Diagnostic Reasoning Guided by a Decision-Support System: a Case Study

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ABSTRACT

A clinical decision-support system for dementia investigation was used in clinical practice. User information was collected based on interactions with the application. The aim of this study is to identify features in logged data that can be used for detecting learning and reasoning patterns in the user. A case of a physician who is novice to both the application and the dementia domain was studied and compared to the case of an expert physician using the system. Differences between them were found, and a clear pattern that indicates that learning takes place, both how to use the system and about dementia, was observed in the novice user. Further studies need to be conducted, focusing on whether patterns become stable over time, and with complementary methods that can detect reasons for observed behaviors. Software for automatic detection will be developed based on the results of this study.

CCS CONCEPTS

• **Applied computing** → **Health care information systems**; • **Human-centered computing** → **HCI design and evaluation methods**; • **Computing methodologies** → **Knowledge representation and reasoning**; • **Theory of computation** → *Theory and algorithms for application domains*;

KEYWORDS

Diagnostic reasoning, Clinical decision support systems, Dementia, Continued medical education, Cognition

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1 INTRODUCTION

Clinical decision-support systems (CDSS) are typically aimed at supporting the medical and health practitioners in their reasoning and decision-making processes [4, 10, 11, 21]. A CDSS may also aim at educating the practitioner at the point of care, and then supporting a clinical work process [5, 8, 9]. The Dementia Diagnosis and Management Support System (DMSS-W) is developed for supporting reasoning and decision making relating to the dementia investigation, and supporting learning and skill development in the user of the system [16, 20].

A study showed that there were limitations in physicians knowledge when assessing dementia diseases [14], in particular, on aspects that are instrumental for dementia diagnosis. This study aims to explore further patterns of reasoning and learning in physicians who uses the decision-support system for dementia diagnosis. The hypothesis is that if a decision-support system could detect reasoning and learning patterns in the user, the system could also provide personalised support to learn and further develop skills in diagnostic reasoning. Moreover, preserved changes in the pattern could indicate that learning and skill development has taken place [20].

The observations outlined in [20] that indicated that learning takes place were the following. A click event on an item that activates an assessment protocol represents a focus shift towards the concept associated to the assessment protocol, which represents a task to be done. A click event on an aid button represents either a) the intention to learn about the system, or b) the intention to learn about the particular feature, which then is assumed to be in focus. Each click event that generates evidence represents a conclusion (decision) drawn by the user. A click event related to the guide functionality represents either lack of knowledge about what to do next, or an intention to speed the process up, as a fast assessment track. A shift from the diagnosis and intervention protocol to the data-capture protocol with subsequent logging of new evidence represents increased awareness of, or new insights about missing information. These assumptions were further explored in the following section.

The aim of the work presented in this paper is to explore patterns of use when physicians have access to the decision-support system over a longer period of time, in our case, at least one year, to see if patterns of reasoning can be detected. It should be noted that the users are typically general practicians who may not meet patients with suspected dementia very often, and when they meet the patient, they have very limited time scheduled for assessment [13]. This is also a reason for why a decision-support system is viewed as an instrument that has the potential to bridge the irregularity of patient encounters, and lack of experiences in general practicians. It has also shown to improve the routine of dementia assessment [13].

In our earlier research some interesting observations that could indicate that learning takes place were outlined [20]. In this work we aim to apply and evaluate these in a new case of a novice physician who has used DMSS for a longer period of time, and complement these features with additional ones before developing software for automated detection.

The paper is organised as follows. A description of the methods applied is provided in the following section. Then, general trends for reasoning and decision making for novice and expert are briefly summarised, followed by a detailed depiction of our DMSS-W system. The data for the case study is described afterwards, and a discussion on the analysis of the data is provided subsequently. The article ends with some conclusions and directions for future work.

2 REASONING AND DECISION MAKING IN NOVICE AND EXPERT CLINICIANS

Studies have shown differences in the reasoning patterns in novice clinicians and expert clinicians [7, 22, 23]. An experienced professional typically first assesses the situation of the patient in terms of various aspects, which are used to build up evidence for syndromes, *before* reasoning about the conclusion about the diagnosis and the corresponding potential causes. This pattern is widely acknowledged as a typical expert behaviour, where he/she collects information such as symptoms from the patients, and then make a judgment/decision based on the rich experiences and knowledge he/she has [12, 24]. The first part of such reasoning strategy is a type of *forward-chaining* reasoning that, in the case of diagnostic reasoning, is combined with a type of *backward-chaining* reasoning, i.e. *causal* reasoning, when sufficient amount of information has been collected. The diagnostic reasoning process involves four types of inferences: abstraction and abduction (drives hypothesis generation [25]), deduction and induction (drives hypothesis testing [6]) [2].

