Medical Operating Documents: Dynamic Checklists Support Crisis Attention

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ABSTRACT
The attentional aspects of crisis computing—supporting highly trained teams as they respond to real-life emergencies—have been underexplored in the user interface community. My research investigates the development of interactive software systems that support crisis teams, with an eye towards intelligently managing attention. In this paper, I briefly describe MDOCS, a Medical operating DOCuments System built for time-critical interaction. MDOCS is a multi-user, multi-surface software system that implements dynamic checklists and interactive cognitive aids written to support medical crisis teams. I present the results of a study that evaluates the deployment of MDOCS in a realistic, mannequin-based medical simulator used by anesthesiologists. I propose controlled laboratory experiments that evaluate the feasibility and effectiveness of our design principles and attentional interaction techniques.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General terms: Design, Human Factors, Performance

Keywords: Checklists, medicine, cognitive aids

INTRODUCTION

Peri-operative patient care in surgery and advanced cardiac life support are two examples of volatile, uncertain, complex, ambiguous (VUCA) task domains, which place great, demands on users' cognitive facilities [4]. Unlike traditional office work, operating room staff and code teams operate in large co-located groups, where tasks are paced and time-critical. Aviation is another high-risk, high-tempo domain [2], but medical crisis care is even more unusual in its co-located team size and multiplicity of information sources and controls, distributed throughout the environment [16]. For example, during a code blue situation, it is not uncommon for a dozen staff members to enter a hospital room at different times, and for crash carts and other equipment to be wheeled in and out at will.

UIST '12, Oct 07-10 2012, Cambridge, MA, USA
ACM 978-1-4503-1582-1/12/10.

Thus, medical crisis care represents an extreme point in the space of interaction contexts. It offers a number of challenging applications, such as collaborative work and decision support under stress. Crisis care demands multi-user, multi-role interactions, and requires usable human-computer interaction techniques that span devices distributed throughout a fluid, information-rich environment.

To push the boundaries of traditional interaction and improve medical crisis performance, I focus my research on the user interface design of medical checklists, which have been shown to greatly reduce patient risk during hospital care [5] and improve crisis response [6, 15]. Whereas checklist usage is standard in aviation, paper checklists are only now becoming commonplace in medicine: they are not yet consistently used in teaching, simulation, and practice. Thus, their adoption faces a number of sociotechnical challenges, such as cultural acceptance, a lack of standardization and design guidelines, and the difficulties of distribution and effective use [14].

My work aims to investigate the development of dynamic, software-based medical checklists. These dynamic checklists implement novel interaction and display techniques designed to support their use in the resource-limited, split-attention context of medical crisis care. I present MDOCS, a medical operating documents system, which embodies these techniques. MDOCS is a software system which offers interactive cognitive aids and dynamic checklists, whose displays are mirrored across tablets and large-screen displays. It is implemented as a HTML5 web application which synchronizes state via WebSockets, to ensure low-latency communication overhead. The web architecture allows portable rendering across different form factors, such as large screens mounted on the wall and wheeled in on crash carts. It facilitates the authoring of checklists and cognitive aids using checkML, a markup language designed for the task domain.

This work contributes to our understanding of how to build interactive systems for co-located teams working in extreme, stressful, multi-role task domains. In these situations, time demands limit attentional and cognitive resources, but user interfaces are typically not designed to scale reliably to these paced, high-tempo, critical care environments. I develop user interface display methods for intelligently optimizing layouts under the constraints of limited pixels and user attention, including priority-based horizontal stacking methods and semantic linking methods for contextually selecting subsets of cognitive aids to display. I incorporate these developments into a larger theory of operating document design that builds on existing research work. Preliminary pilot studies suggest the initial feasibility, usability, and utility of our MDOCS system, and more detailed experiments are currently underway.

PREVIOUS WORK

Attention

Previous work has investigated models of attention in computing [7], notification [9], and the role of interruptions [13]. However, these typically address single-user, single-computer office tasks, which differ greatly from the demands of team-based crisis care. My research aims to extend these models of attention to adapt to the multi-surface, multi-user environment of fast-paced crisis medicine.

Adaptive Displays

Other researchers have investigated the design of display technology, which reduces the cost of information access, such as work in dynamic information visualization [1], such as DOI (degree-of-interest) approaches. In the document-engineering world, researchers have developed ways to adaptively layout text and graphical documents [8].

However, previous approaches are limited in medical crises. Complex information designs can be difficult to quickly assimilate if gaze times are short. They may be space inefficient and not designed for use at a distance. In contrast, adaptive layouts may be space efficient. However, they are not built for single-page applications where focus changes quickly. They assume additional pages can be used, and are built for static not dynamic documents.

