Healthcare information technology's relativity problems: a typology of how patients' physical reality, clinicians' mental models, and healthcare information technology differ

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ABSTRACT

Objective To model inconsistencies or distortions among three realities: patients' physical reality; clinicians' mental models of patients' conditions, laboratories, etc; representation of that reality in electronic health records (EHR). To serve as a potential tool for quality improvement of EHRs.

Methods Using observations, literature, information technology (IT) logs, vendor and US Food and Drug Administration reports, we constructed scenarios/models of how patients' realities, clinicians' mental models, and EHRs can misalign to produce distortions in comprehension and treatment. We then categorized them according to an emergent typology derived from the cases themselves and refined the categories based on insights gained from the literature of interactive sociotechnical systems analysis, decision support science, and human computer interaction. Typical of grounded theory methods, the categories underwent repeated modifications.

Results We constructed 45 scenarios of misalignment between patients' physical realities, clinicians' mental models, and EHRs. We then identified five general types of misrepresentation in these cases: IT data too narrowly focused; IT data too broadly focused; EHRs miss critical reality; data multiplicities–perhaps contradictory or confusing; distortions from data reflected back and forth across users, sensors, and others. The 45 scenarios are presented, organized by the five types.

Conclusions With humans, there is a physical reality and actors' mental models of that reality. In healthcare, there is another player: the EHR/healthcare IT, which implicitly and explicitly reflects many mental models, facets of reality, and measures thereof that vary in reliability and consistency. EHRs are both microcosms and shapers of medical care. Our typology and scenarios are intended to be useful to healthcare IT designers and implementers in improving EHR systems and reducing the unintended negative consequences of their use.

INTRODUCTION

The goal of useable, effective, safe and interoperable healthcare information technology (HIT) remains difficult to achieve.[1] We suggest one of the barriers to this goal is the temptation to focus on tidy use cases of predictable orderliness, which fail to convey the complex reality of medical care.

Looking at what happens in real HIT-in-use settings yields a large set of scenarios in which things do not work according to design, to original understanding of workflow, or to efficient operation.[2 3] Making things better requires vigilant observations and reliable ways of reporting difficulties. To improve HIT, we must be able to organize problems into a systematic typology so we can understand and remedy them. This paper seeks to catalog and organize these messy obstacles, and perhaps illuminate structures underlying them—and by doing so, to overcome some of HIT's significant difficulties.

Ostensibly, HIT directly embodies all the relevant features of a given medical reality, and directly corresponds to clinicians' mental models (as the clinicians must work with it). But no one, not even HIT vendors, believes HIT's design and populated data could correspond to the many differing clinicians' mental models, or even to any one clinician's mental model.

We first offer a typology of misunderstandings between patients' realities, clinicians' mental models of those realities, and representations of those realities within HIT—usually electronic health records (EHRs)/electronic medical records (EMRs), but also computerized provider (physician) order entry (CPOE), electronic medication administration record (e-MAR), pharmacy information technology (IT), etc. Inspired by Norman,[4] we use the term 'mental model' in the general sense, as the way clinicians internally represent and then reason about actions in their clinical world. We then use this framework to examine different sets of troublesome but generic use cases. Finally, we consider limitations and next steps.

METHODS

Our scenarios, or use cases, were based on: the research literature, 20 years of our direct observations, work with our research partners, logs from hospital and clinic IT departments, implementation teams' reports, the Agency for Healthcare Research and Quality 'Guide to Reducing Unintended Consequences',[5] personal communications by users, several HIT vendor forums, help desk logs, the US Food and Drug Administration's (FDA) center for devices and radiological health reports and logs,[6 7] participation in Institute of Medicine- and AMIA-task forces on usability,[8 9] AMIA's implementation forum, and additional reports from the field (although many of these need to be 'anonymous' due to contractual restrictions preventing users of commercial HIT systems from publicly discussing 'flaws').[10] To construct our typology, we employed a grounded theory approach, amassing the scenarios/

problem cases, and then categorizing them according to an emergent typology derived from the cases themselves. This was followed by iterative re-examinations incorporating insights from: interactive sociotechnical systems analysis,[2] with its emphasis on the recursive nature of HIT and workflow; from decision support science's rigorous examination of parameters, constraints and optimizations;[11–13] and from the human computer interaction literature,[4 14–17] a natural fit with our focus on usability, flexibility, and adaptability. Typical of grounded theory methods, the categories underwent repeated modifications.

RESULTS

We constructed 45 scenarios and developed a typology of five types (categories) of miscommunication among: the patient's physical reality; clinician mental models, and HIT.

Almost all of our examples are directly from EHRs/EMRs, but a few are from their digital partners, collectively called HIT. These are: CPOE, the barcoded medication administration technology (BCMA), and the e-MAR. When appropriate, we name the specific subsystem, but for the sake of consistency, we generally use the terms 'EHR', 'EMR', or 'HIT'.

Looking at our initial set of trouble scenarios, we illustrate the types of miscorrespondence and provided a structured way of organizing them.

- Let $\mathcal{RW}$ denote the space of underlying patient realities in the *real world*—usually the patient's condition, vitals, and test results.
- Let $\mathcal{MM}$ denote the space of clinician mental models. (Where relevant, we will add a subscript to indicate the clinician involved.)
- Let $\mathcal{IT}$ denote the data and language of the EMR.

Strictly speaking, our representation of the 'real world' contrasts with clinician mental models and the EMR, because we focus on how these two ($\mathcal{MM}$ and $\mathcal{IT}$) correspond or miscorrespond to the underlying medical reality, the 'real world' here. Of course, all three are parts of reality.

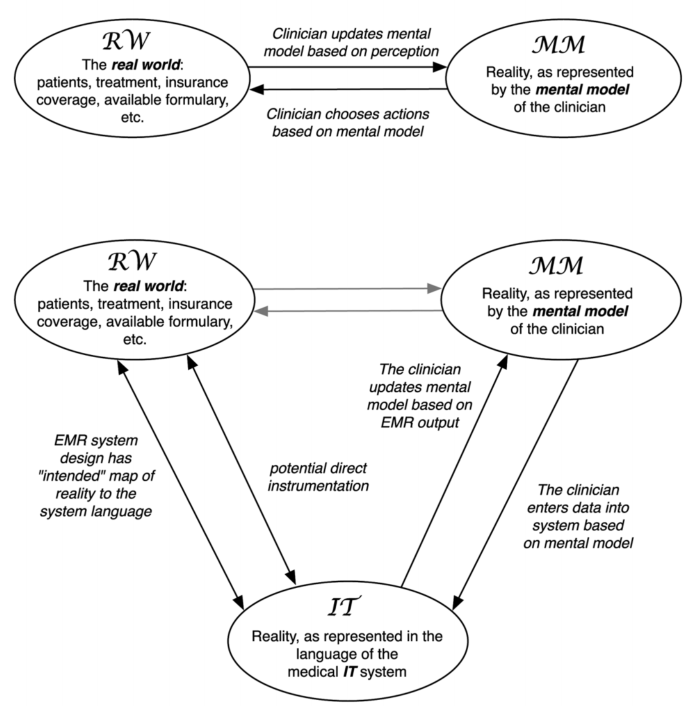
Figure 1 (top-half) shows the initial situation in which the clinician works with the underlying medical reality via his or her mental model. Figure 1 (bottom-half) shows the more complicated picture when we add HIT.

What is relevant here are the nuances of the various mappings between the spaces. When a clinician sees some particular EMR screen or menu from the $\mathcal{IT}$, what model ($\mathcal{MM}$) does she construct? Does this model correspond usefully to the reality ($\mathcal{RW}$) that generated this mental model? Furthermore, if two different clinicians see the same EMR screen, will they draw the same conclusions about the correspondence to reality? Within a typical hospital, there will be thousands of clinicians in many different groupings. There may well be also 150–400 different IT systems communicating with the HIT.

Problems with these mappings provide a way to organize the trouble scenarios, as table 1 summarizes the fivefold typology within which the 45 scenarios are presented.

