Context Sensitive Health Informatics: Many Places, Many Users, Many Contexts, Many Uses
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Safer Design - Composable EHRs and Mechanisms for Safety

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Abstract. As the deployment of health information technology progresses, issues of usability and safety, including the possibility of technology-induced errors have come to the fore. Increased complexity of care delivery models and emergent conditions such as the Ebola scare in the US point to the difficulty of design that allows for human cognitive limits while meeting complex needs. We previously described a modular composable approach to health information systems, which gives the end-user some control of design and allows for creation of systems meeting myriad and varied needs. Here we discuss how the different drag/drop interaction paradigm has implications for health IT safety via several mechanisms. These include display fragmentation and the need to changeably prioritize information elements, interruptions, fit to tasks and contexts, and rapid changeability allowing low-cost readjustments when lack of fit is found.

Keywords. User-configurable EHR, user-composable EHR EMR, electronic health record, MedWISE, human-computer interaction, cognitive support.

Introduction

Healthcare information technology (‘health IT’) and electronic health records (EHRs) have great promise to improve care, reduce costs, and create a ‘learning healthcare system’ in which continuous improvement is possible by using data to analyze which treatments are most effective. However optimal interaction design of such software has proven difficult, with potential for health IT to itself introduce safety concerns.

The US Institute of Medicine 2011 report [1] identifies several concerns related to fragmented displays and the conventional interaction approach in which information location is fixed by the programmer and users navigate through menus. These concerns include mismatch between programmer assumptions and actual work environment, and mismatch between developer and clinician backgrounds, resulting in unmet needs. Current displays may not reflect clinical associations, presenting related data separately. Activities are treated as belonging to individual clinicians, instead of to a sociotechnical system with many intercommunicating components and unpredictable ways [1]. Inflexible order sequences may require providers to hold orders in mind while navigating, and time spent on cumbersome data retrieval and remodeling is time taken from other clinical demands [1]. Middleton et al. and others [2] note that a source of potential error is the mismatch between the user’s model of the task/outcome and what actually happens[3, 4]. In a recent study of 147 malpractice claims arising from health IT at one of the most experienced institutions, 9% were caused by ‘failure of

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system design to meet the need'. Half the total claims resulted in severe injury [5]. Display fragmentation is a major problem [6]. Prior work shows conventional EHRs have a roughly six-fold greater number of clicks and screen transitions required to view complete information [7], than composable approaches for the same cases. Conversely, appropriate information juxtaposition can foster insight, creativity, sensemaking, and problem solving [8-11].

Lack of fit to task is also a problem and can take many forms; here we are primarily concerned with specialty and contextual differences in information needs and interface design. Extensive logfile analysis shows those in different specialties and roles use hundreds of different sets of paths through conventional systems [12]. Design needs vary heavily according to context [2].

Interruptions in clinical EHR work can have serious consequences; Collins et al. found that in a 2-hour CPOE session in a MICU interruptions occurred on an average of every 5 minutes and preceded 2 errors [13]. Alvarez and Coeira found interruptions approached 30% of clinical communication [14].

Understanding and solving these problems to create truly safe and usable health IT requires careful study of cognition and efficiency effects of current interaction design coupled with imaginative software redesign, and testing. In order to understand and improve this 'cognitive ergonomics' using distributed cognition theory we consider a novel approach and system, in which the end user can assemble needed information elements by drag/drop. We have termed this the 'composable approach'. This allows testing of the above phenomena, rapid prototyping and re-testing.

The composable approach itself can have safety advantages. The flexible software paradigm in which nonprogrammers can rapidly change then lock the system, means unsafe designs can be changed in seconds, vastly reducing risk exposure time. We believe this overarching design principle may have major effects for health IT safety.

1. The Composable Paradigm and System Description

The new paradigm we proposed is briefly described in [18]. Giving nonprogrammer clinician users the ability to assemble EHR information via drag/drop and create tools and interfaces has advantages for technology fit to task and user, and is the ultimate 'user-centred' approach. By capitalizing on clinician deep domain (medical) knowledge, it seeks to improve technology fit to task, accommodate rapid change, evolve with user needs, and address some aspects of poor usability.