Unlike experts, novices tend to apply a causal reasoning already at an initial stage of their assessment procedure, which begins in the potential explanation of the condition. That is, the physician first makes a hypothetical diagnosis and subsequently investigate features, which may or may not support the hypothesis. Finally he/she makes necessary adjustment to the hypothesis accordingly. This pattern is often seen among non-expert doctors who lacks the ability to collect and critically analyse all the symptoms, and has to make a hypothesis first and then modify it based on the symptoms. The risk with this strategy is to miss important information. Consequently, diagnostic reasoning is strived for, when novice clinicians develop skills. Also very high level of diagnostic accuracy is seen when diagnostic reasoning is used [22]. However, the causal reasoning pattern is also seen in expert physicians explaining to a medical candidate reasons for diagnosis [7]. Therefore, in our work, the design of the decision-support system is aimed at supporting a diagnostic reasoning process, yet, allowing a user to switch between forward and backward chaining reasoning depending on current experience and skills.

3 THE DEMENTIA DIAGNOSIS AND MANAGEMENT SUPPORT SYSTEM

The Dementia Diagnosis and Management Support System (DMSS) [15] has been developed by medical experts [17, 18] and integrates a number of international and evidence-based diagnostic criteria and treatment protocols. DMSS contains support for learning i) how to use the application, ii) about each relevant symptom, syndrome and disease, iii) how each relates to assessing a cognitive disorder, iv) about the ambiguities and uncertainty related to diagnosis, and v) a procedure for assessment.

Current version of DMSS is built using the ACKTUS Web platform for knowledge engineering of knowledge-based systems (DMSS-W) [19]. The ACKTUS core ontology contains the class *assessment-protocol*, which represents templates for conducting activity such as dementia investigation. All knowledge-based applications developed using the ACKTUS platform are based on an instance of this class [18]. The main assessment protocol that builds the application contains other assessment-protocols representing composite sub-actions, or content such as questions with typically structured answer alternatives. These protocols can be interrelated and be executed as a kind of a loosely coupled workflow in order to aid the user in accomplishing a task.

The main assessment protocol for DMSS-W contains four sub-protocols where we study in this article in particular the Data Capture protocol, Dementia Diagnosis and Intervention protocol, and the Introduction to DMSS protocol. The structure of nested sub-protocols builds the menu system in the user interface, and represents sub-actions in the assessment task (Fig. 1). When the user clicks on a menu item, this is interpreted as the user is shifting focus towards the topic of the selected sub-protocol. A click on a value associated to a phenomenon, or symptom, generates an information node, which is represented as evidence associated to the ongoing event (Fig. 1). A click on a button leading to aid functionality is logged as an observation associated to the event. The aid can be either about how to use the system, or explanations and definitions of concepts relating to symptoms and diseases.

The application functions as a checklist, and supports a systematic process of forward-chaining reasoning, where a professional first assess the situation for the patient regarding various aspects, which are used for building up evidence for the presence of syndromes, before moving into reasoning about the potential causes and conclusions about diagnosis, represented by activating the menu item Diagnosis and intervention and the connected automatic reasoning engine.