Type I: too coarse

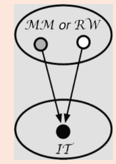
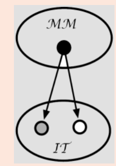
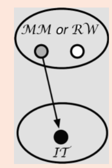
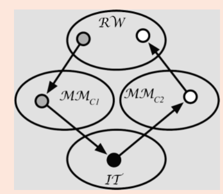
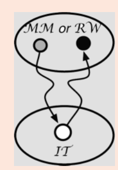
One category of trouble spots arises because $\mathcal{IT}$, the language of the electronic system, is too coarse. Both in $\mathcal{RW}$ and in $\mathcal{MM}$, there exist distinct scenarios whose distinction is significant in what the clinician does—and yet the system $\mathcal{IT}$ maps these scenarios into the same element, losing the significant distinction. Table 1 illustrates this in terms of our framework (and examples follow).



Top: Clinicians address the underlying medical reality by constructing a mental model of it. *Bottom:* EMR adds a third element to how users work with reality. In theory, natural mappings exist between these sets; we can use failures of correspondence as a guide organizing the problems that arise in practice.

Figure 1 Clinician mental models of patient conditions, and their interaction with EMR. EMR, electronic medical records; IT, information technology.

Table 1 Typology of EMR usability problems organized according to errors in the mappings in figure 1

Incompatibility type	Incompatibility description	Sketch
Type I: IT too coarse	Significantly different scenarios in $\mathcal{RW}$ and/or $\mathcal{MM}$ are represented in the same way in $\mathcal{IT}$. Examples: (1) Problem lists that do not permit sufficient qualification of classifications, for example, left side CVA versus just stroke, or inactive asthma, or, (2) Only indicating the patient has cancer is woefully insufficient to be useful to oncologists	
Type II: IT too fine	Scenarios identical to the clinician are represented significantly differently in IT. Examples: (1) Very granular categories within ICD-10 may reflect a level of certainty or understanding that does not exist for a specific patient. The (false) specificity may misguide other clinicians. (2) Unconfirmed suggestion of one very specific subcategory of several possible cancers may lead to premature closure of analysis	
Type III: missing reality	Scenarios or scenario details significant to the clinician are not represented at all in IT. Examples: (1) Only lab reports and medications are listed; not symptoms or history. (2) The EMR implicitly assumes COWs are always network connected, but the clinician encounters reality where they are not	
Type IV: multiplicity	Different communities of clinicians may construct different mental models (and hence infer different realities) from the same representation in the IT. Example: the EMR reflects misleading/distracting judgments by staff or family members in addition to many lab reports with alternative interpretations	
Type V: looking glass	When a clinician scenario is reflect into the IT and back, it becomes something rather different and surprising. Example: clearly incorrect sensor data, which a clinician would reject, becomes enshrined in the EMR, which now describes a reality that never existed	

Categories of representations' misalignments where each category reflects types of incompatibility.
COW, computers on wheels; CVA, cerebrovascular accident; EMR, electronic medical record; IT, information technology.

Such situations can be especially frustrating for clinicians who found that the pre-EMR system allowed for such nuances.

Type II: too fine

Another category of trouble arises because $\mathcal{IT}$, the language of the electronic system, is too fine. There are scenarios in $\mathcal{RW}$ that are distinct but whose distinction is irrelevant to the user—and hence map to the same element in $\mathcal{MM}$. However, the electronic system maps these scenarios into distinct elements in $\mathcal{IT}$, thus preserving an irrelevant distinction—and potentially causing the user to take incorrect action because the system interpreting their action is operating on a scenario that does not match the user's mental model.

Figure 3 illustrates this, in terms of our framework.

Type III: missing reality

Yet another category of trouble spots arises because $\mathcal{IT}$, the language of the electronic system, describes only a proper subset of the models in $\mathcal{MM}$ the users care about. To put it more mathematically, the induced map from $\mathcal{IT}$ to $\mathcal{MM}$ fails to be surjective, also known as onto. Figure 4 illustrates this, in terms of our framework.

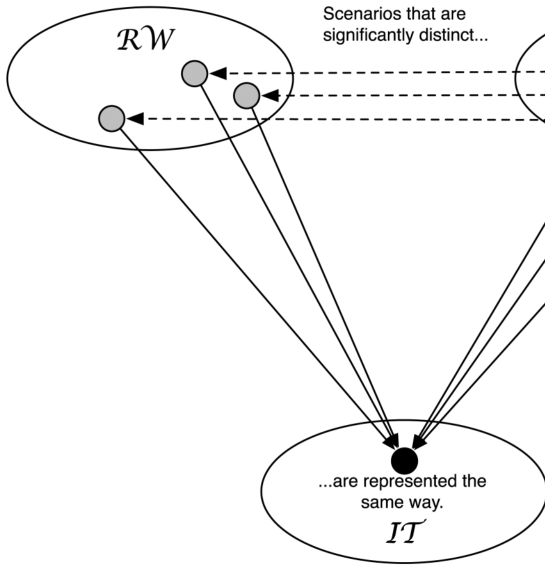
We distinguish type III from type I by considering whether the reality or mental models have critical aspects that the $\mathcal{IT}$ completely fails to include; for example, if an EMR system represents two very different weights the same way, we put that in type I; but if the EMR failed to include weight at all, it is classified within our type III problems.

Type IV: multiplicity

Another category of trouble spots arises because local user cultures or the process of implementation can develop an implicitly understood distortion in users' mapping between $\mathcal{MM}$ and $\mathcal{IT}$. If one clinician (C_1) uses such a distortion when mapping from an underlying reality through her mental model to the $\mathcal{IT}$, but a different user (C_2) does not, then this second clinician (C_2) may conclude significantly incorrect things about the underlying reality. A chief medical informatics officer (CMIO) told us of two local hospitals that both used the same commercial EMR system—but that using them was 'like learning Spanish and Italian' (personal communications between clinicians and the authors, 2008–2012). Figure 5 represents this phenomenon.

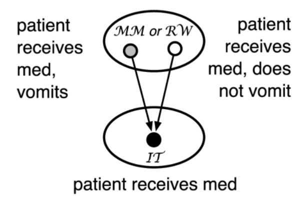
Type V: information distorted by iterative reflections among clinicians and IT systems: through the looking glass

Sometimes, scenarios significant to the clinician are indeed represented in $\mathcal{IT}$. However, when the representation maps back to reality, it becomes significantly distorted, as it has passed



Scenario 1: Vomiting

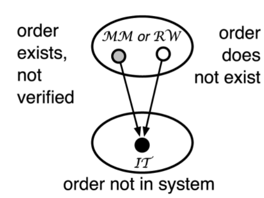
The reality of a patient receiving medicine can be rather messy (literally). For example, consider a patient whose orders indicate she is to receive a pill. The clinician may administer the pill—after which the patient vomits. Has the medicine been administered, or not? Koppel et al discuss [18] an electronic medication administration record (e-MAR) in which the answer needed to be binary: yes or no.



In terms of the model, r_1 is the scenario where the patient successfully receives the medicine; r_2 is the situation where the patient receives the medicine and is able to ingest it (does not vomit). To the clinician, these are critically distinct; however, the system represents them the same way: “medicine was given to patient.”

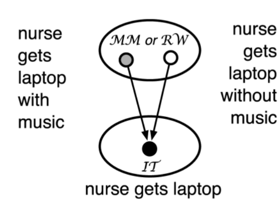
Scenario 2: Schrödinger’s Pharmacy

A similar scenario can arise when a doctor has ordered a medicine but it has not yet been “verified” (approved) by the pharmacy. The order exists, but some of the EMR screens do not show that. The same EMR state thus exists for two very different scenarios: the order exists, and the order does not exist. This situation can sometimes lead to the patient receiving twice the amount of the medication when another physician orders the needed but seemingly missing medication (“double-dosed”).



Scenario 3: Substitutability of Physicians and Laptops

In terms of billing, one 2nd year resident is the same as another 2nd year resident. But the reality of their skills may differ significantly. A more specific example is seen in the stable of laptops maintained by the nurses. Each clinician is to take a laptop from the stable when going to treat a patient. From the point of view of the official IT infrastructure, each laptop is identical, so it matters not which one a clinician gets. In reality, however, we found that certain laptops were in high demand—because they were equipped to play music, which patients found soothing during treatment [3].



Scenario 4: Lab Results

In one medical enterprise, each clinician may have many lab results awaiting physician review. However, that enterprise began using an EMR system in which the suite of lab results are displayed—as a set of items, each with the identical name “lab result”(personal communications between clinicians and the authors, 2008–2012) A decade ago, we saw similar problems with browsers and client-side certificates—if user Alice had several certificates, her browser would offer her a choice, except each choice had exactly the same label. Alternatively, think of the MP3 players with thousands of songs called “Track 1.”