MedWISE (Medical Widget-based Information Sharing Environment) is an example electronic health record (EHR) platform built to exemplify the composable approach [18]. It has a modular composable architecture that provides a drag-drop platform for users to create and share their own resources, tools, and social networking, in combination with some automation. Users can assemble any desired elements from any part of the clinical information system together on the same screen, at any time before or during case review. The user can rearrange items in seconds as his/her thinking about the case changes. Some input can also use composition. These features (analogous to providing building blocks for the user to arrange) and sharing capability are also intended to facilitate 'produsage', i.e. the eventual creation of a large set of user-created resources and tools adapted to user needs and different contexts. MedWISE architecture and some aspects of performance are described in [16,22]. Two relevant concepts emerge from the theory of distributed cognition: a) the division of resources internal or external to the user (i.e. kept in the users' minds or on screen) is important for system usability; the more externalization, the greater the usability[23, 24]. b) cognition should be thought of as occurring across the entire system of humans, artefacts, computers, etc., and not something that only occurs within individuals[21]. The composable approach constitutes a different interaction mode, with different effects, mechanisms and safety implications, described in section 2.

2. Safety Threats Arising From Conventional Interaction Modes and Composable Approaches to Address Them

2.1. Cognitive Load Imposed by Screen Switching

Conventional systems fragment the display of needed information by locating different types on different screens (for example, lab results, orders, and notes are usually found in different parts of the EHR and cannot be displayed together). This requires that the user click around and view multiple screens, retain relevant information in memory, (or write it down) then integrate it in mind. This imposes cognitive load (load on working memory) [1]. Often users must re-view information because they forget it [17,29]. By contrast, the composable approach allows drag/drop assembly of all information the user considers relevant on the same screen, avoiding screen switching and thus the associated cognitive load[16,17].. Our early work gives several indirect indications that composable approaches decrease cognitive load [17]. These are: significantly decreased repetitious navigation, user self-report that cognition is easier, lack of need to use supplementary tools to jot down data, fewer clicks and steps required, and greater externalization of representations. It is well established that human cognitive resources (perception, attention and memory) are finite [25]. If the task of finding and integrating information overloads these resources, fewer resources are available for the essential tasks of diagnosis and treatment. The safety implication is that inability to see everything relevant together may result in failure to integrate important facts into decision-making.

2.2. Composable Approaches Can Be Used to Create Patient-specific Displays

In conventional systems each clinician treating the same patient has to search for information in different pages and integrate them in his/her mind. By contrast, with the composable system only the first team member has to do this; then the patient-specific summary can simply be shared among team members and updated with a few actions. This means that it can serve as a 'common ground' display for clinical communication [26, 27]. Beyond templates, these patient-specific displays can exactly summarize the patient condition by including all the relevant elements and excluding those not important for this particular patient. This has a safety and efficiency consequence. It has been shown that when it takes too long to locate information, time-pressed clinicians may give up searching, or reorder tests. Thus for borderline cases diagnoses may be missed due to inability to find existing information.

2.3. Interruptions, Nonlinear Workflow, and 'Wrong Patient' Errors

Interruptions are common in healthcare work and constitute an avenue for potential major errors such as wrong patient errors, particularly if several people share computers, or where system state is not preserved during automated logouts. Ability to create patient-specific displays could mitigate the effects of interruptions/multitasking, since the user can return to the display without the need to re-search elements. The user returning from an interruption comes back to a (partially completed) patient-specific display and can simply continue at the point at which he/she left off. The existing display will also help to mentally reorient the clinician.

