

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/

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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).

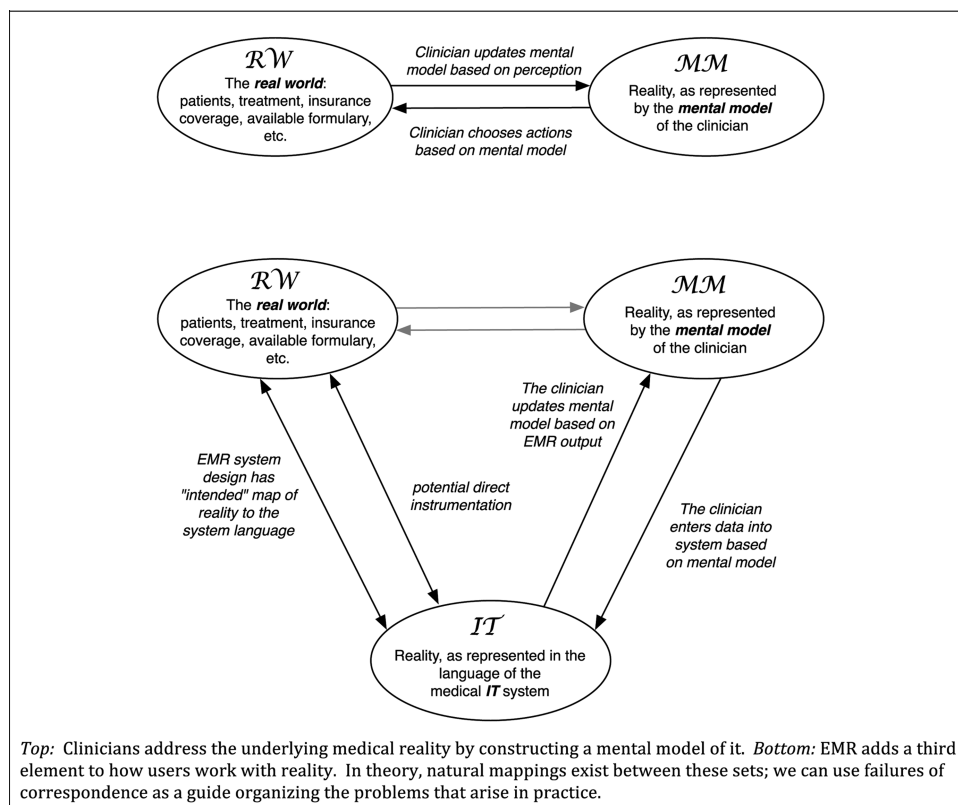


Figure 1 Clinician mental models of patient conditions, and their interaction with EMR. EMR, electronic medical records; IT, information technology.