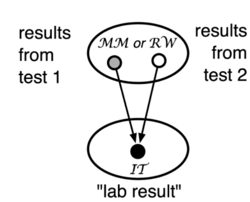
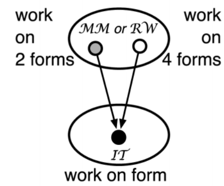


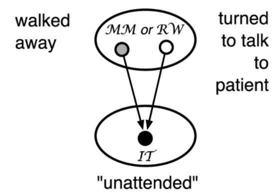
Figure 2 Representations of type 1 problems in which the language of the HIT is too coarse, erasing significant distinctions. EMR, electronic medical records; HIT, healthcare information technology; IT, information technology.

Scenario 5: Open Forms



With the old paper system, clinicians quickly moved back and forth between several forms, which were all open on a desk. However, when the enterprise migrated to electronic forms, the implementers incorrectly assumed clinicians worked on one "open" form at a time—denying the ability to see several forms (screens/data sources) at the same time. The technology provided an electronic system that did just that: let clinicians work on only *one* single open form. In addition, this limitation was thought to prevent clinicians from entering information into a form other than the one directly in front of them. Alas, the solution failed to reflect the very real need to see information from many sources and to enter information from and in several forms simultaneously. The ability to move back and forth between many was lost in migration, although some EMR systems have tried a middle ground, where only *N* forms can be open at a time, for some small *N* (personal communication between the clinicians and the authors, 2008–2012).

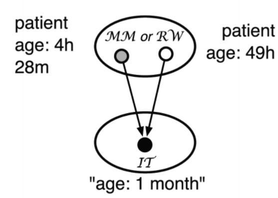
Scenario 6: Timeout



In hospitals, a clinician often works with the EMR via whatever computer is closest. Security officers are understandably concerned that a clinician does not leave himself logged in at a machine after the clinician has moved on. An unattended but logged-in machine could be a significant security problem: passers-by might be able read and modify patient records, or order medications under the identity of that clinician. In addition, Koppel et al [19] report of physicians frequently entering orders into a wrong patient's electronic record because they assumed the open record reflected the patient they had in mind. On the other hand, requiring frequent logins could be a significant usability problem, creating unnecessary cognitive load, distractions, and negatively affecting the clinician's work.

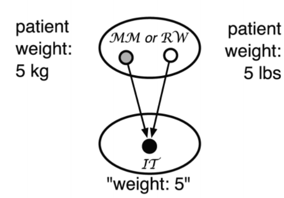
To address this problem, the enterprise introduced a *timeout*: after a fixed period of inactivity, any machine would automatically log out its user. However, the "timeout period" was blind to context: to this electronic system, a clinician walking away from a hallway machine after quickly checking some information looked just like a clinician sitting in an examining room and turning away from a computer to talk to the patient (personal communications between clinicians and the authors, 2008–2012).

Scenario 7: Baby Age



For newborn babies, precise age (in terms of hours or even minutes) can be relevant to determining correct treatment, such as medication dosage. However, EMRs often fail to let the clinician enter such fine-grained age information; the system records a number of months or years, which loses this critical detail. Scenario 25 has an even more complex issue: negative age for operations in utero.

Scenario 8: Missing Measurement Units



In the US, patients typically give weights in pounds; clinicians may use either pounds or kilograms. However, when determining medication dosage all calculations are done in the metric system. This is especially critical for baby weights, where the use of the metric system is always assumed, and where it is essential for a clinician to know the correct body weight. However, some EMRs do not designate the unit of measurement in some of their screen displays, so the "5 pounds" vs. "5 kilograms" significantly different to the clinician—are rendered the same way in the system. Infant patients have died as a result (personal communications between clinicians and the authors, 2008–2012).

Figure 2 (Continued)

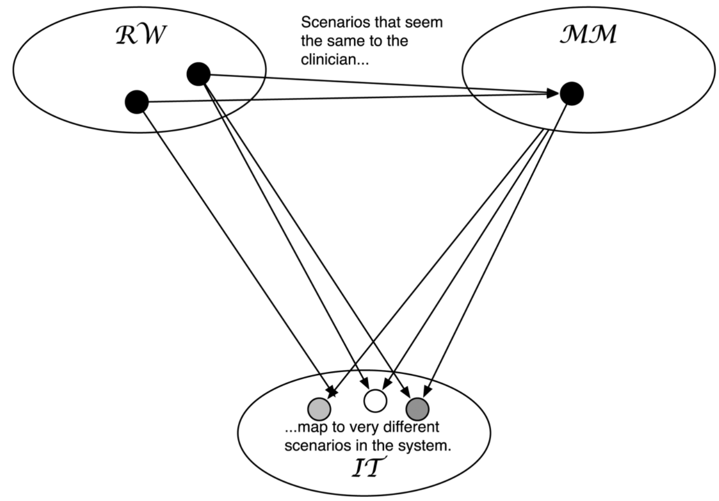
through repeated iterations within the IT and between users and the IT. 'Copy and paste' or 'cut and paste'-induced errors exemplify these problems, which might be termed, 'Alice's looking glass' (to borrow an image from Lewis Carroll). Figure 6 illustrates this, in terms of our framework.

DISCUSSION

We generally understand physical reality through our mental models of that reality. Modern healthcare settings have another player: the HIT, which implicitly and explicitly reflects many mental models, facets of reality, and measures thereof that vary in reliability and validity. The HIT, therefore, is both a medium of communication and a representation of much information—some of which is conflicting, some of which is missing, and all of which interacts with the mental models of designers and users. It is both a microcosm of medical care and it shapes medical care.

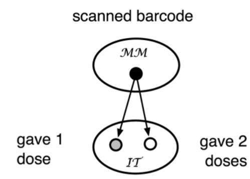
Many times EMRs do a dramatically better job of reflecting reality than paper ever could. The instant availability of graphic representations–nearly impossible to construct with paper records–offer alternative views of laboratory reports (eg, shifting timelines or overlays of results); omnipresent data mean consultants and others can view records anywhere and anytime, and laboratory results and medical images can be sent to several clinicians simultaneously. Supervision by experienced clinicians no longer need be constrained by physical space.

Yet there is a growing literature on HIT dissatisfaction[2 26] and industry practitioners worry that 70% of such installations fail.[1] Analyzing these scenarios suggests at least one common thread is woven by IT systems that fail to correspond to medical



Scenario 9: Falsely Idempotent (Seen as the same when actually different)

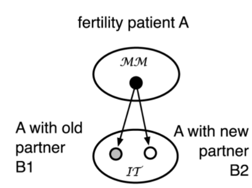
In a medical enterprise where clinicians were to scan a barcode printed on medicine before administering the medicine to a patient. Sometimes, clinicians would scan a barcode more than once in quick succession—in their mental models, a few scans in quick succession were the same as one. However, the HIT system regarded them as separate scans—and drew incorrect conclusions about how much medicine was delivered [18].



In terms of our framework, the HIT system may be in two different states: one in which one dose was given to the patient, or another in which two doses were given to the patient —even though in the clinician's mental model (and the actual reality), only one dose was given.

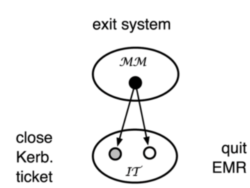
Scenario 10: Changing Partners

In a medical enterprise that provides care for couples with fertility issues, each instance of a couple has its own representation in the EMR—even though membership of couples may overlap. If patient A is now married to partner B_1, but later marries B_2, *IT* does not provide a way to associate (A,B_2) with (A,B_1)—even though, for purposes of treatment, a clinician may associate them in her mind [3].