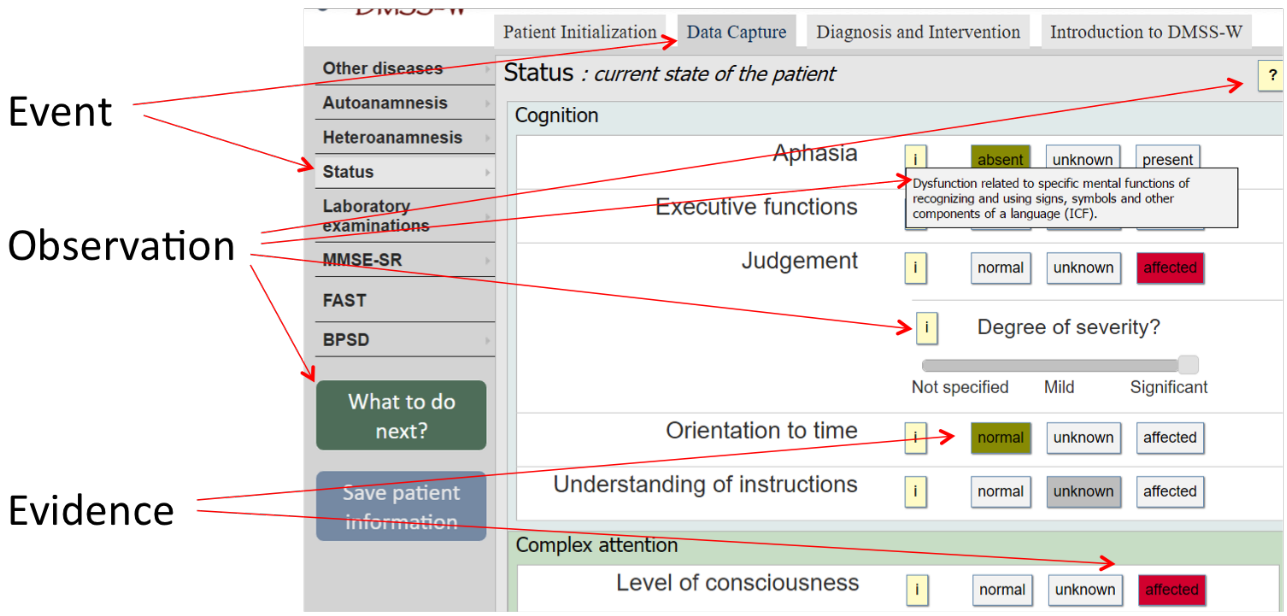

Figure 1: Logged information related to click events.

The application also has a guide functionality, which is activated by a button called "what to do next?" (Fig. 1). This guide functionality further supports the forward-chaining reasoning process by providing the user a subset of the features necessary to investigate in the current situation taking the information collected so far into account and a set of guidelines. This functionality is a step-by-step procedure in three steps, where the necessary information that is asked for leads to an intermediate decision about the patient's condition. The final step presents a set of potential diagnoses, and leads the user to the Diagnosis and Intervention tab.

A different reasoning strategy is to begin with a hypothetical diagnosis and investigate features, which support or contradict this hypothesis, i.e., backward-chaining, or causal reasoning. A user of DMSS-W can any time access this reasoning functionality, which generates support for different diagnoses, and which provides an overview of the available potential hypotheses and their support. In case a medical professional suspects a certain disease, this functionality can provide information about the corresponding diagnosis, and information that are potentially missing that is necessary for diagnosis.

4 METHODS

Java programming language [1] was used to develop DMSS-W. In order to record the log data, OWL ontology technology [3] [1], namely repository was used. We defined the nodes as well as the relationship between the nodes and designed the actor repository as the log file. When physicians used DMSS-W, their click behaviour were automatically recorded to actor repository. The work in this paper is mainly to analyse the log file and to recognise the reasoning patterns of the users.

29 physicians had access to DMSS-W during the past year. The major part of the physicians are using the DMSS-W for the first time. Data regarding their activities has been stored in a log file. For the purpose of this case study, two users were carefully selected out, who have been active over a longer period of time where one assessed himself an expert and another assessed himself being a novice in the dementia field. The data was analyzed semi-automatically to answer the following research questions.

(1) Are the observations outlined in [20] sufficient? If not, what needs to be added?
(2) Can we use these observations to find out if the novice physician generates stable patterns of diagnostic reasoning over a period of time?
(3) Can we recognise any differences between the user's behaviour in the initial phase and later phases of use?
(4) Are there differences between the novice and an expert when using the system?

The process for the semi-automatic analysis of the log data is summarised as the following six steps:

(1) Divide the data into groups according to the different users.
(2) In each group, sort the data by their starting time when the event occurs.
(3) Further separate the data according to their dates.
(4) Assignment each button with a number such that this number reflects the position of the button in the logic chain of the reasoning. The numbers also include the information of the hierarchy structure of the buttons.

[1]http://www.w3.org/OWL/

(5) If there are several cases diagnosed in the same day, make sure the data are separated properly so that they are not mixed and mistaken.
(6) Finally, manually determine the reasoning pattern by summarising the appearance sequence of the numbers. For example, navigating from 2.2 to 3.1 should be considered as a sign of forward-chaining reasoning.

