

# The clinician in the Driver's Seat: Part 1 – A drag/drop user-composable electronic health record platform



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## ABSTRACT

Creating electronic health records that support the uniquely complex and varied needs of healthcare presents formidable challenges. To address some of these challenges we created a new model for healthcare information systems, embodied in MedWISE, a widget-based highly configurable electronic health record (EHR) platform. Founded on the idea that providing clinician users with greater control of the EHR may result in greater fit to user needs and preferences, MedWISE allows drag/drop user configurations and the sharing of user-created elements such as custom laboratory result panels and user-created interface tabs.

After reviewing the current state of EHR configurability, we describe the philosophical, theoretical and practical rationales for our model, and the specific functionality of MedWISE. The alternative approach may have several advantages for human–computer interaction, efficiency, cognition, and fit of EHR tools to different contexts and tasks. We discuss potential issues raised by this approach.

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## 1. Introduction

Developing systems that best fit the needs of healthcare is a complex endeavor. Although decades of research have focused on defining requirements for systems that support clinicians and their tasks, studies suggest that healthcare information systems often fail to support effective and efficient clinical decision making and completion of relevant tasks [1,2]. Systems may fail to take into consideration the significant variability of medical information needs that differ according to context, specialty, role, individual patient, and institution. They may also fail to address the highly collaborative nature of the work, and challenges of addressing rapidly changing or emergent needs. User control of modular user-composable systems has promise for addressing these issues [3].

*Abbreviations:* MedWISE, medical widget-based information sharing environment; HCI, human–computer interaction; NYP, New York Presbyterian Hospital; CIS, clinical information system.

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<sup>2</sup> Medical widget-based information sharing environment.

This approach involves supplementing automation by letting the nonprogrammer clinician user create and share systems (including patient-specific displays) by assembling information elements from multiple sources on screen via drag/drop actions. They can also share their creations (individual widgets or interface tabs or templates) with a click, making them available to colleagues or to all clinicians in a setting.

We expect three main advantages of this approach. First, the ability to move and assemble elements together on the same page has several desirable properties that can impact the cognitive efficiency and efficacy of coordinated interaction with an electronic health record (EHR) system. To substantiate this claim, we draw on theory from human computer interaction (HCI) and the theory of distributed cognition [4]. Second, we anticipate that clinicians can create a system that affords them the capability to solve problems and that better fits the tasks that they are required to perform. The premise is that by providing a set of building blocks that the user assembles to create novel elements and structures, we can leverage the fact that clinician data users have greater medical, contextual and tacit knowledge than do programmers. Their creations may also be more congruent with their mental models of the patients or the tasks. Third, the features that enable sharing may be used to facilitate communication/collaboration and ‘production’, which refers to the construction of a large set of user-created

**Table 1**  
Configurability of current EHRs.

Feature or function and description	EHR examples
Order sets; allow user to select combinations of orders, stored and selected as desired or with specific conditions	Many
Documentation; wizards [13], note views [14,15], summaries, choice of layouts with varying screen information density [14]	eClinicalWorks, Allscripts, Epic
Expandable panels, dot phrases; for fast insertion of user-specified text phrases using an abbreviation [15,16]	Epic, Greenway
Problem list sorting by various categories, e.g. active problems, social history, specialty [14]	Allscripts
Adaptive learning selection lists [14]	Allscripts
Drag/drop appointment schedulers [16]	Greenway, others
Modifiable templates with automatic information import and user-definable norms [17,18]	Acrendo, Versasuite
Customizable meaningful use measures	Most EHRs
Crowdsourced decision support rules authoring [19]	Epic
Forms-based user specification of system generation [20,21]	iCIMS products
Draggable widgets for interface flexibility [22,23]	MIWeb, Medcafe

resources and tools adapted to specific user needs and different contexts.<sup>3</sup>

The purpose of this paper is to describe this novel approach to EHRs, as embodied by our system, MedWISE. We briefly state the theoretical rationale that supports this innovation. However, the primary purpose of this paper is to allow readers to understand the system's capabilities. Empirical studies of users engaging with the system are reported in other papers [6–9]. The conceptual model is covered in more depth in [3]. As background, we describe problems and user configurability in current EHRs, followed by concepts from theory and research in cognition and HCI. These suggest the relative value in this kind of approach. We then discuss our rationale, and describe the system.

## 2. Background

### 2.1. Challenges with current systems

Many current systems offer limited end-user configurability and require skilled programmers to make significant changes. At the individual level, the majority of EHRs requires the user to adapt to the program. However, the interface may not reflect how clinicians think about patient problems, and this may result in a workflow that is not optimally tuned for patient care. Communication and collaboration needs are also frequently not met because systems are designed solely for an individual's linear workflow without the ability to share or to leverage features that support collaboration [1,2]. Accessing large amounts of information via finite screen space necessitates negotiating multiple screens. In addition, the organization of information on a cluttered or poorly organized display may create a burden on limited human cognitive resources [10]. Furthermore, most systems lack the agility required for rapid adaptability to emergent conditions. Integration of multiple information sources may be difficult. Even minor modification or customization of EHRs can be delayed by vendor- and programmer-controlled development processes that require consensus, time, extra cost, and often vendor agreement. Overall, the current approach does not leverage user expertise or provide users with creative potential solutions to clinical technology problems based on their understanding of patient problems. It also sometimes fails to accommodate the complexity of health care and the changes occurring in this sector, which continue apace.

<sup>3</sup> Prodsusage has been defined by Alan Bruns as collaborative and continuous building and extending of existing content in pursuit of further improvement, by creation of shared content in a networked, participatory environment, in a way that breaks boundaries between consumers and producers [5] Bruns. Prodsusage, 2009. All participants are users and producers, (hence "produser"). Usage is necessarily also productive, as the participant's very patterns of *usage* become direct inputs. An example is Amazon recommendations based on aggregated user browsing and purchasing actions.

Giving users greater control of a modular system could potentially address some of these problems, and EHR approaches are evolving to that end. However, current EHRs generally permit user participation and control of configuration and display only in limited areas as determined by the vendor [11]. User-configurable order sets are a well-known example [12], and permit users to select combinations of orders to be stored and selected as desired, or as associated with specific patient conditions. Current EHR user-customizable features are summarized in Table 1.

Overall, most current EHRs require the user to negotiate multiple screens in the course of obtaining information sufficient for the diagnosis and treatment process. Their configuration features are usually form-based, sometimes requiring the user to learn forms navigation, and move away from the usual EHR screens in a separate workflow, or even a separate program. In general, they do not employ a direct-manipulation interaction approach. Most allow the user only partial control of certain categories of information.