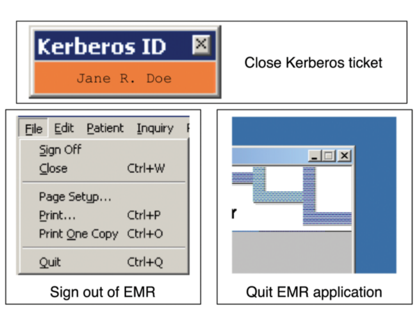


Scenario 11: Exiting

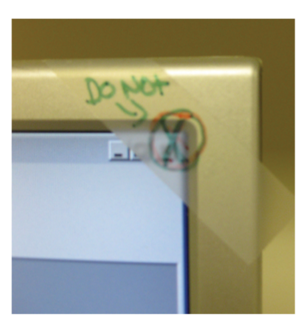
Somewhat analogous to the over-granular ICD-10 classifications noted above, we find that in a medical enterprise which used Kerberos for authentication, clinicians with computer experience saw three different ways to exit the EMR system: close the Kerberos ticket, sign out of the EMR system itself, or quit the EMR application. However, although these three approaches are equivalent in the user's mental model, the system disagrees: quitting the EMR application has dire consequences—sufficiently dire that, in our fieldwork, we found clinicians had taped warnings on monitors admonishing users not to do that [3].



We have also seen other examples of "exiting" confusion: interfaces which give the clinician a choice between "finish" versus "end" versus "submit" versus "save" versus "next" versus "quit." Each option has different functions but appear the same to the clinician.



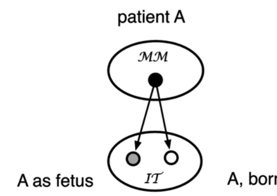
Computer-savvy clinicians saw three ways to exit the system as equivalent.



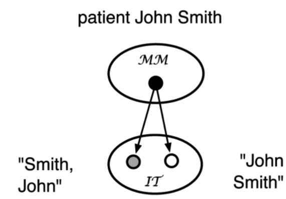
The system treated the one approach so differently that users were compelled to tape up warnings.

Figure 3 Representations of type II trouble spots in which the language of the HIT is too fine, introducing distinctions that the user does not regard as significant and/or of which he/she may not even be aware. EMR, electronic medical records; HIT, healthcare information technology.

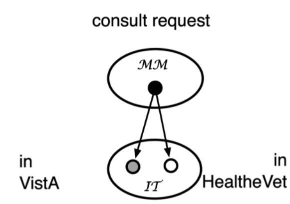
Scenario 12: Individuals
Continuing with the above scenario, the organism as IVF zygote, the subsequent fetus in utero, and the subsequent baby born are all the same individual, but will have three different records in the EMR. Similarly, in many medical facilities, a woman may be seen as general patient A, a maternity patient B, and then a mother with a new baby C. who becomes a patient at the facility—and the EMR will have three separate sets of records [3].



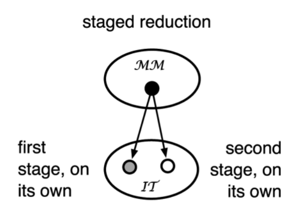
Scenario 13: Multiple Records
The US does not currently have a nation-wide system for unique patient identification numbers. As a result, patient records have to be identified by names, which are seldom unique ("John Smith"), and which can be input many ways (e.g., "Smith, John" vs "John Smith" vs. "JSmith" vs. "SmithJ"). As a consequence, an EMR *IT* can end up with many separate records corresponding to the same patient [20]. Indeed, hospitals have thousands of cases where a new patient record number was established for the same patient—even though the name was in the same format (and of course when the name is in a different format).



Scenario 14: Lack of Interoperability
A variation of "too fine *IT*" can occur when the electronic systems with which the clinician must interact are themselves partitioned into non-interoperable subsystems [21]. For example, a consult request submitted through Vista/CPRS cannot be imported into HealtheVet; consequently, the clinician prints requests and manually enters them into a paper calendar. This may be the root of Scenario 12 above.



Scenario 15: Taper
For some medications, a clinician may need to prescribe a tapered decline (sometimes called *staged reduction*) of dosage rather than an abrupt end. However, the EMR *IT* does not allow for a taper; what the clinician thinks of as a single unit—the tapered end of medicine—must be instantiated as a sequence of separate non-tapered medication orders, with the clinician needing to remember to terminate the earlier items in the sequence (personal communications between clinicians and the authors, 2008–2012).



Scenario 16: Name that Cancer!
A clinician reports that she was almost certain a patient had stomach cancer and needed to refer the patient to a specialist, for treatment. However, the EMR required the clinician to choose from a drop-down menu of 38 different varieties of stomach cancer; there was no option for "I don't know—that's why I am referring the patient to a specialist" (personal communications between clinicians and the authors, 2008–2012).

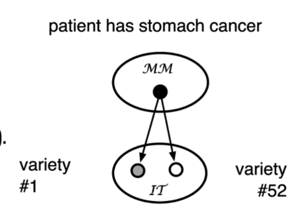
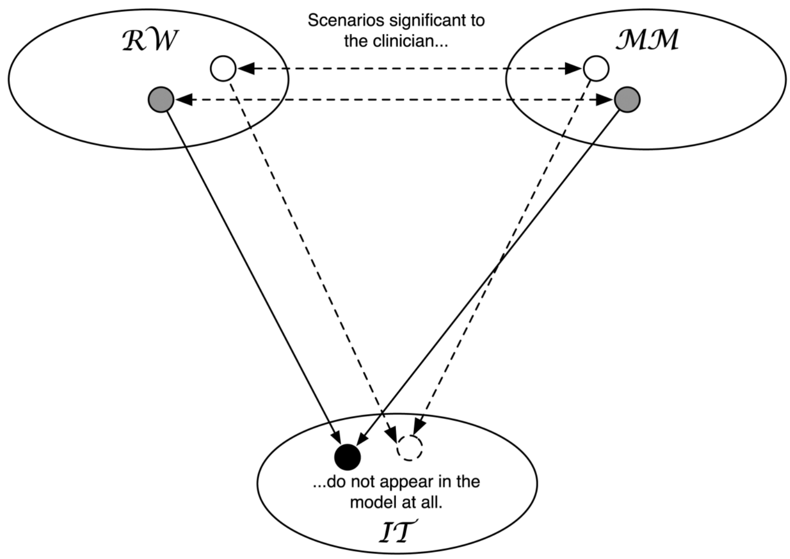


Figure 3 (Continued)

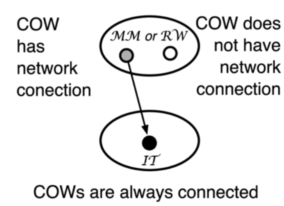
workflow: implementing EHR introduces an additional representation of reality—one that comes between the clinician and the patient, and exists in manifold forms among the many clinicians treating patients. When these representations fail to match the patients' conditions and clinicians' mental models, EHR can distort reality, which they nevertheless continue to array neatly in specified columns and rows.

EHR are certainly not alone in their ability to distort reality. Any representation distorts, be it paper, logs, reports, or even ontologies designed to reduce confusion. But what may be different about computerized health IT as compared to earlier paper-based systems (built with and on the natural affordances of paper) is the rapid permeation of interconnected IT into medical workflow, coupled with the relative inflexibility of computerized systems, which do not know 'when to look the other way'.[27] In addition, HIT is freighted with additional and extraordinary requirements of documentation, categorization, ordering, responding to (and generating) alerts of varying utility, accommodating legacy limitations, and billing. Moreover, HIT must also operate in a diverse interdisciplinary environment dictated by professional societies, state and federal boards, payers, unpredictability, no control over inputs (patients and their severity), limited control over patients' actions, and innumerable unknowns and unreliable data. We add, lastly, that many of the key players are untrained in the HIT's use and may be mastering a complex subject while learning to operate the HIT, which is itself undergoing frequent modifications. All of these factors limit user interface flexibilities and thus may influence responsiveness to clinicians' mental models and patients' always-emergent realities.

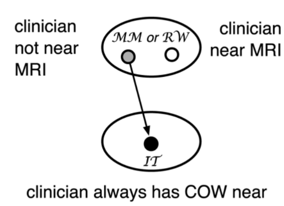
Another approach to addressing the misalignment of physical reality, clinician understanding and HIT might be to look at how the heterogeneity of medical workflows may require each HIT system to be custom engineered, hindering the economies of engineering investment that benefit IT supporting more homogeneous and universal tasks, such as word processing. As the line goes, 'if you've seen one EHR installation, you've seen one EHR installation'. In addition, even if workflows were similar from institution to institution, the number and types of other IT systems that link with any given EHR installation are vast, numbering in the hundreds, with each requiring special



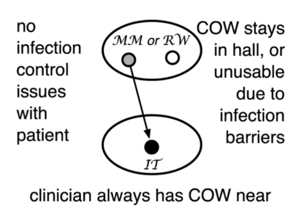
Scenario 17: Unheard COWs: (Unconnected COWs)
Similarly, the system design implicitly assumes that clinicians' portable computers (*computers-on-wheels*, COWs) are always connected to the enterprise network. However, real-world enterprise WiFi deployments provide many instances where certain physical locations may afford poor or no connectivity, due to obvious reasons such as no radio coverage—but also due to more subtle reasons, such as interference between access points or to inadvertent consequences of network topology. If a clinician finds himself in a scenario where a COW cannot connect, he must find a way to work around the system—with similar potential consequences as above [18].