Moreover, object arrangement is frequently used by workers to track stages in a process and allow quick reorientation after interruptions [28]. We found this use among clinicians in our preliminary studies [16]. For example, one user stacked up all the labs to review on the left, opened and compared them to the note juxtaposed on screen, then moved them all to a right-hand column when finished with them. This is a typical use of movable components to track a process [28]. As much clinical work involves nonlinear workflow in which users care for multiple patients simultaneously, the patient-specific display contained on a single tab allows switching between records with no need to re-find information, nor remember or re-do what was done previously. Distinctive patient displays (perhaps aided by deliberate safety design patterns such as different backgrounds, photos etc.) can be a tool to address the 'wrong patient' risk.

2.4. Lack of Fit to Task

The ability to select and arrange elements and create shareable templates could increase fit to task, so that different specialties or professions could design their own displays for specific purposes/contexts. Testing and redesign can be done in minutes.

Information availability and prominence are particularly important in emergent circumstances, as was amply demonstrated in the 2014 US Ebola case in which an infected patient was improperly not admitted to hospital. This was despite the fact that his travel history was, collected by the nurse and subsequently available (in the EHR) to the doctor. In such cases it is useful to be able to bring to the surface, mark (e.g. by coloring headers) and display any elements prominently, without programmer intervention. This is easily changeable as the situation progresses (as happens with changing public health emergencies).

2.5. Cognitive Support

Composable approach capabilities can provide cognitive support, allowing juxtaposition of related elements together, rearrangement as thinking about a case changes, marking of important elements, arrangement in order of importance to diagnosis, or communicating one's thinking to others. Matching interface to task can allow more exact representation matching and greater externalization of information, (e.g., a user could place problems in order of importance instead of keeping this order in memory), reducing cognitive load, as per distributed cognition theory. See [16, 29] for further description of how they were used in prior work. Checklist effects are possible if clinicians create templates with all required information for particular contexts. Users state that the mere presence of such collections serves as a reminder, fostering complete information review [29].

2.6. Extensibility and Vetting

Public internet applications are highly usable because of a history of extensive research designed to foster smooth commercial shopping experiences for the widest possible range of users. Its ethos of free code sharing has meant web developers can leverage design patterns developed for one use, for many others. Web-based composable approaches allow for similar leveraging of public design patterns, with independent code environments for each widget. New safer visualizations or interaction modes could be rapidly incorporated. Examples are list selection including multimodal confirmation, or visually specifying lesion location. As with free or open source software, the 'many eyes' vetting of interfaces by colleagues can correct omissions.

3. Summary of Risks in Conventional and Composable Interaction Approaches.

Conventional approaches in which information locations are fixed impose certain risks in comparison to a composable approach in which all relevant information could be gathered together. These risks are: a) the user must search for each type of element at each session, and risks not finding them, possibly leading to omissions, b) the user must keep information in working memory between screens, engage in back and forth navigation, and therefore risks forgetting or omissions; c) more time may be taken, increasing stress, d) the user may not know what the previous colleague saw, nor whether a colleague's information review was complete; e) items which should be located together (e.g. systolic and diastolic blood pressure) may not be; and the user cannot force this juxtaposition. f) checklist effects possible with composable approaches are not possible in conventional approaches. Composable EHR risks include: a) error-causing omissions by a user designing a page, and b) sharing of the omission without detection propagating the errors (Dx momentum), c) cognitive load could increase for one user using an unfamiliar template designed by another. See Table 1. There is further discussion about comparative risks in the two systems, and comparative accuracy findings, in [29].

Table 1. Partial list of potential risks in conventional and composable approaches.

Conventional EHR risks	Composable EHR risks
a. Omission by user in search, → error	a.Omission by user → error
b. Cognitive load due to need to retain items in Working Memory	b.Shared omission →Dx momentum error?
	c.Cognitive load due to different interfaces
d. User viewing patterns hard to view	
e. Possible lack of fit to patient case, specialty, role	
f. No checklist	
Hard to change as per situation -->potential error?	

4. Conclusion

Safer design of electronic health records requires methods to address the human-computer interaction risks in our current conventional systems. Consideration of composable approaches may provide ways to address these risks, by decreasing display fragmentation, increasing fit to task, providing cognitive support, and allowing for rapid readjustment by nonprogrammers when suboptimal arrangements are found.

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