### 2.2. Rationale for a different approach

In recent years, there have been a growing number of resources, tools and applications that facilitate user control of the computing experience. Modern approaches in the public internet space emphasize the creation of platforms for user-directed remixing of snippets of information from multiple sources, mashups, and interactive visualizations. They also employ social networking, aggregation of user-created resources in new useful ways, and crowdsourcing. These approaches accentuate user participation and control more than the typical highly directed and circumscribed applications to which users must adapt. Metadesign is one of the core concepts underlying our approach. Fisher describes it as follows:

Meta-design extends the traditional notion of system design ... to include an ongoing process in which stakeholders become co-designers—... throughout the whole existence of the system. A necessary ... condition for users to become co-designers is that software systems include advanced features that permit users to create complex customizations and extensions. ... broad participation in design activities (in both design time and use time) is as important as creating the artifact itself. [24]

### 2.3. Human-computer interaction and EHR research

The recently enacted Health Information Technology for Economic and Clinical Health Act (HITECH) has served to dramatically increase the number of EHR implementations and this has revealed the extent to which usability problems impede adoption and diminish the user experience [25–27]. Studies of HCI in EHRs have focused on providing cognitive support [28], particularly on interactive information visualizations such as timelines. Incorporating sufficiently flexible interaction into the highly varied institutional

and clinical specialty workflows has been recognized as a particular problem:

[There is]... no shortage in theories and principles related to the effective display of information in multiple contexts. ...The difficulty appears to be in applying these principles with specificity within the complex clinical environment. Alignment of information displays ...with physician cognition, workflows, and decision making in particular is an aspect of EHR design often cited as lacking in the current product market [25].

Most work has focused on specific tasks such as decision support [29], ordering, medication reconciliation [30], interactive data visualization and exploration via timelines [30–32], workflow, and automated summarization [32]. For example, Plaisant et al. developed a novel interactive visualization for medication reconciliation [33].

**Cognitive load** is an expression referring to the burden on working memory imposed by a task, system or environment [34,35]. Cognitive load is increased when the presentation format on a display does not match task requirements or workflow. Increased load also results from having to manually integrate information from diverse resources [36].

**The keyhole effect** describes a common problem in human-computer interaction when trying to access a large amount of information via a small screen, as if viewing a large room through a keyhole [37]. In conventional systems, this usually necessitates viewing multiple screens, since each screen has only part of the required information.

The most common approach for software development is modeling the task and then designing software to carry it out according to the model. This approach tries to identify common use cases and create software that meets those needs by specifying a series of steps the user must take based on the task model. Models assume that there are classes of commonality, e.g. in information content or task structure, which can be ascertained before system use. Although this is not an unreasonable assumption, the variability of patient care, including factors associated with the individual patient condition and exigencies of context (e.g. time and resource scarcity in emergencies), may mean that there are new needs that cannot be covered or anticipated by any particular class. The cost and difficulty of attempting to ascertain and model every task and variation in advance is likely to be prohibitive.

Metadesign is based on the premise that there are benefits to allowing the user, who is aware of the context, to determine some software features at runtime.<sup>4</sup> Allowing user control might also result in a set of software resources adapted to the actual tasks and contexts at hand, in a way that is not possible when this is done in advance by programmers lacking in medical expertise. For example, five patients in a given clinical unit at any one time may have the same condition, require the same investigative measures, and necessitate similar drug regimens. In this scenario the creation of a template could greatly simplify the work process. Although templates are extremely useful, they are limited in their expressiveness. For example, one of the patients may also have an unrelated condition and be on additional drugs that could conflict with his/her present treatment, requiring different interventions and monitoring. The concept of metadesign means greater flexibility and customizability that goes well beyond templates.

The assertions regarding the limitations caused by HCI problems are substantiated by research findings. Weir et al. found that the number of EHR screen transitions affected the preparation and control of the visit, and concluded that

“information relevant to a patient encounter is scattered throughout the EHR. Providers spend significant time organizing information in the EHR, either by searching and sifting or by constructing pre-documents [...]. The VA’s EHR and most others available today do little to help providers collect and organize pertinent information. These findings imply that utilities built into the EHR to help organize information [...]are likely to improve healthcare processes.” [38].

Horsky demonstrated that the absence of a relevant set of external representations (as expressed on the display) can increase cognitive load and exacerbate usability problems [39]. Stagers found that nurses eschew computerized handoff tools because they are not flexible enough for their needs, preferring to produce paper ‘brains’ of their own design, that summarize the patient condition and are updated throughout the day. A HIMSS’ study of usability “pain points” based on a survey of 106 clinicians, identified workflow, data integration, and data presentation as top pain points in EHR usability [40]. Comparative studies show that including all relevant information on one screen is associated with greater efficiency without decreasing accuracy [41,42].

Concepts from formal theory and research on cognition and interaction reveal deeper reasons why the new functionality in MedWISE (e.g. drag/drop ability to assemble elements on screen) could have advantages. We briefly describe these here with a view to characterize how these features may facilitate performance on clinical tasks.

### 3. Theoretical bases for MedWISE interaction

The basic task in clinical case appraisal involves assembling and considering multiple pieces of information. The use of any complex system such as an EHR necessitates that the user divide his or her attention between negotiating the system (e.g., navigating to the needed screen) and performing the task at hand (e.g., characterizing the patient problem) [10,43]. MedWISE aims to provide a physical manipulable platform that can more closely approximate the clinician’s cognitive processes. It aims to reduce the effort necessary for negotiating interfaces so that more cognitive resources can be put towards thinking about the patient problem.

In the next sections, we discuss the conceptual basis for MedWISE functionality. This is grounded in theories such as distributed cognition, and concepts derived from the literature on work, HCI, and modern web techniques, such as produsage [4,43–46].

#### 3.1. Produsage

The practice of produsage, involving the creation of shared content in a networked, participatory environment, is effective when it is easy and appealing for a wide range of users to participate. Hence the simple drag/drop, single-click configuration and sharing features involving screen ‘objects’, incorporated into the normal EHR workflow, were designed to facilitate easy use, acceptance, and ideally, appeal to busy clinicians.

#### 3.2. Distributed cognition

Distributed cognition is a theory in which the boundaries of cognition are stretched across technologies, artifacts and other humans [4]. It is one of a family of theories including, situated action [47] activity theory [48] and enactive and embodied cognition [49]. Although the theories differ in certain respects including their historical origins and domains of application, they all share the intent to extend the locus of cognition beyond the solitary individual and situate it in the social and technological world. The theory of distributed cognition has been widely used in informatics

<sup>4</sup> Spreadsheets are an example of software involving metadesign; the end user does the final configuration.

research [4,10,43] and provides an appropriate theoretical lens to characterize the ways in which various kinds of artifacts serve to differentially mediate creativity and cognition.

