has accomplished many of its initial goals. First and foremost was the development of a typology of decision areas for respiratory problems encountered in acute care (non-ICU) environments. Secondly, the development of an original model depicting the novice nurse decision making process, used to facilitate development of a decision support system that will have relevance and utility to practice. The third contribution concerned the development of a framework to extract, examine, evaluate and determine the level of confidence for the nursing knowledge domain. The fourth major finding was the construction of nursing procedural rules linking nursing data rules consistent with nursing practice. Finally, the completion of nursing practice maps (data & procedural rules) for Acute Sinusities, Nosocomial Pneumonia, and PCP.

The development of a multi-tiered architecture capturing nursing clinical knowledge and nursing clinical decision-processes in software was described. This architecture has three major components: data rules, meta-rules, and state information. These components equate to knowledge rules, process rules and the patient chart in nursing terminology. The architecture also includes structure that allows rules to be grouped together to manage the temporal nature of the nursing process. The logical arrangement of these blocks forms a decision tree, through which there are many correct paths. This tree is traversed as follows. The data rules produce or act on patient information. That information is stored in the state. If the state changes, meta-rules operate to enable or disable blocks of data rules. Thus the architecture as well as the individual data rules and meta-rules capture nursing knowledge.

The work still to be accomplished on this grant includes the field-testing of the framework for nursing knowledge and the prototype DSS nursing system. We are running a series of expert nurse practitioners through a variety of acute clinical scenarios to test the broader applicability and completeness of the DSS models and their application to clinical nursing practice. Secondly we are fielding a small number of our hand-held DSS systems with novice senior nursing students during their two clinical sessions in the fall of 2004 and the spring of 2005 to further test the usability, completeness and accuracy of the device.

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