Scenario 18: No COWs near MRIs
Similarly, an EMR system design may also make other assumptions regarding about clinicians always being able to have a COW near them—assumptions that the real world may inconveniently violate. For one example, COWs do not work near MRI machines, and they certainly can't go into the MRI suite.



Scenario 19: No buggy COWs
For another example, due to reasons of infection control, a COW is unlikely to be sterile and thus is not allowed into some patients' rooms. The solution is to cover the scanning head in enough protective barriers (plastic bags) that unfortunately render it unusable. However, leaving the COW in the hallway, and covering the scanning head creates two problems: first, the clinician can't hear or see the alerts; and, more directly, the plastic wrapping on the scanning head prevents reading the barcodes. Sometimes, the clinician tries to compensate by making a hole in the protective barrier for the scanner to work. This, of course, negates infection control.



Scenario 20: Unreadable Wristbands
With barcoded medication administration systems, the design implicitly assumes that each patient has a unique, appropriate, and readable barcode wristband. Alas, this is often not the case. Studies enumerate many reasonable scenarios in which this assumption fails to hold: children chew off the bands, incontinent patients can render the barcode unreadable, neonates suck out the paper barcode, and barcoded wristbands may reflect previous hospitalizations or a former institution or even hospital unit. If a clinician finds himself in one of these scenarios, he must find a way to work around the system (providing medications to a patient without a barcode) [18].

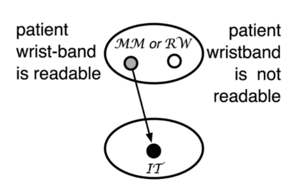
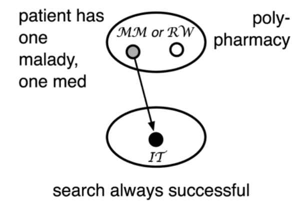
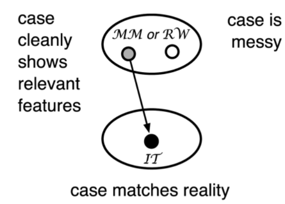


Figure 4 Representations of type III problems arising because the HIT misses critical detail—even though mapping between the system language and mental models may be articulate, it only covers a proper subset of the relevant mental models. COW, computers on wheels; EMR, electronic medical records; HIT, healthcare information technology.

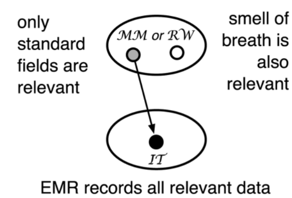
Scenario 21: Multiple Maladies
In scenarios used in clinical trials, each patient has exactly one malady and is taking one medication. The logic of the experimental design excludes the real-world probabilities that patients have more than several maladies (*comorbidities*) and are taking many medications (*polypharmacy*). Most patients, in fact, have several comorbidities and are taking 8 to 14 medications. The observed symptoms are almost certainly a union of several conditions and many medications. Computer decision support algorithms that provide alarms or recommendations are based on clinical trials and thus fail to reflect the complexity of most patients [23]. A similar misconception about single causes and single remedies can hamper software debugging.



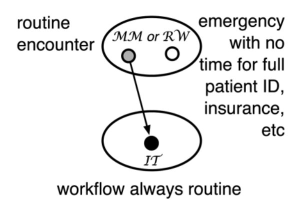
Scenario 22: Cherry-Picking
Exemplar medical cases used for samples and tutorials can be "cherry-picked": the cases cleanly show the relevant features and problems, and do not present any messy scenarios that would complicate the message. However, efforts to customize EMR interfaces generate data presentations and histories that may focus on only one set of diseases (e.g., the "rheumatologist's view") and fail to reflect the almost ubiquitous messy real world cases [23].



Scenario 23: Smell of Breath
One clinician expressed frustration at a migration from a paper-based reporting system to an electronic one with *field-defined data*—that is, the user needed to select pre-defined choices, rather than adding freetext. In particular, this clinician lamented that the new system provided no way to record the smell of a patient's breath—even though that can be a significant clue for certain diseases, including common ones such as diabetes (personal communications between clinicians and the authors, 2008–2012).



Scenario 24: Access Control is Not Context-Aware
Emergencies occur for which a system has no workflow allowance, e.g., accessing a patient's medical record in the case of an emergency. Clinicians are often prevented from entering an order for life-saving medications because the computer system first requires a full patient ID, insurance information, etc. The unrealistic assumptions of workflow, reflected in the access control system, is getting in the way of the primary goal of helping patients [3].



Scenario 25: Negative Age.
When treated in-utero, a fetus may need to be represented in *IT* as a patient. However, the EMR system may implicitly require an "age" field to be non-negative—leaving the clinician no way to represent the age "three months before birth." Some systems use gestational age, but there is no consistent metric for that.

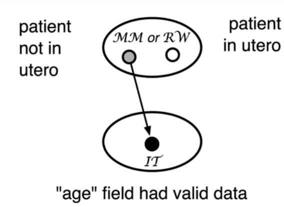


Figure 4 (Continued)

codes and connecting algorithms. Every EHR, no matter how similar to its sister, will be different when running in a different institution.

Equally important, these systems are always in flux, with ongoing efforts to improve them—efforts that combine both iterative refinement of the IT system and modification of workflows over time. Like a beneficial version of Zeno's paradox, HIT and workflow are challenged to improve processes and outcomes through interactive changes, each change offering yet new opportunities for improvements.

In response to these challenges, our work centered on cataloging these 'hard-to-use cases' (instead of the more typical focus on 'use cases'). Earlier work on decision support software[2 11 12 13] was beneficial by emphasizing the interaction of workflow and HIT, which is clearly a major theme of the clusters. Earlier work on human computer interaction literature, for example[4 14–17] led us to consider the role of the EMR user's mental model in relation to the EMR system itself and the medical reality in which the user must act. Interactive sociotechnical systems analysis[2] stressed the need for, and absence of, malleability of the software. In this sense, the previous theories helped us in generating the clusters of hard-to-use cases, and of our resulting typology, which builds on and extends the earlier work.

To help solve these problems, we need to identify better and reduce incorrect mappings between HIT and patients' bodies, and between HIT and clinicians' mental models. For example, suppose the clinician could press a button, take a screenshot[28] and scribble on it with a magic stylus. Clinicians could then correct or annotate the EHR to reflect distortions, for example:

- Type I: When the IT language is too coarse: clinicians could circle the checkbox and say 'these options don't reflect reality'.
- Type II: When the IT language is too fine: clinicians could circle several items on the EHR's screen and annotate 'it's one of these, but not just "this one"'.
- Type III: When the IT language is missing or 'too small': clinicians could say 'you're missing this thing I care about'.