Distributed cognition theory states that work takes place across a network of human actors and artifacts that can be considered a primary unit of analysis [4]. A representational state is a particular configuration of an information-bearing element, such as monitor display or written document that has a role in a work process. Representational states are propagated across media and agents to coordinate task performance in the workplace [50]. Fig. 1a has an example. In addition, because humans have limited cognitive resources (perception, attention, and memory) the division of information resources internal to the human actor or external is significant for system usability [39,51]. Externalizing resources, for example, by making them available on a visual display, can serve to reduce the burden on working memory. The more relevant information that is externalized (up to a reasonable limit), the fewer cognitive resources the user must employ to retain information and the more resources are available for higher cognitive functions such as diagnostic reasoning [51].

3.3. Matching users' thinking

Ability to compose displays allows the user to create his/her own representations by creating, selecting, arranging, marking

and sharing desired elements. This enables the user to create a representation that matches his/her mental representation of the case more precisely, and thus facilitate task performance. For example, the ability to order elements in the screen corresponding to their priority for treatment, or their importance to the diagnostic process, is a more informative representation than a random or alphabetized order such as is found in many conventional EHRs. See Fig. 1b. The ability to visually categorize elements (e.g., by assigning them the same header color and placing them together) can allow the user to communicate to colleagues his or her thinking about how the case evidence, diagnostic tools, or other information should be used in treatment and/or considered in diagnosis. Sharing a complete externalized view could facilitate rapid comprehension and subsequently save search time for colleagues.

3.4. Intelligent uses of space

Kirsh studied how workers' restructure their work environment by arranging objects. He classifies intelligent uses of space into three main categories: arrangements that simplify choice, arrangements that simplify perception (such as calling attention to a group of items e.g. radiology studies), and spatial dynamics that simplify computation (such as juxtaposition aiding calculation of clinical ratios) [52]. He found that experts constantly rearrange items to

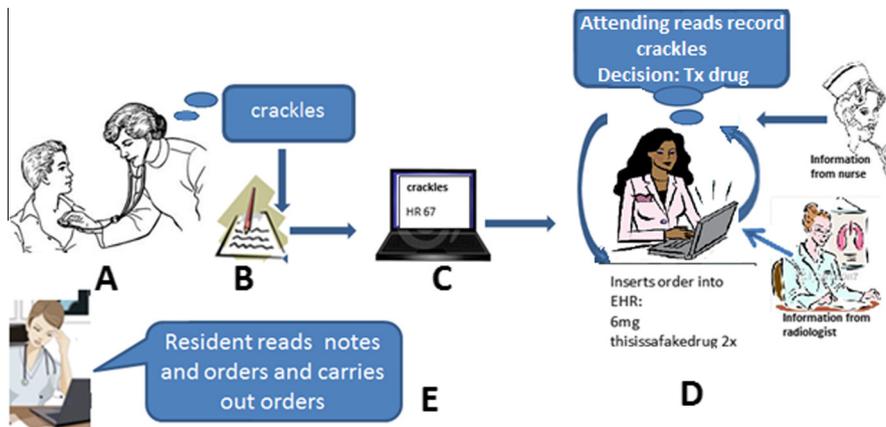


Fig. 1a. Example of distributed cognition: (A) A doctor examines the patient and retains some information in memory until the end of the exam, when she (B) copies it to paper, and then (C) to a computer. (D) The attending reads the data, integrates it with other information including the nurse's phone call and radiology images, decides on treatment, and enters orders into the computer. (E) A resident reads and carries out the orders. The representations and actions take place across multiple persons and tools, including the computers.



Fig. 1b. Intelligent uses of space. Movable objects means the clinician can arrange the system to reflect his/her concepts and priorities about the case. Here the clinician is thinking of the problems in a particular order, and can arrange the screen to show the problem list in the same order. In the left diagram, the user arranges the problem list on screen in the same order she thinks of it in mind. This means that once this is done she need not retain it in memory, thereby offloading cognition (see right panel). It is well established in cognitive science that human cognitive resources (perception, attention, memory) are limited. Thus, reducing memory tasks can free resources for other activities such as clinical reasoning. Humans often use externalization to aid their work (e.g., writing things down on paper when it is too difficult to retain them all in mind) and this exemplifies that principle.

track the task state, assist in memory or understanding, predict effects of actions, and so on. Restructuring often serves a cognitive function: it can reduce the cost of visual search, make it easier to notice, identify and remember items, and simplify task representation (see Fig. 1b for an example of how the user can arrange problem list items in the same order of priority on screen as she thinks of them. This means the user need not retain that order in mind, since it is available externally. This is one of the ‘intelligent uses of space’).

### 3.5. Interaction and representation

Researchers have studied related interaction and representation effects. Zhang found that depending on their form, external representations do not merely provide affordances for offloading short-term memory, but also constrain, guide and determine cognitive behavior in the context of problem solving [53]. Kerne et al. conducted extensive studies demonstrating that the ability to arrange and juxtapose information objects can facilitate brainstorming, insight, creativity, and knowledge acquisition [54–57]. Kirsh and Maglio et al. studied ‘**epistemic action**’, which they define as actions that are not required as part of the goal task but which provide an advantage for intermediate mental processing [58]. An example of epistemic action would be a customer creating a table to compare cell phone brands and features before buying, and juxtaposing valued criteria (e.g., price) to make the brand comparison easier. The simple act of juxtaposing to create a more usable representation can minimize visual search and significantly reduce cognitive load. Examples of how spatial arrangement might assist in case review include clustering like items or items pertaining to a diagnostic facet, or ordering items according to treatment priority.

To summarize, a system that exemplifies these ideas may facilitate distributed cognition in several ways:

1. Representations may be constructed to better fit the case.
2. A system that can be modified in seconds can change accordingly as the user’s thinking or the patient’s condition changes.
3. It decreases the need for working memory needed to manage multiple screens, thus potentially decreasing cognitive load and repeat navigation [59].
4. More aspects of the patient problem representation can be externalized, thus further decreasing cognitive load.
5. Providing a ‘common ground’ display for communication might facilitate transfer of representations among colleagues.

We will now describe our system, MedWISE, which embodies these theoretical concepts. Studies of users interacting with the system are described elsewhere [6,7,9,59].

## 4. MedWISE capabilities and system description

### 4.1. Scope and rationale

MedWISE is an illustrative EHR platform built to realize a model for a healthcare information system that incorporates metadesign and draws on the theory of intelligent uses of space. It attempts to accommodate the immense variability of healthcare information needs and the need to assemble information from multiple sources. In the past, advanced programming skills were required to create new configurations (such as the patient-specific displays described above). Our aim is to provide a simplifying technology that will allow nonprogrammer users to do so within certain constraints. This is analogous to the way in which word processors allow anyone to produce complex documents, or how graphical browsers allow everyone to use the Internet. It is beyond the scope

of this paper to elaborate on the model. The model is described in [3] and the system architecture is described in [60].

