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Cognitive Engineering in Interface Design

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Abstract. Today, many medical information systems are not satisfactory to their users. To ensure ultimate acceptance of health care information systems asks for systems that map on health care workers' tasks and on their cognitive processes in performing these tasks. The development of human-oriented computer interfaces requires insight in users' information needs and information processing in view of the tasks that will be computer-supported. Cognitive engineering aims at understanding the fundamental principles behind human activities that are relevant in designing a system that supports these activities. The application of cognitive engineering methods may therefore contribute to computer systems that fit better in health care working practices. We used cognitive engineering methods in designing a user interface for a physicians' workstation to support them in preparing their patient screening. The information needs and information search strategies of 4 physicians were revealed by systematic analyses of verbal protocols and video's while they successively worked through 10 paper-based patient records in preparing their patient visits. The results of these analyses were used as input for the design of a conceptual higher-order model that represents both the information needs and information search strategy of these physicians. Based on this higher-order conceptual model, we developed paper-mock ups and a first prototype of the user interface. The physicians will evaluate this prototype in the next phase of the project.

1. Introduction

Human Computer Interaction (HCI) has emerged relatively recently as a research area within the medical informatics field. One of the reasons of this rather be late introduction of HCI is clearly the major focus on advanced technological solutions without consideration of the cognitive demands placed on the computer users in operating these systems [1-3]. The ideal design of an interactive system would incorporate knowledge of users' cognitive processes to produce an effective interface presentation.

Today, many medical information systems are not satisfactory to their users. To ensure ultimate acceptance of information systems in health care asks for systems that map on health care workers' tasks and on their cognitive processes in performing these tasks. Greater concern for system usability in the medical informatics fields asks for fundamental research into users' information needs and information processing in view of the tasks that will be computer-supported. Cognitive engineering aims at understanding the fundamental principles behind human activities that are relevant in the context of designing a system that supports these activities. The application of cognitive engineering methods may therefore contribute to computer systems that fit better in health care working practices.

We used cognitive engineering methods in designing a user interface for a physicians' workstation. In the remaining of this paper, we will first introduce a general framework for human computer interaction and discuss problems that may arise in the interaction cycle between humans and computers. We will use this framework in elaborating on the usefulness of cognitive engineering methods, in particular user models and task models in specifying user interface requirements. Then, we will describe the method we used in designing the interface in detail. Finally we will elaborate on the role of cognitive engineering in the software engineering process of medical information systems.

2. A general framework of human computer interaction

An interactive system can be envisaged as composed of three elements: the System, the User and the Interface, that is further decomposed in an Input and an Output channel (Figure 1). As the interface is the only communication channel between the user and the system, an interaction cycle can be viewed as passing through four steps consecutively, each step requiring a translation from one element of the interactive system to the next. A user starts the interactive cycle with a goal in mind and translates this into a task (structure) that he has to perform in accomplishing that goal.

The only manner in which the user can articulate his task to the system is by using the input channel. The user's input is translated into system operations. The execution of these operations leaves the system in a new system state that must be presented to the user through the output channel. The user evaluates the system state by the output and assesses whether the interaction resulted in the accomplishment of the goal he set himself. If so, the interaction is completed, if not, a new cycle starts all over again.

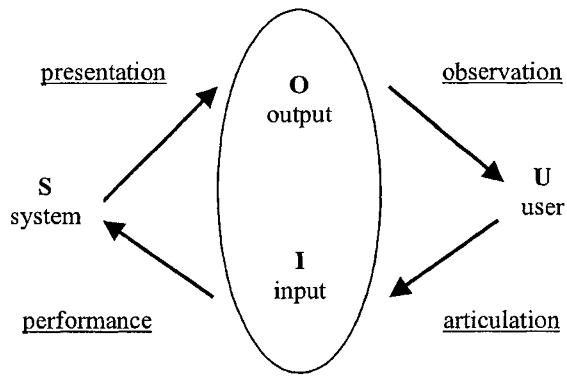

Figure 1: Human computer interaction process. The interface is represented as an oval, which represents the combination of input and output. After Dix, Finlay, Abowd and Beale [4]