During the last step, the data was sorted into three categories of sessions where i) the patient cases were complete, in the sense that diagnosis is considered, ii) partial information is entered about a patient case, and iii) sessions when no patient-specific information is entered, the physician is only navigating around the user interface. These different types of sessions were mixed throughout the period of use.

The theoretical framework that we use as lens to analyse the case study in depth is described in Sect. 5. In brief, the typical expert and novice behaviours are different. Studies show that experts typically apply a diagnostic reasoning procedure that begins with forward-chaining reasoning. They start with the symptoms, etc., which are used to build up evidence for syndromes (abstracted interpretations of the evidence, e.g. a state of dementia), before reasoning about the potential conclusion regarding the cause of the symptoms and the syndrome, e.g. Alzheimer's Disease. On the other hand, non-experts too often begins with a potential and most likely conclusion and then use the observations of symptoms to test if this conclusion is correct or not. These differences are well recognised in literature and are based on previous statistical studies [7, 22, 23], and have impact on the quality of the assessments. Therefore, in this work we opt to use it as the basis of our theoretical analysis.

5 DIAGNOSTIC REASONING PATTERN WHEN USING A DECISION-SUPPORT SYSTEM: RESULT OF A CASE STUDY

Clinical physicians from Japan diagnosed dementia patients using DMSS-W. Their activities were logged in the actor ontology. Fig. 2 is a screenshot of the log file which is shown in Protege[2]. The left panel of Fig. 2 is the events; while the right part is the properties and values of the selected event. The value of the property "is-activity" corresponds to the menu the user clicked. "has-start-time" and "has-end-time" mean the start time and end time the event occurred, respectively. "has-evidence" means the symptom the patient has or the disease diagnostic decision the system made. All these properties and their values are shown in Fig. 2. Apart from these property values, an event may have "has-observation" which indicates the user clicked on a kind of help button. An event at least has the first three properties. It may have from zero to many "has-evidence" and/or "has-observation" property values. In this way, we logged all user click behaviors and the relevant information needed for analysis the behaviour.

[2] http://protege.stanford.edu/

Using the six steps mentioned in Sect. 4, we analysed the log file.

As mentioned in Sect. 4, one expert and one novice were selected for further detailed analysis. The numbers of cases in the three different categories the two users have dealt with are summarised respectively in Table 1. This paper mainly focuses on the data in first category. Although all the data from the users have been analysed, only two users are selected for the reasoning patter study. The practical reason for this is because other users either spend not enough time in using the system, or their behaviours are free-rein-based to some extent, where we have difficulties in finding systematic conclusions based on their data.

For the first 12 complete patient cases the novice physician's use pattern is a mixture of forward-chaining reasoning and back-and-forth reasoning. During the "back-and-forth" reasoning, the user joggles one or two times between the patient symptoms and the conclusion/hypothesis. Subsequent to these cases, the physician continues to diagnose another three patients, where it is very clear that he/she uses pure forward reasoning pattern. It was observed that the forward reasoning in Cases 13-15 is fundamentally different from the forward reasoning appeared in the earlier cases. In the last three cases, the physician is moving systematically from "register new case" to "data capture", then to "diagnosis and intervention", and does not utilize any help functionalities. A conclusion can be reached that this novice did show a learning process of how to use the system and developed a computer assisted diagnosis routine over the course of more than 10 completed patient cases.

No obvious and clear patterns in the reasoning could be detected in the expert physician's data. For 4 of 12 completed cases, this expert physician seems to have used forward reasoning and the time spent on each case is much less than the other completed cases, which indicates that these were less complex cases. In the other cases the physician navigates back and forth among the buttons to a significantly higher degree, which indicates that the reasoning patterns are mixed and complicated.

Table 1: The numbers of cases which the novice and expert have dealt with summarized as into 3 categories.

Case type \ Professional	Novice	Expert
i) Completed cases	15	12
ii) Partial information cases	4	1
iii) No patient-specific information cases	16	15

No particular time differences could be detected between the novice and expert physicians. In earlier studies the time spent using the application depended primarily on the complexity of the patient case [13].

Figure 2: Screenshot of logged events in actor repository shown in Protege.