This approach differs from the traditional approach in several ways: First, it is a general approach to EHR interaction rather than one that is narrowly focused on a single task such as medication reconciliation. Second, it is based on a modular composable architecture that supplements automated interfaces by providing a drag-drop platform for users to create and share their own resources and tools. Third, it allows social networking, including sharing of user-created elements. Direct manipulation and ongoing clinician involvement are prominent features of MedWISE.

### 4.2. System description

The MedWISE core novel functionalities are listed in Table 2. These basic features are used compositionally (assembled like building blocks in theoretically infinite ways) to meet user needs in a specific situation. As a consequence, basic features can be combined and repurposed to support multiple functions. Table 2 has descriptions including composed uses, their purposes and their expected advantages.

The core functionalities include the ability to select any EHR information elements, or create new ones via special mashup tools, and mark them (for example, by coloring the header), gather them on the same screen, arrange them spatially into a multi-column ‘tab’ (screen interface), and share created elements or interfaces with colleagues. Information is included in draggable blocks, or ‘widgets’, that have editable titles, and can be collapsed to show only the header line, or alternatively expanded to full screen. External materials such as RSS feeds from medical journals or other sources can also be included. ‘Sticky notes’ (text blocks) can be added anywhere, and users can plot any desired laboratory results together on the same axes, as well as create custom lab panels; both of these can be shared.

Users can also set an assembled screen as a template, in which case the laboratory results will automatically update. This template can be applied to other patient records.

In summary, the ability to select or create information elements allows increased presence of relevant items on screen, thereby decreasing the keyhole effect and reducing screen transitions. In addition, this leads to increased externalization of the information the user has to consider, facilitating distributed cognition. The ability to spatially arrange elements allows the user to create a representation that better fits the user’s internal mental representations and/or the external features of the task, such as problem priorities or diagnostic categories, making use of the ‘intelligent uses of space’. The sharing features allow produsage, the eventual creation of a large set of customized tools better fitted to the work context. In addition, it might facilitate the development of ‘common ground’ for communication, by employing the visual space as a means of explicitly communicating intent with colleagues (e.g., items are grouped together for a reason or may signal the need for closer scrutiny).

MedWISE was built as an illustrative system to test the new user-composable widget approach. To ensure that it is only the new features are being tested, the MedWISE information menus match those of WebCIS [61], an EHR used at New York Presbyterian Hospital (NYP), with which all clinicians at the institution were familiar. WebCIS users click on links in a left-hand menu to view individual laboratory panels, notes, and study (e.g. X-ray) reports, which appear one at a time in the right-hand pane. Users usually start with a recent note to obtain an overview. Reichert et al. provide a detailed illustration of WebCIS use [62]. The left-hand menu links in MedWISE are the same as those in the usual WebCIS system; thus the usual WebCIS interface is simultaneously available

**Table 2**  
MedWISE basic features, related theory, coding and relationship to care process.

Feature/functionality/mechanism (Theory concepts)	Codes/behavior it facilitates	Example relationship to Diagnostic/care process
Gather and spatially arrange any information elements from the EHR together on the same page, by click and drag. [CL,E]	Identify information sources, arrange display elements to support prioritization, juxtaposition, data examination, exploration, explanation, hypothesis evaluation, discrepancy processing, assign regions for particular purposes	Make relationships between variables, order according to diagnostic or treatment importance or relevance, communicate significance to self or colleagues, assist thinking, store data
Make and share custom lab panels from any user-selected labs; and likewise, share user-created tabs (page interfaces) containing collections of notes, lab panels, plots, RSS feeds, or other information. Creators are identified in the list from which one imports an element, so users may choose on the basis of their informal knowledge of the authors, such as their specialty or expertise level. (DC,P)	Create display more exactly fitted to patient case or general needs, share this with colleagues, facilitate data examination, exploration, and discrepancy processing	Display all elements to patient case on one screen, facilitating thinking and decision-making without need to navigate, speeding process
Set a tab containing user-gathered elements as a template so that labs in the page are automatically updated as new information becomes available. (P,communication/collaboration)	Automatic information updates, standardization	Facilitate rapid & up to date case review in subsequent sessions, standardize process across sessions, patients and clinicians, communicate with colleagues
Create multi-axis plots of any desired types of lab test values together on the same plot (a mashup) encompassing all available patient data; pan, and zoom from a years-long scale to minutes/seconds .	Data examination, exploration and summarization, discrepancy processing	Facilitate decision making
Collapse/expand widgets and edit header colors and titles, and view widgets full-screen. (IS (marking, grouping, perception, choice...))	Data identification, examination, exploration, marking, grouping according to topic or relevance, increasing perceptibility, summarization, data storage	Facilitate reading notes or full-text journal articles, speed case review and decision making
Stickynote - click inserts a 'stickynote' that allows insertion of text into the interface. Customizable background and header color	Allows user to write notes or anything else desired in a widget	Combination of user-created text with other information on same screen
RSS feed widget - in a multistep process user can set up RSS feeds to appear in a widget	Inclusion of self-updating (therefore current) information (e.g. standing Medline search results) in a widely used format, and drill-down to full text journals in the interface	Facilitating EBM/guidelines, alerting, etc. Any RSS feed allowed. Inclusion of diverse external information sources
Mouseover preview of lab results - mouseover of the left lab menu link gives a preview of the lab panel	Allows user to preview widgets before inserting them into the tab, facilitates selection and mitigates the need to take action to remove unwanted widgets	Decreases unnecessary actions in widget selection and placement; rapid information overview

DC = distributed cognition, K = Keyhole effect, E = epistemic action, CL = cognitive load, IS = intelligent uses of space, P = produsage.

during MedWISE use (see Fig. 2 caption). In MedWISE, clicking on a link in the left-hand menu puts the element into the MedWISE interface as a single widget, so that as the user continues clicking on different items they are gathered together in the large right-hand pane. Clicking on the icon next to the link makes items visible in the right pane one at a time, WebCIS-style. MedWISE interfaces are saved by default. Thus, 'creating an interface' in MedWISE is not a separate activity from using MedWISE for case assessment. Since the links for MedWISE and WebCIS are adjacent in the same menu structure, merely gathering the widgets in MedWISE requires the same number of clicks as viewing the same items in WebCIS. Saving them as self-updating template requires two more clicks. Fig. 4 compares the interaction style of the two systems.

Fig. 4 illustrates the fundamental interaction differences between conventional systems (here WebCIS) in which information location is fixed, and the composable approach. Diagrams should be read in the numbered order.

