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Ubiquitous computing to support co-located clinical teams: Using the semiotics of physical objects in system design

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ABSTRACT

Objectives: Co-located teams often use material objects to communicate messages in collaboration. Modern desktop computing systems with abstract graphical user interface (GUIs) fail to support this material dimension of inter-personal communication. The aim of this study is to investigate how tangible user interfaces can be used in computer systems to better support collaborative routines among co-located clinical teams.
Methods: The semiotics of physical objects used in team collaboration was analyzed from data collected during 1 month of observations at an emergency room. The resulting set of communication patterns was used as a framework when designing an experimental system. Following the principles of augmented reality, physical objects were mapped into a physical user interface with the goal of maintaining the symbolic value of those objects.
Results: NOSTOS is an experimental ubiquitous computing environment that takes advantage of interaction devices integrated into the traditional clinical environment, including digital pens, walk-up displays, and a digital desk. The design uses familiar workplace tools to function as user interfaces to the computer in order to exploit established cognitive and collaborative routines.
Conclusion: Paper-based tangible user interfaces and digital desks are promising technologies for co-located clinical teams. A key issue that needs to be solved before employing such solutions in practice is associated with limited feedback from the passive paper interfaces.

1. Introduction

Several researchers have concluded that physical objects are used supportively when co-located professionals perform everyday cognitive tasks and join forces to solve problems [1–3]. For instance, paper folders are arranged in the office so that they serve as memory structures and representations that preserve task states [4]. Sticky notes function as flexible reminders [5] that draw attention to important information and tasks, and, similarly, making annotations and underlining text can serve to highlight the significant contents in a document and in this way facilitate re-reading [6]. Arrangements of this type facilitate interpersonal communication because several modalities can be used to achieve interaction and mutual understanding, i.e., in addition to speech, gesture, and gaze [7–10]; also physical manipulations of the objects. From this perspective, the present desktop computing paradigm has several limitations, e.g., by that the tangibility and flexibility of physical objects are difficult to replicate in the graphical user interfaces (GUIs) [11]. Lack of these properties is, there-

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fore, an obstacle to the development of systems that optimally can support co-located teamwork [12]. Moreover, the relatively small computer screen along with a standard keyboard and mouse are designed to be used by one person at a time, which makes it difficult for several people to simultaneously view, discuss, and interact with the systems [13].

An ultimate consequence of "overvirtualized" desktop computing-based workplaces is thus that users are deprived of their resources and natural strategies to offload cognitive demanding tasks to the environment, as well as their means to use physical social cues to facilitate collaborations [9,14]. The aim of this study is to investigate how tangible user interfaces can be used to support collaborative routines among co-located clinical teams. For this purpose, we develop an alternative user interface design for clinical computer systems that also takes advantage of the semiotic value of the physical objects used in everyday cognitive tasks among these teams. The reasons for the disappointing adoption rate for present electronic patient record systems may be found in decisions made already early in the design of these systems, and which today are taken for granted. For example, the graphical user interface that is employed today is a direct descendant of the Rank Xerox 'Star' system interface of the late 1970s and early 1980s [11]. The Star interface was developed with *office tasks* in mind and it also replicates tools of a physical office. For example, the semiotics used in the system refer to the office environment (e.g., 'desktop' and 'folder'). Researchers have criticized this interaction model for not effectively supporting co-located teamwork; the screen of a desktop system is small, which makes it difficult for several users to work simultaneously, and it is impossible to quickly hand over a document to share information. This interaction paradigm, therefore, imposes unnecessary tasks on closely collaborating personnel, e.g., clinical teams managing patients in serious conditions.

2. Background

2.1. *Distributed cognition*

Most cognitive theories presuppose that cognitive processes can be described and understood by using the individual actor as the unit of study. However, alternative socio-cultural theories reject the widespread notion that cognition is limited to the individual. These theories assume that the human mind operates in physical environments that are rich in structures such as tools that direct and support individual cognitive processes [15]. Distributed cognition is such an approach to cognition and it considers larger systems comprising groups of people and their tools [16]. The cognitive processes of individuals are seen as being distributed among members of a social group, as well as among their supporting tools. The temporal perspective is also important: cognition can be distributed over time in that preprocessing of tasks (i.e., to prepare tasks) can change the nature of subsequent tasks and make them easier to perform.

Empirical studies of distributed cognition have been conducted in a variety of collaborative work settings such as airline cockpits and ship navigation [16]. This type of research usually includes identification of the overall system goal and analysis of communication patterns in groups of individuals. The investigator examines ordinary ways in which people deal with cognitive tasks, and it is of particular interest to determine how the studied subjects opportunistically *exploit and transform* the physical environment to communicate in the group and represent tasks. For example, it has been observed that professionals readily convert cognitively demanding tasks into easier tasks by changing (i.e., re-representing) the work environment in ways that allow the use of perceptual routines rather than costly high-level reasoning [17,18].

Researchers have also documented similar phenomena at clinical workplaces [19]. Berg, for example, has discussed the many mundane roles of medical paper charts and forms, particularly, how they support coordination among staff members [20]. Hazlehurst et al. have studied distributed cognition in cardiac surgery [21]. They argue that the setup of tools that precede surgery such as special physical layouts embody the operative plan and that this streamline action according to predefined sequences.

2.2. *Ubiquitous computing and tangible user interfaces*

Ubiquitous computing emerged due to dissatisfaction with the existing paradigm in which computers are housed in box-like casings, and interaction is achieved through windows, buttons, keyboards, and mice. Inspired by the work of sociologists showing how people interact with physical tools, researchers wanted to construct computer-based systems that blend into the environment in order to create more natural ways of working with computers. Early work in this area involved the development of mobile tablet computing devices and ways to transfer information wirelessly. More recent efforts include the development of specialized input devices that permit interaction with computers through manipulation of physical objects.

Tangible user interfaces are techniques that enable physical interaction with computer technology [22]. These interfaces can serve as dedicated physical interface widgets, affording physical manipulation and spatial arrangements. The benefits of these types of interfaces are according to Fitzmaurice, that they allow users to employ a larger expressive range of gestures and grasping behaviors but they also support user's innate spatial reasoning skills and everyday knowledge of object manipulations [23]. Ullmer and Ishii have developed a tangible user interfaces where small wooden blocks served as physical icons for the containment, transport, and manipulation of media in systems used for controlling video recorders [22]. Jacob et al. developed a tangible user interface in which users control the computer by moving bricks on the surface of a two-dimensional grid; the system reads the positions of the bricks on the grid, and functions are assigned to the different locations that initiate actions on the part of the computer [24].

2.3. *Approaches to workplace augmentation*

Several different technical approaches can be used to amplify ordinary physical tools and environments with functionality