6 DISCUSSION

Our case study confirms that the detection of diagnostic reasoning pattern by computer assisted decision support system is indeed possible and feasible, which gives a satisfactory answer to the research question posed in the introduction of this article. The novices and experts use the software system in a significantly different way. Through detecting the reasoning patterns, we can get information on how the novice users get familiar witht he system and eventually develop themselves towards experts. It also provides us useful feedbacks which we can use to design the software such that it can offer a better educational function to the users.

Interestingly, the pure forward-chain reasoning pattern the novice has developed was commonly expected from an expert [12, 24]. This follows the intention with the design of the system, to guide the novice to use a reasoning pattern more typical for experts, which is desired.

In contrast, the expert's behavior is more likely a test of the system, in order to see if it behaves as expected. If the computer's conclusion is not exactly the same as he/she expects, he/she will go back to data capture to check if some symptoms are missing or wrongly inputted. That would explain why the expert does not exhibit an obvious reasoning pattern, instead joggles back and forth between different buttons.

In earlier studies the expert physicians saw benefits of using DMSS in difficult cases in particular [15]. This could also be an explanation to the expert physician's behavior. The physician may be exploring a difficult patient case from different perspectives, while moving between data capture and diagnosis.

The limitation of the current study is that the logged data is not complemented with qualitative methods for data capture that could identify the reasons for different observations. Future studies will have such design, in order to gain a better understanding of the observed patterns of use. Moreover, studies over even longer periods of use than in this study are needed in order to verify that changed patterns of use towards applying diagnostic reasoning are persistent over time.

Further studies are needed to identify more differences in the diagnosis patterns between novices and experts, however, our study indicates that it is practically possible to detect these patterns by software systems such as DMSS-W, and then use the software to educate the novices accordingly. Of course, the detection of the individual diagnostic reasoning has a finite error rate, but when the number of users are large (which is a situation not easily manageable by conventional means), the statistical correctness of the detection can be guaranteed, contributing greatly to the following education of the physicians. One of the advantages of using computers is its ability of handling large amount of data. This feature is especially suitable for the detection of reasoning patterns, because it typically requires more data points to ensure the statistical correctness of the theory and analysis. In the future, more tests and applications of our DMSS-W system in the medical sector will be performed, and a larger number of users with longer time of using our system is expected. More advanced algorithms can be utilized in the pattern detection and improve the reliability and accuracy of our pattern analysis.

Finally, continuing our work, once the clearer reasoning patterns can be reproducibly detected, we can test and practice our DMMS-W's educating function. As mentioned in the introduction, apart from being an assistance for the diagnosis, another important functionality of our system is for education. In many medical diagnosis and treatment fields such as dementia, education of the doctors is vital, in order to accumulate enough medical professionals within a short time span. Such reasoning pattern detection and subsequent education will be best done with computer systems, as it is practically very difficult to deal with a large quantity of end users by traditional means.

7 CONCLUSIONS AND FUTURE WORK

Data was collected when physicians used the decision-support system for dementia diagnosis DMSS-W. A case of a novice physician using the system over a longer period of time was analyzed and compared to the case of an expert physician. The purpose was to identify features to use for designing software for future automatic analysis of the development of skills and knowledge in an individual user. A number of features were identified, that will be targeted in data driven analyses. Moreover, the patterns of use indicated that learning was taking place, initially and briefly, to learn how the system works, and after this mainly to learn about the symptoms relating to dementia. The studied physician reached an efficient pattern of assessment procedure after 12 completed patient cases.

The dementia application is currently being evaluated in clinical practice. The results in this paper will be further extended when more data has been collected.

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REFERENCES

[1] Ken Arnold, James Gosling, and David Holmes. 2005. *The Java programming language*. Addison Wesley Professional.

[2] J.F. Arocha, D. Wang, and V.L. Patel. 2005. Identifying reasoning strategies in medical decision making: A methodological guide. *J Biomed Inform* 38, 2 (2005), 154–71.

[3] Sean Bechhofer. 2009. OWL: Web ontology language. In *Encyclopedia of Database Systems*. Springer, 2008–2009.

[4] Eta S Berner (Ed.). 2007. *Clinical decision support systems: Theory and Practice (2 ed.)*. New York: Springer Science and Business Media.

[5] David A Davis and Anne Taylor-Vaisey. 1997. Translating guidelines into practice: a systematic review of theoretic concepts, practical experience and research evidence in the adoption of clinical practice guidelines. *Canadian Medical Association Journal* 157, 4 (1997), 408–416.