In the conventional interaction, each screen has only part of the required information (keyhole effect), so the viewer must view several screens. In between screens s/he must keep information in memory (or externalize it in some way, such as by writing it down). Thus the balloons over the user's head show information being kept in memory. Successive screen views require more information to be stored in memory; then the user considers this information (clinical data) with his/her medical knowledge, decision making occurs, and note writing is done.

In the second (MedWISE) set of diagrams, the user chooses relevant information, which stays on screen, so the user does not need to retain it in memory; hence the balloons over his/her head are blank. Successive views of different information allow the user

to gather information s/he finds relevant on screen, so between screens the user does not have to keep it in memory. S/he can view all the relevant information s/he has assembled together on screen, combine it with his/her medical knowledge, and decision making, to create a note.

In the composable interaction style afforded by MedWISE, the user does not have to retain information in memory between screens. Thus information is external to the user for a greater part of the whole process. This putatively decreases cognitive load and fosters enhanced usability/distributed cognition. The ability to juxtapose information in the way the user considers useful (such as putting lab tests that must be compared next to each other) makes use of epistemic action processing. Thus the system can mitigate the problems of negotiating multiple fixed screens and the associated cognitive burdens and attentional bottlenecks.

#### 4.3. Context of use

MedWISE was built for use on ward and office desktop computers by clinicians in a large inner city tertiary care academic medical center. Many patients in this environment are seriously ill with multiple comorbidities thus requiring extensive laboratory tests and studies. This information as well as notes written by a range of clinicians (e.g., attendings, nurses, residents, and physician assistants) are available in WebCIS, a home-grown system that aggregates and displays information from dozens of clinical systems [61]. All clinicians in this institution typically have access to all patient information for all patients, and read colleagues' notes asynchronously in collaboration among care teams and in consultation with colleagues in other departments. Thus, our clinicians

**Table 3**  
Main MedWISE features, their purpose and expected advantages.

Feature or capability	Description	Purpose or tasks facilitated	Expected advantages
Drag and drop widget arrangement	Menu click inserts widget into right pane, and dragging via the header allows placement into columns on the page	User can gather and arrange any desired information spatially on screen	Greater fit to user information needs, efficiency in review, increased information relevance/space, direct manipulation interaction easy to understand and use; allows modeling, decreased cognitive load
Color widget header, edit header text	Click on icon opens header form from which user can set header color; header form allows change of text	Allows marking widgets and categorization; user can set title to more suitable one, identify custom widget contents	Emphasis, grouping, marking; user can fit header to task or emphasize, call attention to important information
Collapse/expand widget	Information may be hidden or shown as desired by clicking on header icon, leaving only header visible	Inclusion of information while hiding details, saving space, alerting user to its presence; allows storage of information until needed	Saving space, clustering like items
Custom lab panel composer	Create custom lab panels with any combination of 908 lab test results, by click/drag from a list; created panels appear on the shared custom panel list from which other users can import	Users can fit information display to their needs and preferences, e.g. creating a custom lab panel for a specific disease	Better task-technology congruence; more relevant information display/space
Multiplot mashup plot composer	Plot any number of different lab result sets on the same axes; change time scale from overview of all data; zoom and pan over the entire range	User can combine results as the case calls for, and compare and monitor trends in time or around particular events	Visibility of trends or patterns around events or in time, facilitating reasoning/decision making
Single-item lab plot	Click on lab test name during case review; interactive lab plot pops up	Rapid access to trend data during review	Speeds case review and accommodates both types of user preferences for lab view formats (trend and table)
Automatic saving of interface	User-composed interfaces (tabs) are saved by default and brought up on next login	User need not save deliberately, reducing required actions; user need not open a separate application to create or design	Mitigates the effect of interruptions, prevents work loss, saves user work/search time; creation not separate from clinical workflow so users more likely to design; creations are saved and available for future data mining/recommender systems
Shared tab	Click on share icon puts tab on shared list, with author, title and date. Others can import the tab by clicking on link	Share interfaces or templates with colleagues	Saves search and/or creation time for subsequent users, can aid common ground communication advantage, collaborative tool development
Template feature	Click makes lab widgets in the tab self-updating; template can be shared and imported for other patients	User is assured of the most up to date information without doing extra search & retrieval	Templates allow reimport and customization for other patients, reduced work, collaborative determination of what information should be shown (e.g. by a specialty or care team)
Stickynote	Click inserts a yellow 'stickynote' which allows insertion of text into the interface. Custom background/header color	Allows user to write notes or anything else desired in a widget	Combination of user-created text with other information on same screen
RSS feed widget	In a multistep process user can set up RSS feeds to appear in a widget	Allows inclusion of self-updating (and therefore current) information (e.g. standing Medline search results) in widely used format	Allows inclusion and drill-down to full-text journals in the interface; facilitating EBM/guidelines, alerting, etc. Any RSS feed allowed. Inclusion of diverse external information sources
Mouseover preview of lab results	Mouseover of the left lab menu link gives a preview of the lab panel	Allows user to preview widgets before inserting them into the tab, facilitates selection and mitigates the need to take action to remove unwanted widgets	Decreases unnecessary actions in widget selection and placement; rapid information overview
Ability to move, mark and juxtapose any desired items	All the intelligent uses of space (see appendix), decreased navigation to view items	Juxtaposition can foster insight into problem, creativity, better communication of case features such as severity/priorities	Decreased cognitive load, better communication
Users have control, objects can be used for other than expected or intended purpose, and assembled in new ways	Select, assemble and arrange any information desired from the clinical data and external websites/RSS feeds and author text; affords user considerable expressive power	Users can formulate tools according to their needs and preferences; tacit knowledge may be externalized	Better tool congruence with needs and contexts; increased satisfaction, externalization of hitherto tacit knowledge, giving us insight into user tacit knowledge and medical cognition