Several problems may arise in this interaction: the user may find difficulty in articulating his task through the input channel because of inadequate coverage of this task to input or relative effort with which this translation can be accomplished. The user phrases the task in terms of a coherent cognitive task model and if this model maps clearly on the input, then articulation of the task will be relatively simple. Otherwise, articulation of a task in the input will require a greater amount of user processing and may eventually fail. Second, presentation of the new system state requires preservation of system attributes that are relevant in the context of the user's task (structure). Again, difficulties may arise if the presentation of this new system state through the output channel does not map on the user's task model for the user must ultimately interpret the output in terms of accomplishing the task at hand. Summarizing: the interactions between the user and the computer system involve the transfer of knowledge representations. In order to design effective interaction cycles between the end user and the computer system, their respective representational structures should in some way be mapped on each other.

3. Cognitive engineering methods

The interaction framework provides a basis for discussing other issues that relate to the human computer interaction. For example, the framework makes evident that system and interface design ànd evaluation should concentrate on a detailed analysis of the way in which users perform tasks in the context of a specific goal to be achieved in some application domain.

Cognitive user modeling and task analysis are used in revealing aspects of the user's understanding, intentions or problem solving processes in the context of a task at hand. Cognitive user models try to understand the internal cognitive processes as a user performs a task, whereas the focus of task analysis is on the observable behavior of users rather than their internal processes. Both cognitive user modeling and task analysis may address the acquisition of a plan, that is with understanding the user in the context of the task he aims to perform, or with execution of that plan, that is with articulating his plan through the system input channel [4]. In the first case, these methods may be used to specify the requirements of a system's functionality in the context of its utilization; the results of this analysis can be used to transform end user and task requirements to technical functionality. In the second case, these methods may be applied to analyze inherent problems in using information systems; that is by evaluating to what degree the system's functionality and interaction map on users' tasks and accompanying mental processes. In this perspective, human computer interaction evolves to a mutual adaptation of two systems, the computer system and the cognitive system of the user.

4. Method

The core object of modeling in designing human oriented user interfaces is the human cognitive processing in performing a task. A well-known approach for describing the cognitive processes involved in performing tasks, is the protocol-analytic technique [5]. In this approach, subjects are asked to verbalize their thoughts while they are presented with a real-life problem situation. The first stage of elaboration involves the transcription of these verbal protocols. Part of these transcribed protocols is then used to develop a coding scheme to analyse the remaining protocols in detail. These coded protocols are input for some sort of representation formalism, such as a semantic network or conceptual graph to represent the higher order cognitive processes and to facilitate the creation of task-transparent user interfaces.

In the PLEKsys project [6], we used cognitive user modeling in designing the user interface of a physicians' workstation for support in screening patients on late cancer treatment effects. In the Academic Medical Center of Amsterdam, an outpatient clinic is installed for screening childhood cancer survivors yearly on serious medical conditions that may be related to the earlier cancer treatment. PLEKsys is a computerized record system used for documenting and analyzing these screening data. PLEKsys offers review facilities of patient (cohort) data, but is merely used by clinical researchers. The physicians engaged in screening do however have a demand for computer support in preparing their patient visits. In order to design a physician-oriented user interface for retrieval of patient data, we focused on the information needs and information retrieval strategies used by oncologists in the context of preparing their patient visits. We collected the data by thinking aloud protocols and video recording of 4 physicians as they worked through 10 different paper-based patient records. A coding scheme was constructed for analyzing the verbal data and video's. Coding and analyses was performed on transcripts of the verbal data.

5. Results

Protocol and video analyses revealed identical information needs across physicians and a recurring pattern across patient cases and physicians in the order in which the physicians searched through the patient record. The patient information data that the physicians reviewed were clustered into main categories. A higher-order conceptual model was constructed to represent both these information categories and the sequence in which physicians searched through these categories in the patient record (Figure 2).