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

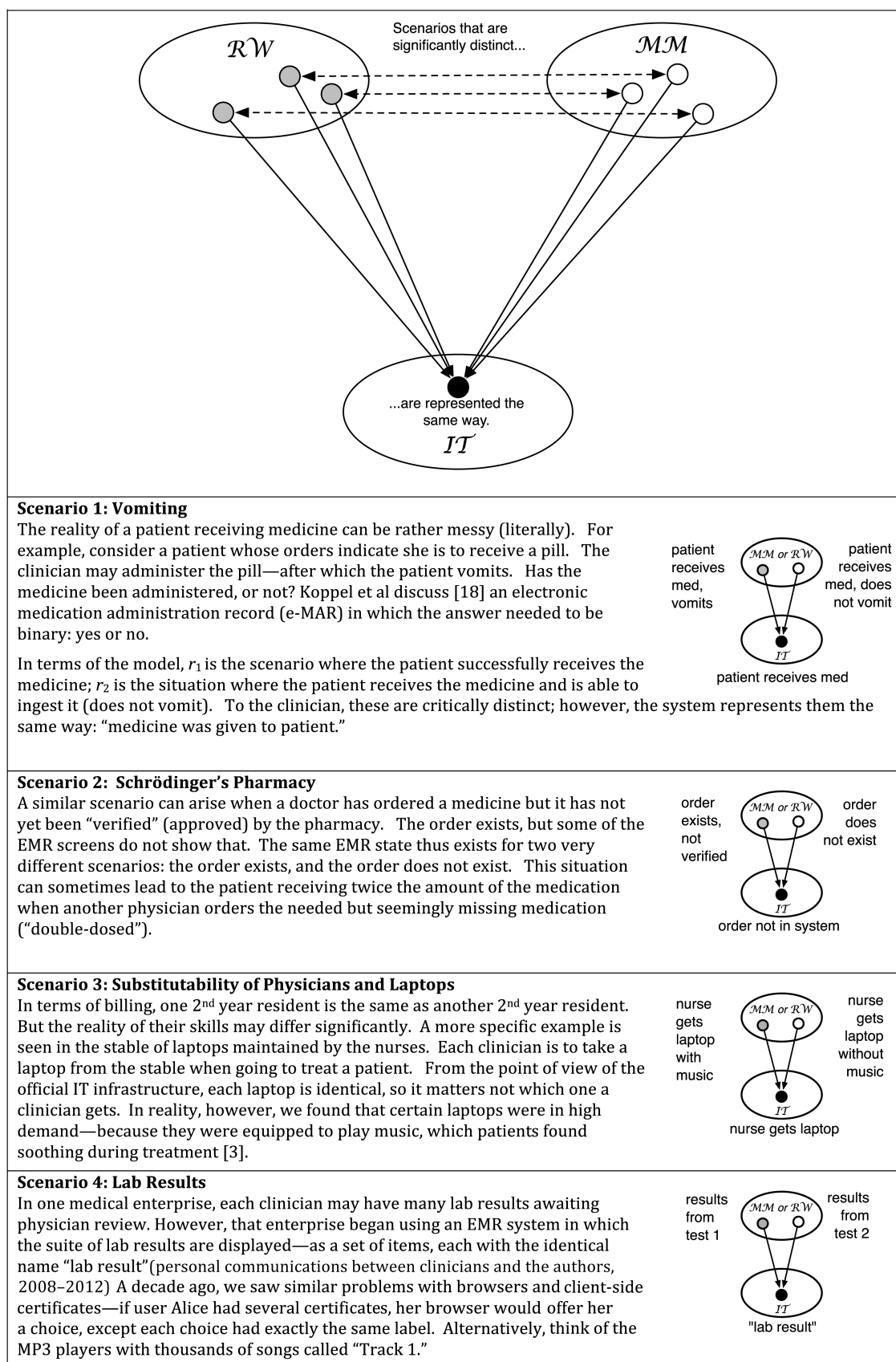
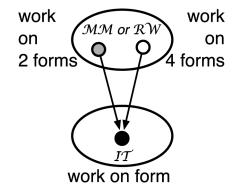


Figure 2 Representations of type 1 problems in which the language of the HIT is too coarse, erasing significant distinctions. EMR, electronic medical records; HIT, healthcare information technology; IT, information technology.

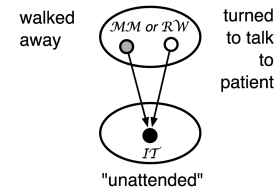
Scenario 5: Open Forms

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).

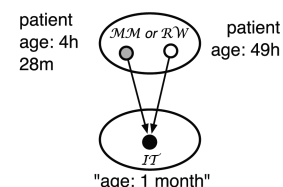
**Scenario 6: Timeout**

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).