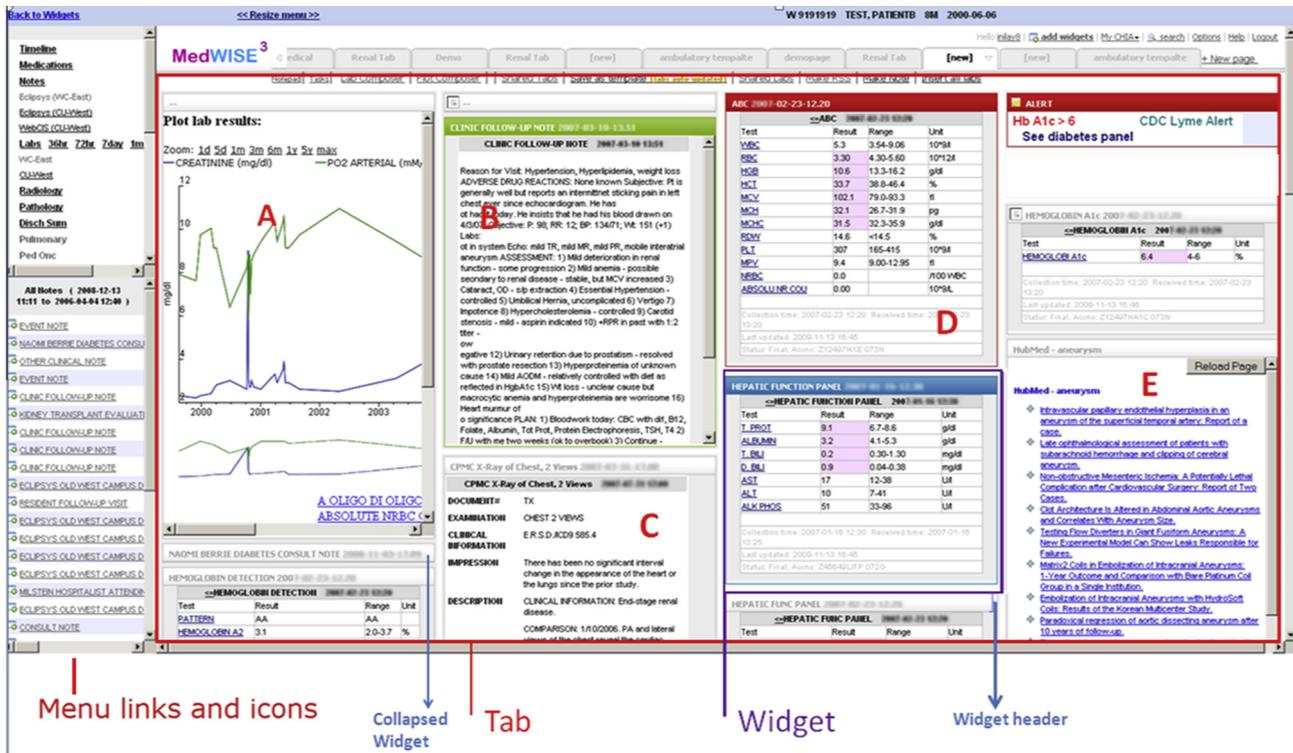
were familiar with the note and laboratory test formats, colleague authors, hospital service organization, and other pertinent aspects of the context.

Since normally all clinicians at the same level can see all patient records, there are no additional privacy restrictions. The architecture separates interface configurations from patient information, so user creations (e.g. widgets/templates) may be shared by individuals or groups. Our model's produsage paradigm allows for different degrees of sharing, allowing clinicians the flexibility to share information amongst their own teams, amongst other clinicians

with the same role (for example, residents sharing care of the same patient), or more widely (e.g., for a specialty).

## 5. Discussion

In this paper, we have defined a novel paradigm for EHR interaction, based on a set of theoretical concepts such as distributed cognition, keyhole effect, and produsage. The rationale for this paradigm is to afford greater flexibility and leverage clinician users' deep domain and contextual knowledge. This may allow a better



**Fig. 2.** Screenshot of MedWISE. Clicking on the links in the left-hand menu inserts data items (as movable rectangles, or widgets) into the right hand pane ('tab'). Plots (A) notes (B), study reports (C), laboratory results (D), orders, and RSS feeds (E) are shown. Users can thus gather and arrange any desired elements of the clinical record together on the same page. These interfaces are stored and can be shared. For safety, the usual EHR interaction is available by clicking on the icons next to the menu links. Definitions: A widget is a single draggable window containing information display such as a note, lab panel, RSS feed listing, and lab results plot. A tab is a single full screen accessible by clicking on the tabs across the top of the interface, in the large right-hand pane. "Creating a tab" consists of populating it with widgets. Users can create and share original widgets, for example, custom lab panels, which are created by dragging and dropping the lab tests of their choice from the complete list of 908 lab tests that are used at this institution. They can also share the complete screen (tab) of widgets they assembled, which could include lab panels, RSS feeds, notes, user-created notes, user-created mashups of lab plots, orders, and so on. Thus a user could create a tab containing all the relevant information for a particular patient and share it, or set it as a template and share the template. Templates are tabs in which the laboratory panels are self-updating (that is, when new results are available the screen automatically shows the newest information). Teams or specialties can set up templates (e.g. for renal function) that they use and share. Importing a tab or widget is done by bringing up the 'shared tabs' or 'shared widgets' list and clicking on a link; this opens the tab or inserts the widget into the current interface respectively. Users can control the information density on screen according to their preferences, by distributing widgets over several tabs if they desire, by dropping widgets onto other tabs. Video examples of MedWISE features in use. More detailed feature listings and descriptions are included in Table 3.

fit to task, provide more robust cognitive support, and facilitate rapid configuration to accommodate the complexity and changing nature of the healthcare domain. We described a set of functionality and core candidate features, which are hypothesized to confer significant advantages over conventional systems for clinical computing. Although we describe their instantiation in a particular system, MedWISE, the individual features are broadly available in modern computing environments. We believe that this approach may be applicable more generally in health care, including applications for patient personal health records, clinical research protocols, specialized visualization needs such as those found in critical care, public health surveillance, handoff, and rapid development of tools for emergent public health threats [63].