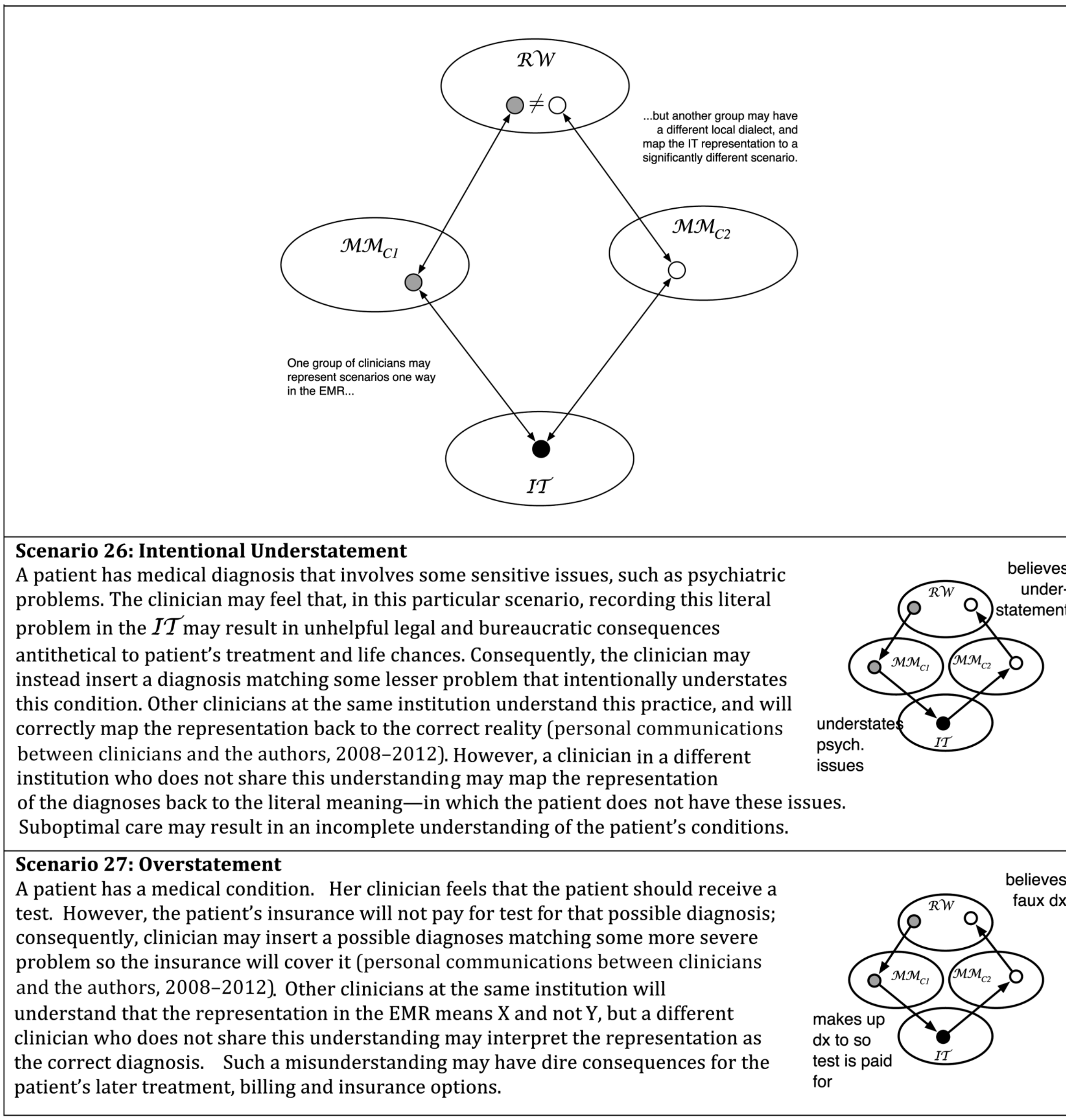


Figure 5 Representing type IV problems in which ambiguities arise because of multiple communities. Local user cultures apply implicitly understood distortions to their use of the system language, which causes users who do not share that understanding to draw significantly incorrect conclusions about the underlying reality. EMR, electronic medical records; IT, information technology.

- Type IV: When the IT language lends itself to a multiplicity of interpretations: things are trickier; maybe the second clinician could note 'this is what I thought this meant', and the system could forward this back to a representative of the first clinician.
- Type V: When the IT offers a distorted looking glass reflection: clinicians could note 'this is very, very wrong'.

Such an approach could also help with ambiguities and provides the affordances of paper, so lacking in most digital interfaces. When clinicians are uncertain and/or the data are ambiguous (as is often the case), clinicians could reflect the ambiguity and suggest a range of possible options. When clinicians were uncertain about the most appropriate consultant, they could indicate the ambiguity and request clarification by specialists.

HIT will also benefit by improving the way we discover and remediate these problems.[29] This requires work by local IT teams, requests to vendors, analyses of linkages with other IT systems, ongoing observations of clinicians' work, focus groups, interviews, etc.—or, most probably, a combination of these methods. Remediation will require working with all parties and, perhaps more important, empowering clinicians and others to observe problems and to request changes and improvements. Most important, problems that have been reported and requests for improvements or modifications must be addressed. Adding enhanced awareness of difficulties to the existing frustration will only increase alienation and learned helplessness. Encouraging clinicians to act without subsequent action on the IT side is perhaps worse than doing nothing.

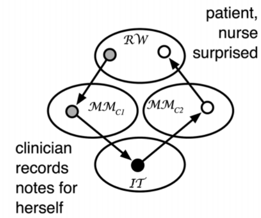
As discussed above, we also need to recognize and address the role of the myriad other IT systems that interact with each HIT system. Problem solving often requires understanding how several IT systems work together, or do not.

We need to recognize the role of workarounds as both needed solutions and as symptoms not of user laziness, but of system design failure, or at least system non-responsiveness—and we need to figure out how to fix these designs.

Scenario 28: Multiple Viewers

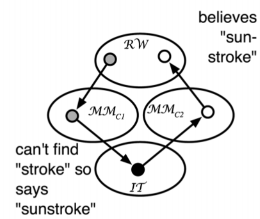
A beneficial consequence of electronic media is that it becomes easier to share records among multiple users. This is not always an advantage. It may be problematic to have different users see the same view, i.e., a physician may wish to record questions to themselves (e.g., "consider asking about cancer? abuse? drugs?") without sharing this with the patient. However, this information will appear extraneous and perhaps misleading when viewed by other classes of users.

(On the other hand, unfortunately, the natural solution of having different users see different screen views also causes problems: the nurse may see a different screen from the physician, and draw different conclusions about the patient's condition (personal communications between clinicians and the authors, 2008–2012).) Indeed, UI designers expect this and find it as normal; each UI emphasizes different data.



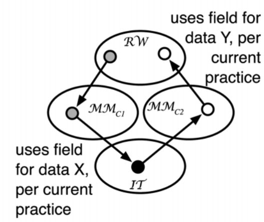
Scenario 29: Approximating the Option: When the menu category is obscured

A patient has a diagnosis X_1. Within the EMR system language ($\mathcal{IT}$), a natural way to encode this diagnosis exists, as X_1. However, clinician C_1 cannot easily find this option among the myriad dropdown menus, and so chooses instead to record X_2, reflecting some diagnosis that approximates the real scenario, to his mind. For example, C_1 might choose "sunstroke" instead of "stroke" because C_1 could not find the entry for the latter (personal communications between clinicians and the authors, 2008–2012). Other clinicians at the same institution will understand that X_2 means X_1, not X_2. However, a different clinician C_2 who does not share this understanding may interpret X_2 as X_2—the patient has sunstroke.



Scenario 30: Evolution

When thinking about challenges of *interconnected* EMRs, it's tempting to think about communication problems across different enterprises. However, many of the medical IT systems at just one enterprise change over time. One staffer noted "occasionally, fields would even fall out of use for a while, then suddenly be used to store entirely different data." In terms of our model, at one point in time, a clinician C_1 applies a map to reflect a given reality from some representation within the $\mathcal{IT}$. However, later, the natural map the institution applies may change; a different clinician C_2 at this point may record or interpret that same reality or representation as something very different (personal communications between clinicians and the authors, 2008–2012).



Scenario 31: The 85% Solution

A smart infusion pump ("smart" in that has a small IT system) alerts clinicians when a patient's IV bag is empty. To give himself more time to find and hang the next replacement bag, a clinician C_1 would program the smart pump to reflect that the bag was only .85 liters rather than the real amount, which is one full liter, as ordered. This gives extra time when the warning emerges. However, if there is a link between the smart pump and the EMR, the EMR will (falsely) show that the patient received only 0.85 liters. Clinician C_1 understands that the "0.85L" in $\mathcal{IT}$ to "1L" in $\mathcal{RW}$—but another C_2 (or other modules in $\mathcal{IT}$) may not. A tightly coupled automated system would incorporate the information based on the .85L into the EMR and physicians ordering subsequent medications would make judgments based on the .85 L input, not on the full L input that was actually administered. Similarly, charts reflecting input and output would also reflect that distortion.