Checklists

In aviation, checklists have been a staple of teaching and crisis management for decades [2]. In comparison, checklists are only now entering medical practice [5, 12]. They face various adoption issues [14], from social hierarchy to perceived value, and a model of care that differs from how doctors are trained [5]. Studies have investigated the effectiveness of checklists in surgical care [12], operating room crises [15], and rare medical events [6]. However, research into how systems may be automated, or how static checklists may be made dynamic and interactive is limited.

NASA researchers have done work on design guidelines for checklists [2] and for the more general operating documents [10]. My work aims to expand the theory of operating documents to include system interactivity and adaptivity, and to explore their role in crisis care medicine.

MEDICAL CRISIS INTERACTION CONTEXTS

In routine care, medical doctors are beginning to adopt electronic health records but during a crisis, information technology use is typically limited to interacting with patient monitors, such as vitals displays and surgery-specific views [4]. A surgical team may include a small (6) to large (15+) team of medical doctors (surgeons, anesthesiologists, cardiologists, etc.) and staff (nurses, technicians) each of which come from a different culture of education and work practices. These differences translate into challenges for the adoption of technology such as paper checklists [14].

Work Practices

Researchers have investigated the role of paper in domains such as air traffic control [11]. My work has found very different work practices regarding checklist use, from no use, to quick scans & glances, to huddles and “hail-mary” read-throughs to see if any step was missed.

Stanford pioneers developed courses in Anesthesia Crisis Resource Management [4], as a parallel to cockpit resource management in aviation. These teach non-technical skills such as effective communication and coordination [3].

My work helps to develop a theoretical understanding of crisis care practitioners, from an information theoretic and interactional lens. This includes methods such as gaze pattern analyses [16], and participatory design work.

MEDICAL OPERATING DOCUMENTS

As part of the design process of MDOCS, I engaged in participatory design work with doctors from the Stanford School of Medicine. We held weekly meetings and over the course of the last 12 months, I observed dozens of hours of simulated crisis scenarios, each involving 1-2 anesthesia resident participants and 3-5 confederate actors (doctors, nurses, technicians and patients played by doctors, nurses, technicians and patients). Our collaborators walked us through video recordings of simulated crises, including both surgical and cardiac code situations.

As part of the participatory design process, we iteratively built paper, wireframe, and interactive prototypes. These were deployed in the lab as well as designed *in-situ*, in operating rooms with a full-theater of working equipment.

Design Insights

We initially thought we could build interactive checklists where medical doctors click on items. However gaze analysis and observation [16] demonstrated that such seemingly simple interactions were in fact heavyweight. We instead gave tablet input to nurses, allowing doctors to give them verbal commands. Noticing the cost of information access, we built an always on, always visible system useful in routine care, transitioning seamlessly when a crisis occurs.

Another aspect of the evolution involved the transition from medical checklists to cognitive aids to a more general perspective of supporting resource management. In this context, resources include medical information (patient records, lab results, checklists). But other resources include environmental support (who is on call? how much blood do I have?) and even people in the room. For example, during a code situation a dozen people may enter a room separately, and no leader may be obviously designated. Half of the people may not know the names or roles of a large fraction of the staff.

Design Features

Based on our design process, we deployed large-screens on the periphery of the operating room [16], to encourage a shared mental model. However, our observation also uncovered work patterns such as the crisis huddle, and the way in which doctors under stress would focus their gaze patterns in certain arcs (anesthesiologists in an arcs that center around the head of the patient, code team leaders in larger arcs that cross-cut the operating room). Thus, this supports the deployment of tablet devices, which mirror information seen on the large-screen display.

Whereas nurses can use tablets to enter patient data (for example, recording that epinephrine was pushed) or to call for doctor-requested resources (backup, crash carts, blood available, cognitive aids), doctors may also periodically engage with information directly. Thus, a design that supports coordinated, mirrored tablets allow multiple crisis personnel to engage with the information at whatever granularity or distance they desire (hand-held, in pairs, or across the room with the large-screen display).

Information Design

MDOCS displays three columns of information. On the left is a mechanism for selecting relevant checklists, and an action-oriented interface, which contains cues to action paired with salient directives. In the middle, an interactive checklist contains list items can trigger dynamic timers (recording a dose of epinephrine triggers a redosing timer). On the right, people are listed: both crisis staff (pictures, names, roles) and patient information (procedure, medical history, lab results). A docked set of icons in the corner allows easy access to backup (who is on call, how far away are they?) and services, from cardiologists to crash carts and 12-lead EKGs.