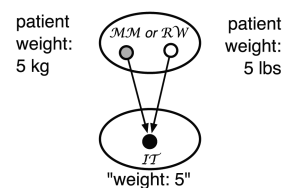


Figure 2 (Continued)

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

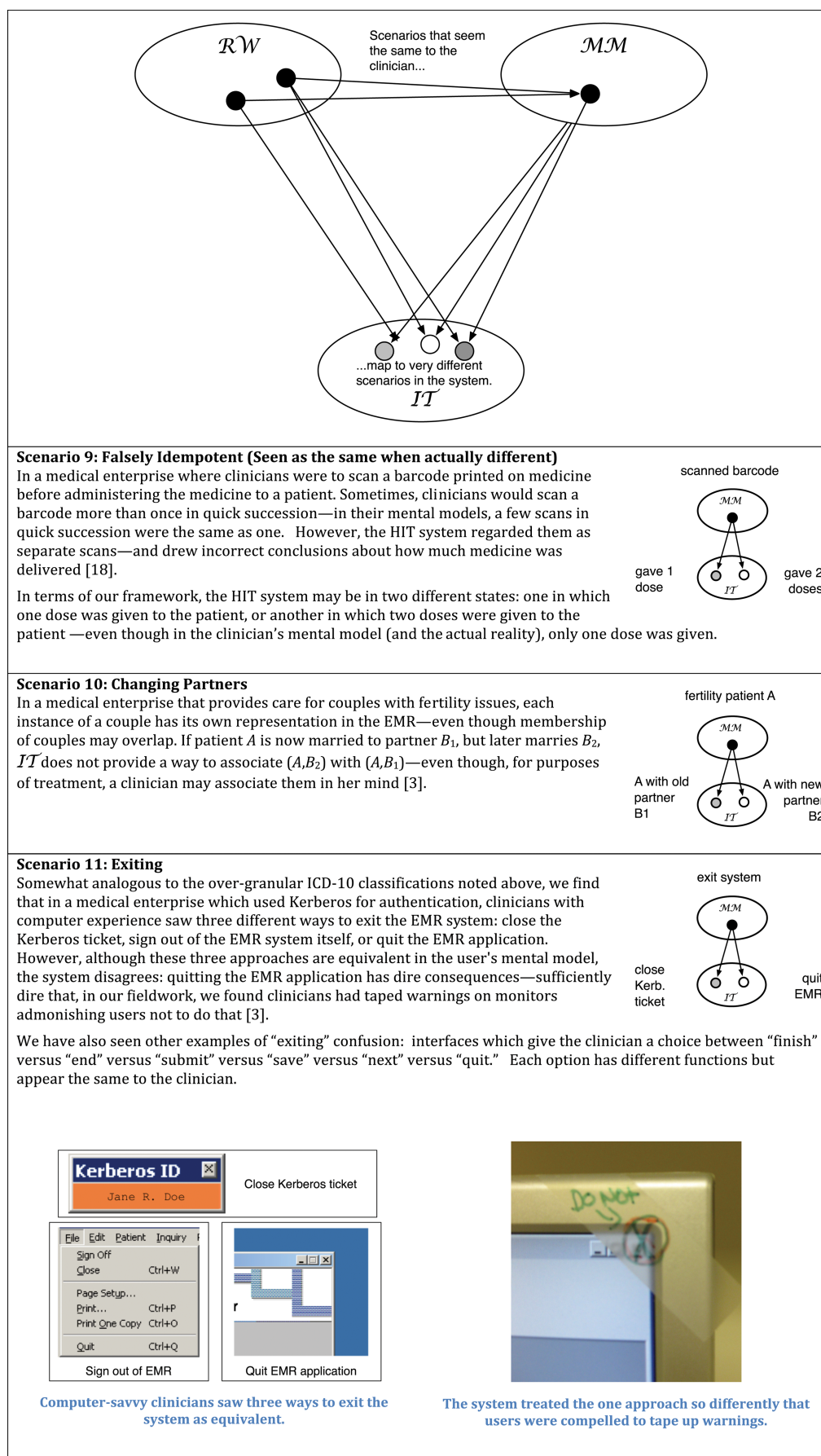


Figure 3 Representations of type II trouble spots in which the language of the HIT is too fine, introducing distinctions that the user does not regard as significant and/or of which he/she may not even be aware. EMR, electronic medical records; HIT, healthcare information technology.