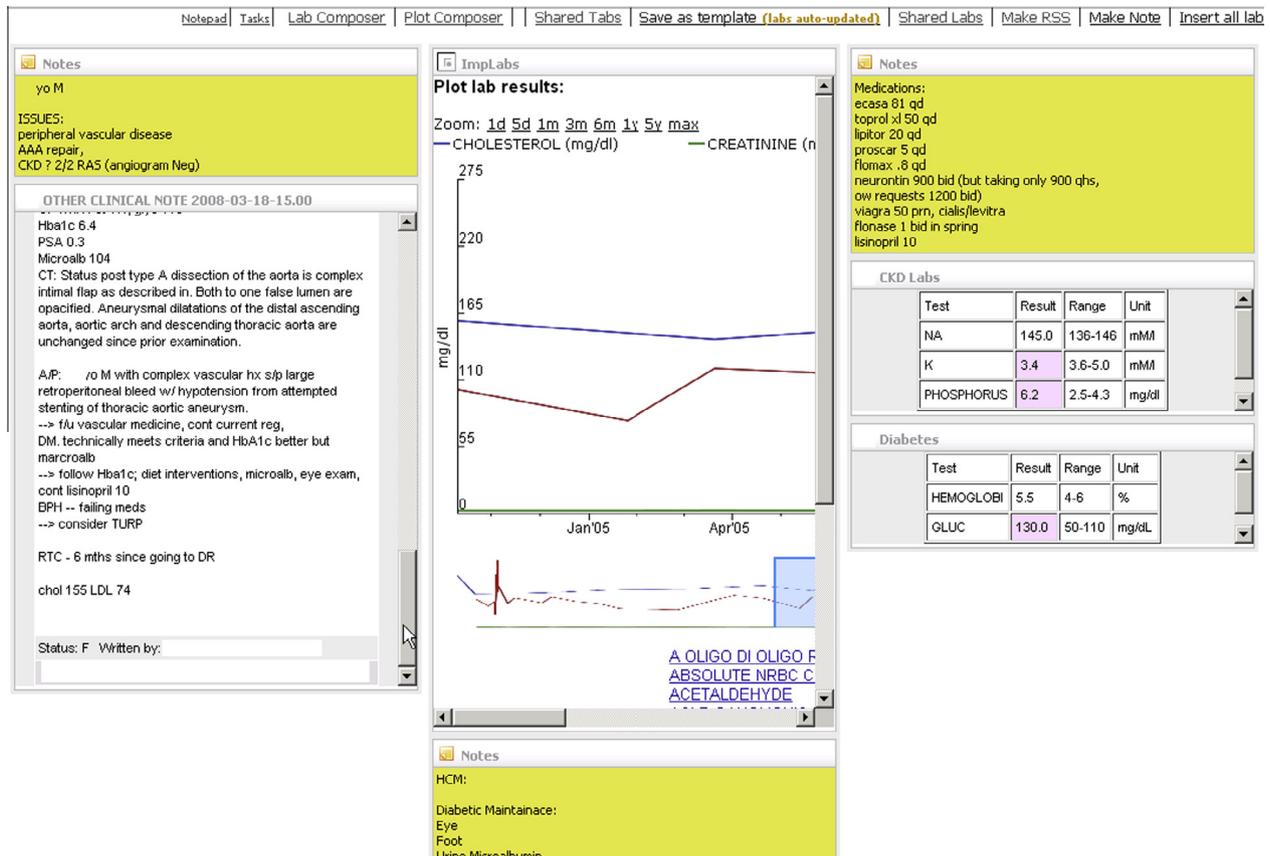
The architectural features allow rapid accommodation of a wide variety of contexts, without the time, cost and obstacles involved in programmer/vendor changes in conventional fixed systems; thus it might also be a new mode of software development with attendant changes in the economics of system creation. Of course, this remains to be tested. In our experience, the code base and amount of programming required to create a flexible composable system may be smaller than that required to accommodate each individual need and context ad hoc.

User control and sharing may also affect user attitudes toward EHRs and hence facilitate adoption, as well as usability and transmission of user expertise. Simplifying technologies that shift some

control to the user (such as the aforementioned web browsers and GUIs) have led to a proliferation of activity in the public sphere, with transformative effects.

There are also safety implications of the MedWISE model. Systems that are designed and evolve based on hundreds of clinician judgments, fit a myriad of local needs, and in which errors or omissions can be corrected by clinicians in seconds, may be safer than static systems designed by programmers. Some of the arguments put forth in this paper have been subjected to empirical testing (discussed in [6,7,59,60]) and others await further substantiation.

There is a potential risk of increased errors or error propagation if users using a shared element fail to detect omissions of essential information, or are overly influenced by a prior clinician's diagnostic reasoning (diagnosis momentum error) [64]. The magnitude of this risk can only be determined by empirical studies or logfile analyses of deployed systems [65]. The experimental system is in equipoise with current practice, in which clinician viewing of clinical information (aside from attested notes) is not monitored for completeness. Thus the risk of a user neglecting to review important information is putatively the same as with current practice. In general, in existing practice each user reviews the elements of his/her choice, and this review is not overseen or checked. See [7] for further discussion of this issue of omissions, errors and safety. Users sharing interfaces could potentially experience increased cognitive burden if newly borrowed interfaces clash with



**Fig. 3.** A user-created screen including stickynotes. The user has assembled different information types together, and split note functions according to his preference for having a short summary at upper left to orient himself when first viewing the record. Healthcare maintenance (the stickynote at bottom center) is coupled with the plot of laboratory results. Medications are at right, with custom-created laboratory result panels.

their mental models. This is discussed below in 'future work'. Theoretically users might also experience cognitive burden due to initial learning how to use the system, or from the process of creation.

The work presented in this paper is aligned with a growing number of innovative initiatives that share the common goal of affording greater control and flexibility in the user's EHR experience. Kohane and Mandl [66] present the idea of substitutability, with independent applications interchangeable in a common framework, such as the Smartplatforms project. This does not involve user creation, but presents an idea similar to the updateability of widgets by third parties. Patrick [20] devised a paradigm in which clinician users design the system including database fields and features via a system generator that facilitates the process. The project employs technical approaches different from ours, but shares the basic concept that users can be instrumental in designing the system from a set of familiar resources that can be manipulated. Mitre Corporation's MedCafe employs an approach [67] that similarly uses movable blocks, though with different specific features. In another high-stakes domain, NASA's Mission Control software (MCT) employs a user-composable platform approach in order to cope with the need for software change while accommodating consistency and reliability [68]. There have been various calls for use of more modern web approaches and tools, such as the call to have a 'Facebook'-like collaborative documentation system. As the need for greater usability and fit to task is increasingly recognized, and the progress of the cell phone apps paradigm continues, more and more researchers and developers are thinking about how these may be adapted as solutions for the multitude of user-related problems presented by healthcare systems.

It is important to note that MedWISE is an experimental system that has not been tested in a production system in a clinical setting.

Therefore, we cannot say with any degree of certainty that the system will be well-received and widely adopted by users. In this paper, we have explained the advantages of this kind of system from both a theoretical and practical vantage point. However, we do not know if users will perceive such advantages or whether they will expend the effort to master the system. In other papers [6,7,59,60] we report on user behavior and perception which indicate favorable attitudes towards this approach. Nevertheless, such a system needs to be tested by actual users in routine clinical practice to discern patterns of user behavior and scale of adoption. Of course, actual use will be determined by a multitude of factors including the support of stakeholders in an institution, convenience of use and a host of other factors that are well beyond our control.