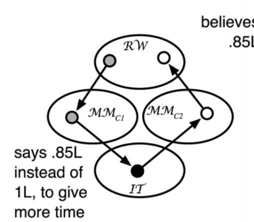


Figure 5 (Continued)

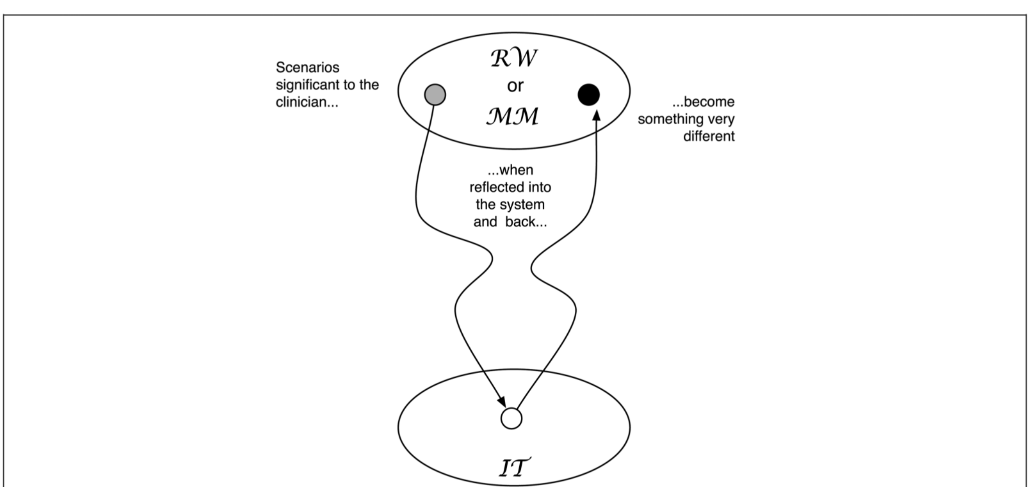
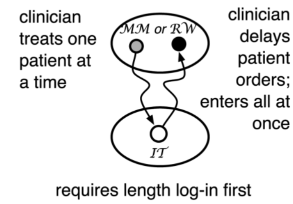


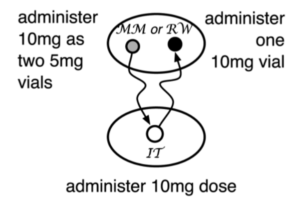
Figure 6 Representing type V problems in which the information technology functions as Alice's looking glass, reflecting scenarios of interest into a bizarre alternative reality. EMR, electronic medical records; HIT, healthcare information technology.

Scenario 32: User Authentication Too Long
During peak network traffic hours, for instance, authentication of a user can be frustratingly long, forcing certain clinicians to work around the traffic schedule and not around the patient's needs [3]. For example, a clinician may want to enter each patient's orders directly after seeing that patient; however, if authentication is too cumbersome, the clinician may delay and enter the orders for all patients all at once, later.



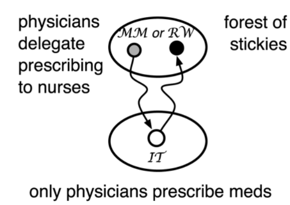
In terms of our framework, the clinician has the mental model "I want to log in as part of treating this patient." But when that mental model gets reflected through the EMR and back, the clinician ends up with a different mental model (and corresponding reality) in which the original state has been complicated with extra and unwanted properties—in this case, unclear delays or altered schedules. The implications of this alteration can be profound: medication orders may be delayed (sometimes for more than 24 hours, as in requests to start the drug "this morning" is now "next morning"); results from new tests may indicate the earlier medication order is now inappropriate; contrast dyes accompanying yesterday's x-rays may be irrelevant but still administered, etc.

Scenario 33: Dosage Multiples
In a barcoded medication administration system, the design implicitly assumed that dosages would be given as a single unit. In reality, however, clinicians encounter situations such as a 10 mg medication being given via two 5 mg tablets or vials. In such a situation, the clinician has no way to convince the system that she has administered medication matching the order [18].

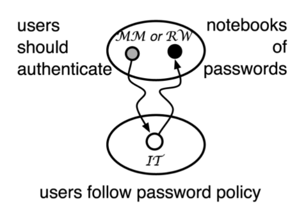


In our framework, the clinician faces the reality of giving the 10 mg does via two 5 mg tablets. The simpler reality where the clinician had a 10 mg tablet, is theoretically possible—but that's not what happened. Nonetheless, the computer system only understands the single-pill 10 mg reality; it has no representation for the two-pill 5 mg reality.

Scenario 34: A Cave of Stickies
In the standard model of medical workflow, clinicians prescribe medicine. In the model embodied in many electronic systems—and also in the minds of regulators—only a specially privileged subset of clinicians (e.g., "physicians") issue prescriptions. However, in the model as realized in many real-world workflow systems these privileged clinicians regularly delegate their privileges to nursing staff (even though this practice varies by state and may not match the law). When such institutions transfer to an EMR system that doesn't permit such delegation, frustration results. Nurses must keep records of the physicians' passwords. Because there are many passwords for each physician, and because they change so frequently, some hospital areas contain stalactites of stickies with various passwords (personal communications between clinicians and the authors, 2008–2012).



Scenario 35: A Forest of Stickies
Many enterprise IT systems—not just those in healthcare—assume a usage model where: users authenticate via passwords; the passwords are hard to remember; users use different passwords for different accounts and services; users never write the passwords down.



In fieldwork, we witnessed a clinician, with a mixture of sheepishness and exasperation, look up a specific password in a notebook. Again, the HIT designers assumed an oversimplification of the real-world scenario—and, again, clinicians found a way to keep things working that unfortunately violated the assumptions the HIT designers made [3].

This is similar to the above-noted case of medication preparation rooms where post-it notes with physician passwords plastered the walls. Added here are examples of physician RFID cards left tethered to a card reader—all to enable the real-world system to operate despite the constraints the HIT imposed. Indeed, such "forests of stickies" are often the rule, not the exception. For someone who thinks about computer security, the natural explanation is "access control restriction" —although often the root cause is simply password burden.

Furthermore, when such workarounds easily evolve, system designers and managers may not even know their assumptions do not hold—and may then make policy and other decisions based on fantasy. These rule-bending scenarios may, in fact, be closer to general operating procedures than are often recognized. The unreal views of the system designers remain untouched by feedback, by (non)observation, by fast-held beliefs and by lack of alternatives.

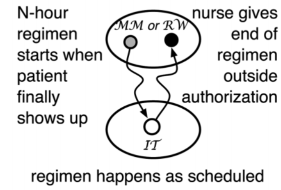
Figure 6 (Continued)

Limitations

There is no listing of distortions generated by the interactions of patients' physical reality, clinicians' mental models and HIT. We used many information sources, but there are inevitably hundreds of additional examples and scores of more use case scenarios that will emerge. We therefore make no claims of completeness. Also, as noted earlier, given the delicacy of some of the situations and the contractual restrictions preventing users of commercial HIT systems from publicly discussing 'flaws',[10] systematic collection of these examples is probably impossible.

Scenario 36: Medication Timeshift

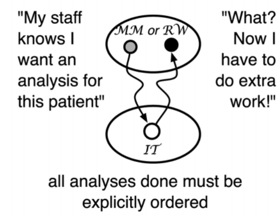
In the standard model of medical workflow, nursing staff can be authorized to administer a medication regimen to a patient for some specified number of hours (e.g., 12). In some electronic systems, the period of authorization begins exactly when the authorizer specifies. However, in most real-world workflow systems, logistical reasons can cause the time the medication regimen starts to shift later a few hours. If a nurse in such a situation finds himself with an EMR that assumes everything happens exactly as originally planned, then the nurse must either deprive the patient of the full regimen or (to accommodate the tail end of the regimen) operate outside of authorization (personal communications between clinicians and the authors, 2008–2012). However, this latter workaround has risks: for some drugs, such as insulin and aminoglycocides, administration outside the time window can have horrific consequences.



Groopman [23] notes a related problem: models of workflow systems that fail to take into account the discontinuity of clinician shift changes.

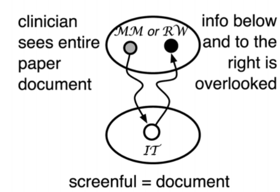
Scenario 37: Implicit Understanding/Explicit Requirements/Misplaced Frustrations

A nurse reports that, pre-EMR, the standard practice was that a certain physician would always want to order urinalysis for a certain category of patient—and thus that's what they did. However, the EMR requires that all tests and lab analyses must be explicitly ordered—so the clinicians now castigate the EMR for causing extra work.