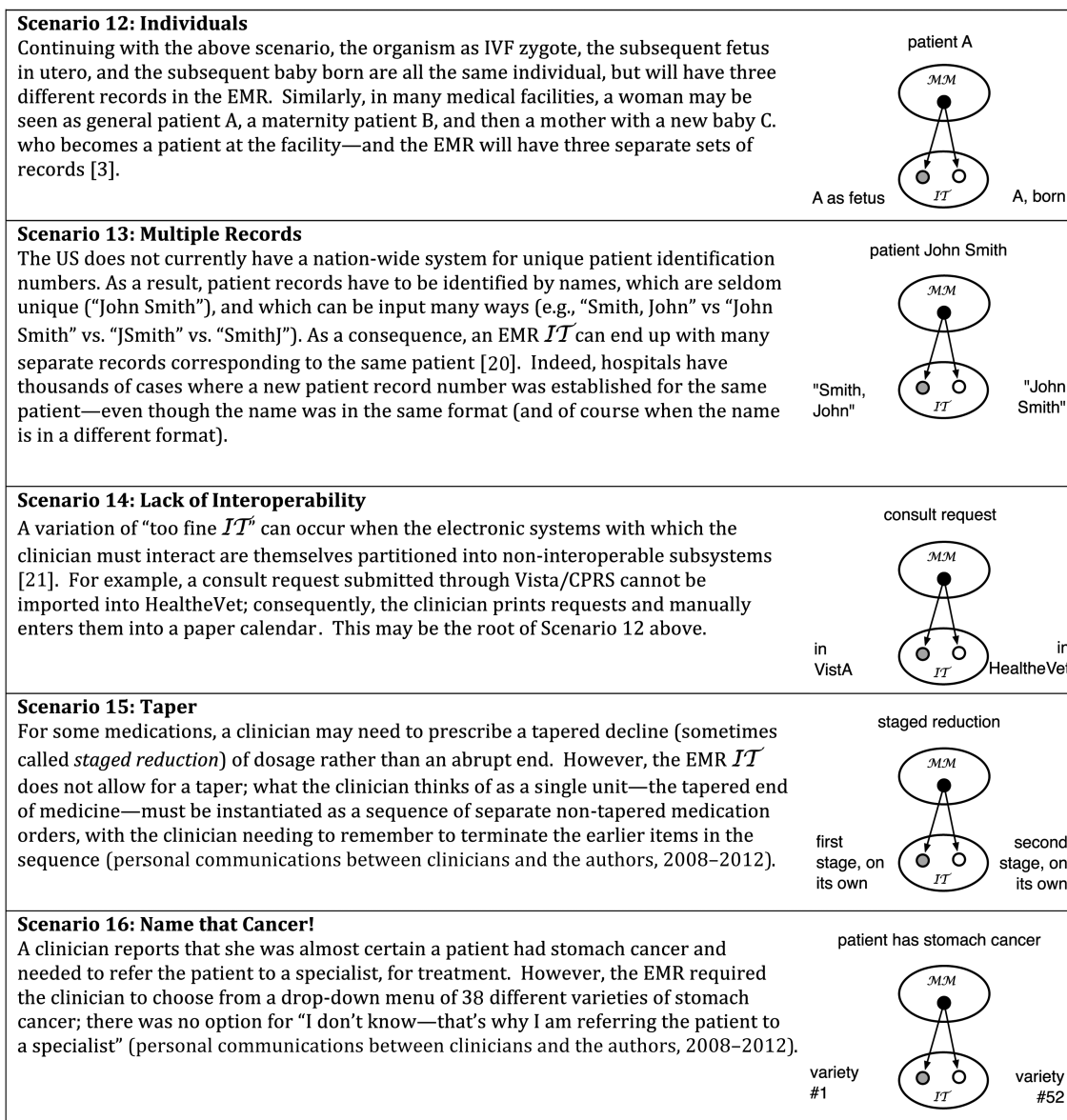


Figure 3 (Continued)