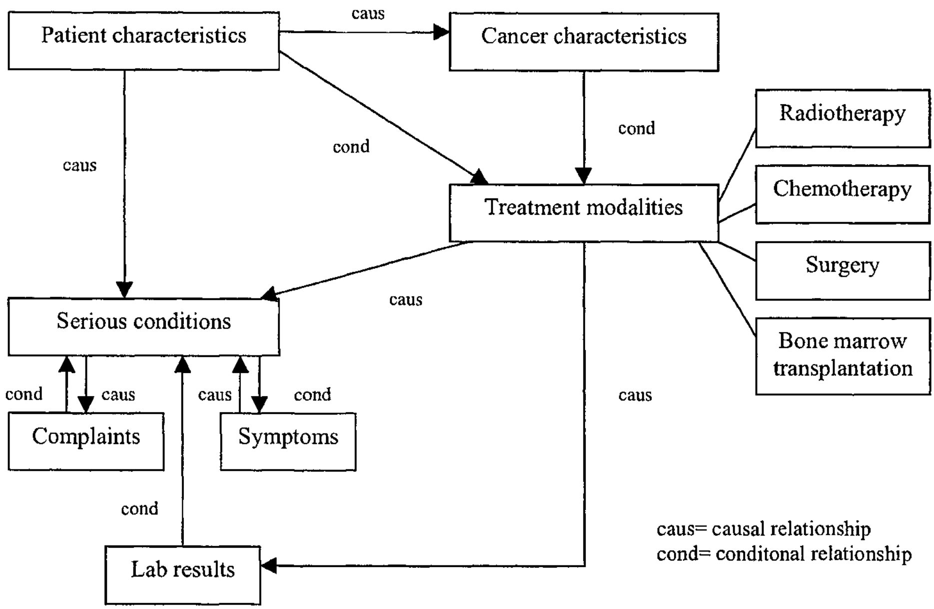

Figure 2: Higher-order conceptual model of physicians search strategy through information categories.

In general, a physician would typically start his search by identifying the patient (1). Then, he examines the cancer characteristics (type, stage, body location) the patient suffered from in the past (2). After retrieving this cancer data, which is conditional to its treatment, the physician would typically create a hypothesis as regards the cancer treatment the patient must have received in childhood. A physician would verify this hypothesis by searching the record for the treatment data (3). The cancer treatment in turn, determines the serious conditions that the patient may suffer from today. The cancer treatment acts a trigger for the physician to hypothesize about these potential serious conditions and to verify these subsequently (4). Then, the physician reviews the complaints (5) and symptoms (6) that the patient reported at the previous screening. These complaints and symptoms may be manifestations of the serious medical conditions the patient is suffering from that have already been recognized or may become apparent in the near future. In the last case, these complaints and symptoms alert the physician on typical serious medical conditions the patient may have developed more recently.

Finally, the physician reviews test results in the context of these complaints, symptoms and known patient conditions (7).

In designing a prototype user interface, we used the higher-order conceptual model as input for formalizing the user interface specifications for PLEKsys. We first designed paper-mock ups of the user interface and evaluated these with the potential end users of the workstation PLEKsys. Based on these evaluations, we developed a prototype user interface.

6. Preliminary experiences and future work

In the PLEKsys project, we used cognitive engineering methods in designing a user interface of an oncologists' workstation for support in preparing patient visits. The combined protocol and video analyses were found to be extremely helpful in gathering detailed information on the information needs of the oncologists and on the cognitive strategies they employ in searching for this information. Based on these detailed descriptions, we were able to develop a conceptual model of the cognitive activities involved in reviewing patient information in the context of the next patient visit.

In testing the resulting work station on usability, we will employ the same principled methods as we used in the requirements analysis phase: that is, to identify problems in the user interface, potential end users of the work station will be asked to verbalize their thoughts and actions as they interact with PLEKsys in reviewing patient cases. The analyses of these verbal protocols, in combination with video and logfile analyses will give us a deeper insight in the source of usability problems that users may encounter during system interaction and be used as input to optimize the user interface and interaction.

Human computer interfaces serve as a layer between the system's and the users' representations, that mutually modulate and influence each other. If we want to capture the context of this interaction, we need to model users in the context of the tasks that they want to accomplish aided by the computer. Cognitive engineering methods seem promising in designing user interfaces that map on users' cognitive models in accomplishing tasks. User interface design cannot be handled in isolation but should be integrated in the software engineering process from requirements analysis to final evaluation of the computer system. Medical information systems can only be designed to support health care workers when cognitive requirements in context of their tasks drive the design process throughout.

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