## 6. Future work

It is well established that interface consistency is important for users to find items easily, learn the system, and operate smoothly within it [69]. It is important to note that this is initial work. Since user configuration could result in unwanted inconsistencies, further research may look at methods to ensure consistency appropriate to context and/or meet user preferences while still retaining the same relevant patient information in the interface. This could include 'locking down' parts, switching optional or user-specific default formats, marking regions, coupling items which should be viewed together for safety reasons, recommender systems, and interface methods of constraining choices (e.g. autocomplete/preview). This would also assist in the management of large numbers of user-created resources. It is important to note that modularity and composability can be separated. For example, since

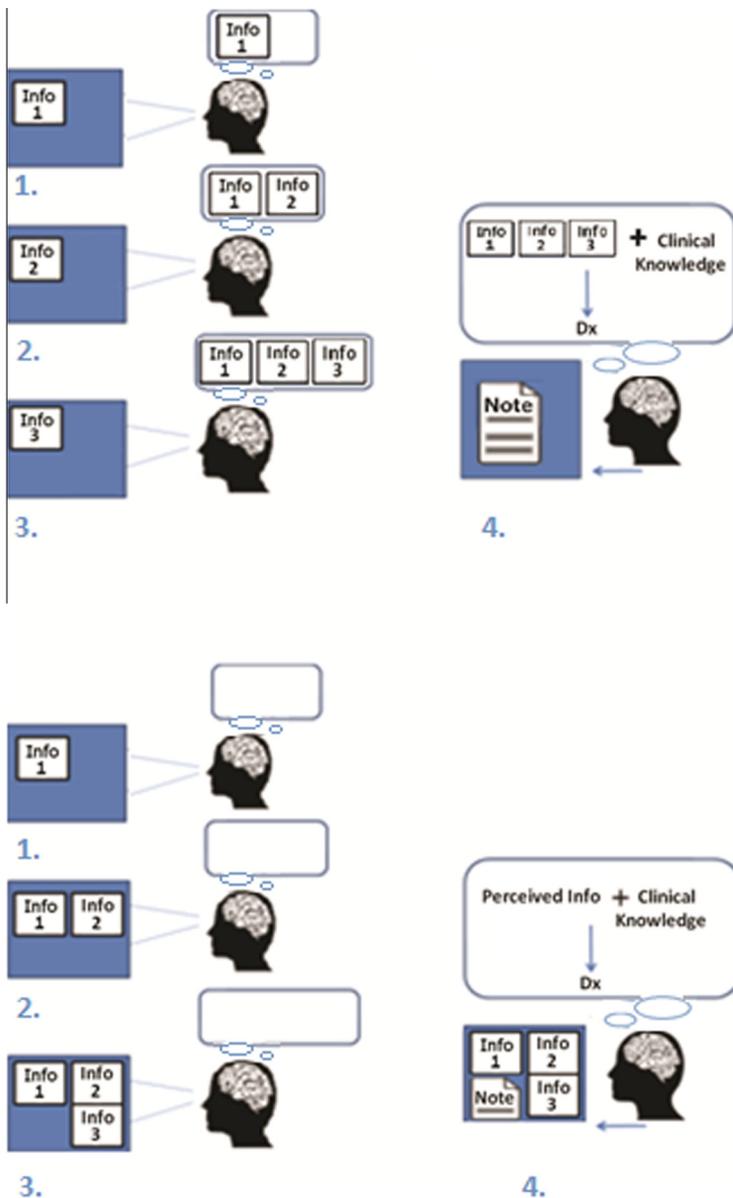


Fig. 4. Conventional system (WebCIS) and MedWISE use.

### Conventional system use:

The user perceives each piece of information sequentially and keeps it in working memory while reading the next item (usually on a different screen). This information combines with the user's clinical knowledge, and decision-making occurs. The user then writes a note in the external (screen) space. More screen switching may be required for copy-paste.

### MedWISE use:

The user selects items which are placed together, visible on the screen. The user uses direct perception of the juxtaposed information, which combines with the user's clinical knowledge, and decision-making occurs. 1-click entry enters all selected items into a note. The user then writes into the note.

MedWISE is a widget-based system, it could anticipate user needs based on context, via knowledge or data analytics, and automatically prepopulate the interface.

Advanced mashup features exist, and may be used for rapid configuration (e.g. for decision support for emergent public health threats [63]), or implementation of new treatments. As with modular systems in general, the time taken to build such systems can be offset by the rapid configuration possible when needed [70]. Likewise, MedWISE could be used for testing the effectiveness of different information collections, tools, visualizations and interfaces for different contexts. Rapid configurability could allow rapid prototyping and iterative testing of new functions, an important component of the diffusion of innovation [71].

It is also important to note that our philosophy does not mean nonprogrammer clinicians design everything. Our 'metadesign' model aims at creating a simplifying technology platform carefully incorporating diverse expertise including that of security and usability experts, administrators and others [63]. Information selection, arrangement, and a certain level of creation and sharing

are functionalities given to clinicians because those functions are most appropriate to be governed by their deep medical and contextual knowledge. To continue the word-processing analogy, a word processor allows the user to create complex documents, but does not require that s/he design fonts. Complex aspects of the programming should be left to the relevant experts. For example, usability principles such as consistent and prominent display of patient names, or Tall Man lettering for drug names, are the province of usability experts and should be included without option.

Usefulness of this paradigm includes the potential ability for clinicians to create software that truly addresses their needs, centered on the necessities of clinical care rather than billing and administration. The flexible architecture allows for new functionalities to be incorporated easily as new components or widgets, placing them directly in the existing EHR. For example, a widget providing treatment recommendations based on 'outcomes of patients like this at this institution' could be included easily without complete reprogramming or introduction of a new system.

While individual users may create tools with greater or lesser efficiency and validity, the rapidly changeable system means items found to be erroneous or suboptimal could be changed in seconds. Our paradigm includes levels of vetting corresponding to potential risk [3]. It is unlikely that all users would have the same level of engagement, but the paradigm allows for this, allowing a range from no use to complex tool creation. It is likely that most users would use the simplest select/arrange functions while fewer more interested superusers would create more complex tools which colleagues would borrow, as happens in the public web. This is consistent with the responses from focus groups [65]. The ready availability of functions does however allow for a user to learn gradually.

The sharing feature is a simple but critical function for the model, potentially saving time and resources by allowing component reuse, saving search time for colleagues caring for the same patient, and allowing consistent display configurations. Most importantly overall, it allows for evolutionary growth of the system. Users start with a consistent set of building blocks, the selection and organization of which are mediated by each clinician's creations and judgments (akin to a form of crowdsourcing). Sharing allows the system to differentiate to fit needs and contexts, mediated by clinician creations and judgments. Further explanation is found in [3].

## 7. Conclusions

We propose a new modular, user-composable platform approach to developing healthcare IT that can adapt to variable or rapidly changing needs. In developing an illustrative system that gives clinicians greater control of the EHR, we demonstrated the technical feasibility of this approach. User-configurable interfaces have relevance to system design for other fields in which deep user expertise in complex critical processes is paramount. The system flexibility opens new options for developing EHRs as real tools for information organization and thinking, beyond the storage and retrieval (paper-like) paradigm from which current systems originate. Precisely how much control should be assumed by the user is a matter for empirical study. Some studies of user behavior are described in separate papers [6,7,59,60].

There is still much left to learn if we are to produce the simplifying inventions that could shift some control to the user and perhaps increase widespread productive EHR use, analogous with similar change as has been realized in other spheres such as the public web. The current project provided building blocks toward achievement of that goal.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.jbi.2014.09.002>.

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