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

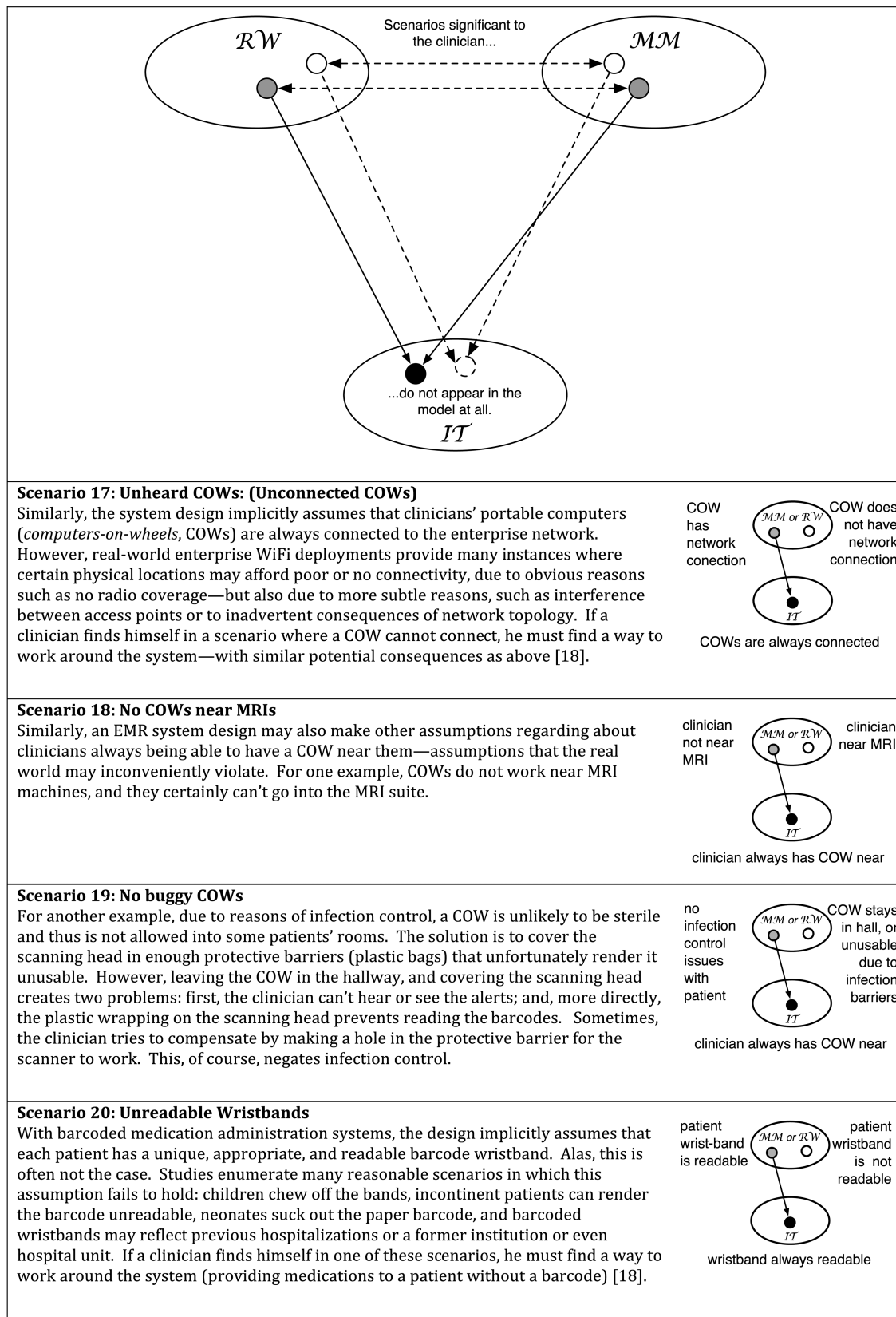


Figure 4 Representations of type III problems arising because the HIT misses critical detail—even though mapping between the system language and mental models may be articulate, it only covers a proper subset of the relevant mental models. COW, computers on wheels; EMR, electronic medical records; HIT,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