[6] Arthur S Elstein and Alan Schwarz. 2002. Clinical problem solving and diagnostic decision making: selective review of the cognitive literature. *BMJ: British Medical Journal* 324, 7339 (2002), 729–732.

[7] D. Evans and V.L. Patel. 1989. *Cognitive science in medicine*. MIT Press.

[8] B. Kaplan. 2001. Evaluating informatics applications clinical decision support systems literature review. *Int J Med Inf* 64 (2001), 15–37.

[9] Daniel Karlsson, Christer Ekdahl, Ove Wigertz, and Urban Forsum. 1997. A qualitative study of clinicians ways of using a decision-support system. In *Proceedings of the AMIA Annual Fall Symposium*. American Medical Informatics Association, 268–272.

[10] Kensaku Kawamoto, Caitlin A Houlihan, E Andrew Balas, and David F Lobach. 2005. Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to success. *BMJ: British Medical Journal* 330, 7494 (2005), 765–773.

[11] Gilad J Kuperman, Anne Bobb, Thomas H Payne, Anthony J Avery, Tejal K Gandhi, Gerard Burns, David C Classen, and David W Bates. 2007. Medication-related clinical decision support in computerized provider order entry systems: a review. *Journal of the American Medical Informatics Association* 14, 1 (2007), 29–40.

[12] Jill Larkin, John McDermott, Dorothea P Simon, and Herbert A Simon. 1980. Expert and novice performance in solving physics problems. *Science* 208, 4450 (1980), 1335–1342.

[13] Helena Lindgren. 2007. Knowledge Management for Decision Support in the Investigation of Dementia. (2007).

[14] Helena Lindgren. 2011. Limitations in physicians knowledge when assessing dementia diseases - an evaluation study of a decision-support system. *Studies In Health Technology And Informatics* 169 (2011), 120–124.

[15] Helena Lindgren. 2011. Towards personalized decision support in the dementia domain based on clinical practice guidelines. *User Modeling and User-Adapted Interaction* 21, 4-5 (2011), 377–406.

[16] Helena Lindgren, Patrik Eklund, and Sture Eriksson. 2002. Clinical Decision Support System in Dementia Care. *Stud Health Technol Inform* 90 (2002), 568–576.

[17] Helena Lindgren and Peter Winnberg. 2010. Evaluation of a Semantic Web Application for Collaborative Knowledge Building in the Dementia Domain. In *eHealth (Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering)*, Martin Szomszor and Patty Kostkova (Eds.), Vol. 69. Springer, 62–69.

[18] Helena Lindgren, Patrik J. Winnberg, and Peter Winnberg. 2011. Domain Experts Tailoring Interaction to Users - An Evaluation Study. In *INTERACT (3) (Lecture Notes in Computer Science)*, Pedro Campos, T. C. Nicholas Graham, Joaquim A. Jorge, Nuno Jardim Nunes, Philippe A. Palanque, and Marco Winckler (Eds.), Vol. 6948. Springer, 644–661.

[19] Helena Lindgren and Chunli Yan. 2015. ACKTUS: A Platform for Developing Personalized Support Systems in the Health Domain. In *Proceedings of the 5th International Conference on Digital Health 2015 (DH '15)*. 135–142.

[20] Helena Lindgren and Chunli Yan. 2015. Detecting Learning and Reasoning Patterns in a CDSS for Dementia Investigation. *Stud Health Technol Inform* 210 (2015), 739–42.

[21] Mark A Musen, Blackford Middleton, and Robert A Greenes. 2014. Clinical decision-support systems. In *Biomedical informatics*. Springer, 643–674.

[22] V.L. Patel and G. Groen. 1991. *The general and specific nature of medical expertise: a critical look*. 93–125 pages.

[23] V.L. Patel, D. Kaufman, and J.F. Arocha. 2002. Emerging paradigms of cognition in medical decision-making. *J Biomed Inform* 35 (2002), 52–75.

[24] Vimla L Patel and Guy J Groen. 1986. Knowledge based solution strategies in medical reasoning. *Cognitive science* 10, 1 (1986), 91–116.

[25] Rick P Thomas, Michael R Dougherty, Amber M Sprenger, and J Harbison. 2008. Diagnostic hypothesis generation and human judgment. *Psychological review* 115, 1 (2008), 155–185.