Scenario 38: Screen Space Limited

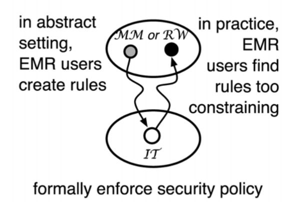
When a form or report needs to be viewed, a clinician may prefer a paper version that can be laid out such that the entire document can be viewed at once. This is not possible on a screen where the document must be scrolled vertically and horizontally or both (personal communications between clinicians and the authors, 2008–2012). Often the need to scroll is unknown to the clinician, and thus essential information is never seen. There are many reports of screens that do not inform the user that more information is below or to the right.



Similar situations arise when the GUI expects the user to "click for more information."

Scenario 39: Access Control for Thee, not Me

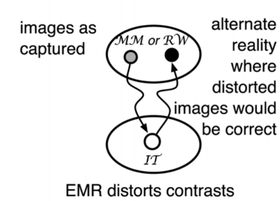
Standard practice teaches users to create access policy in terms of abstract roles; the EMR typically offers a monolithic control panel of access control settings in one place, with little or no explanation or personal relevance. However, anecdote reports circumvention, and experiment shows that reasonable EMR users, when presented with abstract access policy questions (e.g., "It is appropriate that the hospital privacy policy gives local addiction treatment programs full access to a patient's medical record if the patient is diagnosed with serious alcohol abuse") may establish policy rules that reasonable EMR users, when confronted with the same scenario but in a direct clinical setting, will find overly constraining [24].



Scenario 40: Too Few Shades of Gray

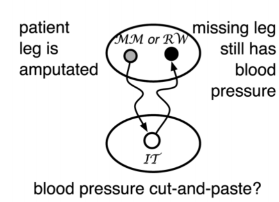
When asked whether they can see x-rays and MRIs within the EMR or whether they need to leave the system, clinicians have answered "Yes." Apparently, clinicians can see these images within the EMR, but the gray scale is off so badly that the clinicians would make incorrect judgments; seeing the images in correct contrast requires leaving the system to view the images in the dedicated image viewing software.

The EMR's images correspond to a simplified but incorrect reality.



Scenario 41: Duplication and Paste

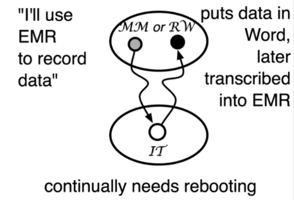
The ease of "copy-and-paste" in electronic media leads to its frequent use in EMR, which can cause repeated and even surreal data to metastasize in the record. For example, one clinician reported seeing several weeks of identical foot blood pressure readings for a patient whose foot had been amputated (personal communications between clinicians and the authors, 2008–2012). In terms of our framework, the clinician sees the reality of a patient with an amputated limb. However, when this reality is reflected through its EMR representation and back to the real world, we end up with a very different reality where the missing limb still has blood pressure.



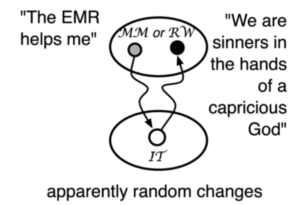
The copy-and-paste issue gives rise to much trouble. A three-page medical record can now be a 3000-page medical record; this unnatural growth makes it almost impossible for the next clinician to read and find the relevant information, and fails to reflect patient's real progress. For example, a patient entered hospital comatose and immobile from a car accident. The patient walked out of the hospital three weeks later without assistance. However, until the last hour near discharge, the patient record showed the same comatose and immobile status. Copy and paste hid all progress and action.

Figure 6 (Continued)

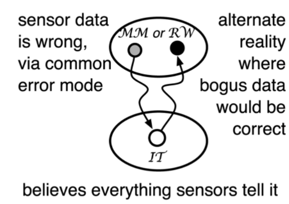
Scenario 42: System Startup Took Long
Outdated hardware combined with off-the-shelf software can take too long to reboot when the clinician desires critical information or functionality [3]. For example, clinicians in one ICU floor reported that they spent most of their time on the computer rebooting because they frequently lost connection with their routers. As a consequence, rather than entering data directly into the EMR when treating patients, they created WORD templates for mobile use, and later transcribed the data into the EMR. The WORD template was a poor mirror of the EMR, required double entry, and increased the likelihood of transcription errors.



Scenario 43: Perceived and Actual Unreliability
Some users find the computerized system unreliable or untrustworthy. Systems with a perceived history of failing at critical moments will lose user trust [22]. Systems get weekly or daily patches; the IT department makes daily alterations; drugs fall off formularies or are shifted; rules about tests are changed frequently; *drug-drug interaction* alerts and dosage alerts change frequently. Clinicians feel that things just appear and disappear without any understandable reason.



Scenario 44: Faulty Equipment with Digital Directness
A clinician reports that in a pre-electronic world, it was well-known that certain medical instrumentation devices had common failure modes (e.g., the sensor fell off the patient or the wire leading to the sensor pulled out when the patient rolled over in bed). When the clinician entered the readings into the patient record, the clinician would recognize potential error cases and investigate before recording them as fact. However, when the instrumentation is wired directly into the EMR without this vetting, the recorded configuration in the $\mathcal{IT}$ can reflect elements of a reality that did not exist in $\mathcal{MM}$ or $\mathcal{RW}$ (personal communications between clinicians and the authors, 2008–2012).



Scenario 45: Correcting Faulty Equipment with Digital Directness
Litigation reveals the opposite situation has also happened: instrumentation reported correct but unusual data, and the computer system incorrectly decided that was an error and "fixed" them [25]. For example, a patient may be near death and showing profoundly low blood pressure. The computer, working off of preset algorithms, "assumes" it is a false reading and "raises" it to be within the permissible range.

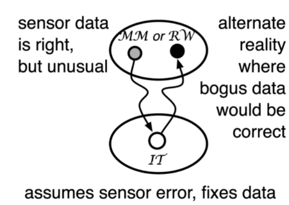


Figure 6 (Continued)

In that this paper is a conceptual typology of problem scenarios, data source limitations are obvious but only temporarily problematic. New scenarios will be offered and evaluated. If they do not apply, they will be quickly removed from consideration. If they are helpful to improving HIT, they will be included.

To our knowledge, this is a new typology, incorporating the commonalities of HIT functions and medical workflow. Undoubtedly, there are areas of possible overlap, but we have made every effort to disambiguate and clarify. There are also inevitably missing elements, and we assume further refinements are probable. Also, we did not include a separate node for patients' mental models—a most worthy addition that we hope will be addressed in future research.

CONCLUSION

Our goal is to attenuate the gaps among patients' realities, clinicians' mental models, and representations of those realities in EMR—and perhaps to offer some insights about how clinicians gather information about patients' conditions via EMRs. We hope our typology and scenarios enable HIT designers and implementers to reduce their systems' ambiguities, missing elements, over-generalized or too granular categories, obfuscated data and uncertain navigation. The scenarios we present, then, are intended to guide both our understanding of misrepresentations (the typologies) and as tools for addressing each distortion or inadequate presentation of reality. The typology is thus a first step to make HIT work better with patients, clinicians' cognitive models, data (structured, unstructured, misclassified) and our representations of all three.

Updates

We invite readers interested in tracking updates to this work—or contributing new examples—to visit our website, http://www.cs.dartmouth.edu/~trust/emr-usability/

Also, a more challenging approach would be to rethink the IT system a priori, to prevent them before they occur or to address these troublesome scenarios on the fly. To this end, one of the authors is currently exploring using capabilities to support dynamic user-directed reconfiguration, and another author is developing seamless ways of reporting problems to vendors and IT leaders.

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both contributed sections to the initial document and both were repeatedly involved in editing and finalizing the document. RK wrote the first draft of the response letters, but SWS edited the final versions.

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Data sharing statement These are models based on observations, interviews, and literature. There are interview forms from which some of these data derived. The authors could share those interview results when they are de-identified fully.

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Healthcare information technology's relativity problems: a typology of how patients' physical reality, clinicians' mental models, and healthcare information technology differ

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