EVALUATION

Pilot Study

We deployed MDOCS to anesthesiologist residents (n=4) in training. The system was implemented on an Apple iPad and a 27" large-screen display mounted on the wall of an operating room. It contained five different interactive cognitive aids for asystole, pulseless electrical activity, myocardial ischemia, and VTach/VFib, as well as a pre-surgery time-out list. It was deployed to two different pairs of medical residents, where one served as the primary and the other came in as a backup. The confederate staff typically included four roles: surgeon, attending, nurse, and technician (played by myself or another graduate student).

The residents were engaged in a crisis resource management class, so they knew they were being observed from behind a one-way mirror. However, they did not know any details of the operation, or the expected crisis.

Before the simulation, they received basic training on equipment in the room, such as the vitals monitor, and were briefed for five minutes regarding the use and role of our interactive cognitive aids. They agreed to be recorded on video and took part in post-simulation debriefing.

We received useful usability feedback regarding the information design of the system. For example, some cognitive aids spanned two columns, however doctors did not realize that there was an additional column. They also struggled with the glut of information. Given this we made design features more salient to group information, and even more mercilessly cut elements from the icon dock (from 5-6 to 2), and removed a historical event record and information and blood supplies. We iterated on the design of the checklists, including more progressive disclosure.

We also introduced "crisis petals" inspired by a flower-shaped set of principles taught in the crisis resource management class. Each crisis petal in the interface is embodied by a single directive, question or informational statement, along with a clickable cue to action. For example, a question may be "Who is the leader? Designate leadership" with the second phrase underlined and clickable. These petals appear and hide based on the situation, and forming an action-oriented interface that saliently draws attention.

MDOCS 2.0

The rest of my thesis work will include the design, implementation, and experimental validation of techniques and algorithms to make the interactive checklists in our system even more dynamic. Currently, interactivity is limited to checking off items, collapsing or expanding text fields, and triggering drug redosing timers. I propose to improve checklist systems in at least three ways:

- Implement dynamic layout methods on the micro-scale (formatting lines and boxes) and on the macro-scale, adaptively adjusting what information is shown, where, in the display.
- Support intelligent dispatch / selection of related checklists and diagnoses through an attention-sensitive implementation of alternate competing hypotheses
- Study the systematic impact of attentional cueing: how doctors are cued to take action by interactive aids? How do we design directive attention systems? Can we validate a "change, capture, cue" framework for implementing directive attention?

Implementation

MDOCS is implemented as a HTML5 web application that synchronizes through WebSockets for low-latency synchronization across devices. I developed a state management system to manage subscribing to and publishing user interface updates, along with a client-side model-view architecture to allow for mirrored data and views. I am currently implementing adaptive display techniques.

We are developing a markup language for authoring interactive cognitive aids called checkML. It allows the specification of semantic structuring (lists, blocks, and relatedness between information elements), interactivity (timers) and visual styling (emphasis, block sizing and flow).

LABORATORY EXPERIMENTS

There are several laboratory experiments in the works. The first focuses on evaluating the effectiveness of the system regarding its attention-saving properties. We are developing a set of ten medical tasks to be performed in a medical simulator, each of which takes five minutes to perform. For example, a task may be to diagnosis a rare event relating to an allergic reaction to the anesthetic, or to successfully defibrillate a child-sized mannequin patient. Medical students will be trained on the system and evaluated on how effectively they can absorb the related information and select the appropriate aid, as well as take action.

Another addresses the sociotechincal aspects of action-oriented interfaces which dynamically cue doctors to take action. I hypothesize that a human-mediated cueing system, where a computer prompts a nurse or medical student to cue another medical doctor, will be more readily accepted than a direct computer-human cue.

Conclusion

This work addresses an underserved need in medicine: developing software systems for real-time information needs in fast-paced, multi-user crises where interaction times are at a premium. It aims to expand the understanding of attention-sensitive user interfaces to this new class of tasks, developing display and interaction techniques for managing the limited resources of pixels and human attention. Based on process of design and observation, the system was evaluated in simulation and will be further explored through controlled experiments to tease out the theories that undergird the development of dynamic operating documents.

ACKNOWLEDGMENTS

Thanks to my co-advisers, Stu Card and Pat Hanrahan. Jesse Cirimele is the other PhD student working on the project, with a focus on the effect of large displays on shared mental models. Scott Klemmer, along with doctors Larry Chu and Kyle Harrison serve to guide the project, and with my co-advisers form the reading committee who approved this PhD thesis project. Dr. David Gaba also served to advise and steer the project. Undergraduates Katherine Chen and Kyle M. Barrett helped the initial design process, with input from Sara Goldhaber-Fiebert and Wendy Mackay on design. Thanks to the Stanford DARE fellowship for supporting the completion of my thesis research.

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