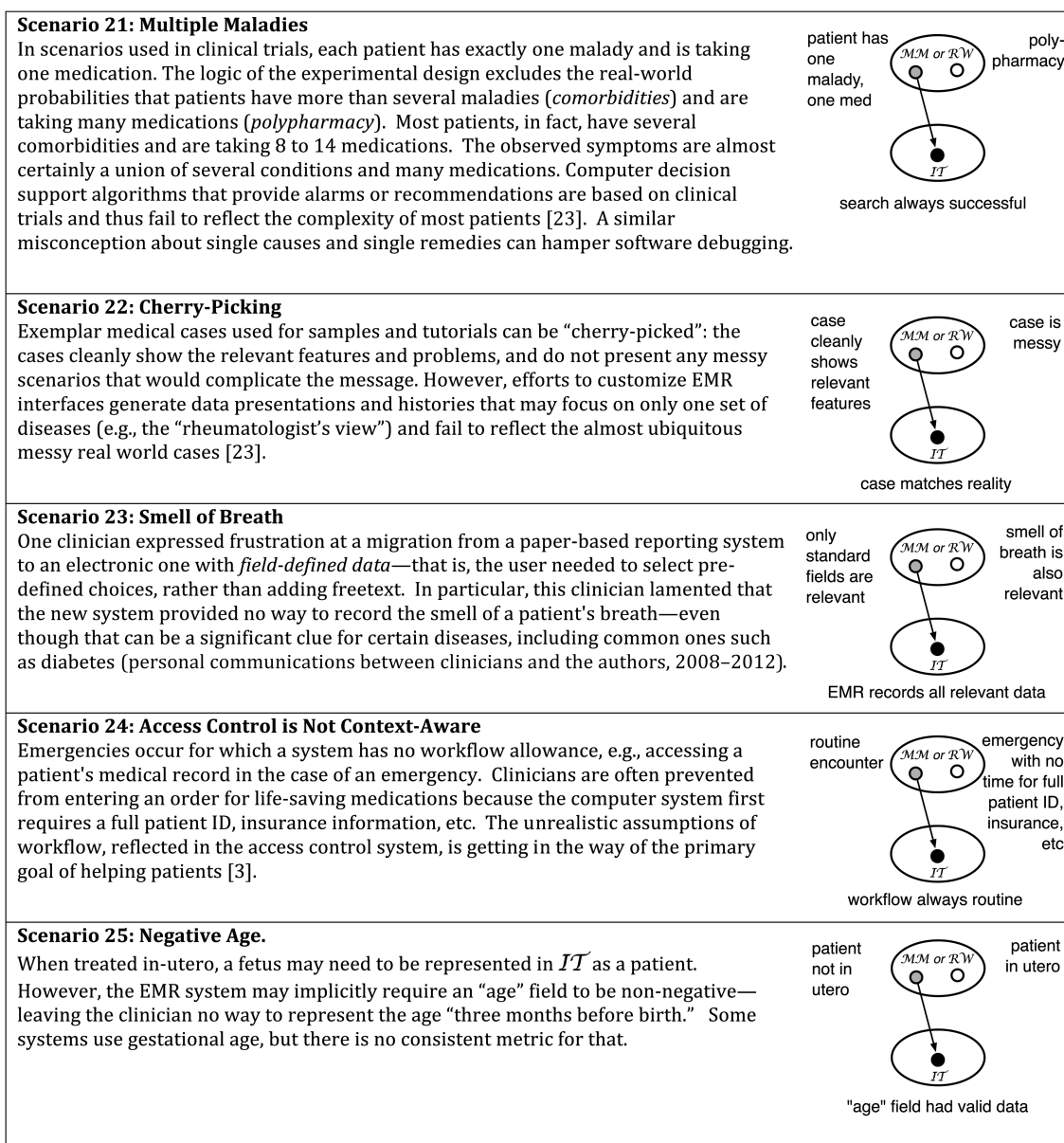


Figure 4 (Continued)

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

analysis² 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 screenshot²⁸ 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’.

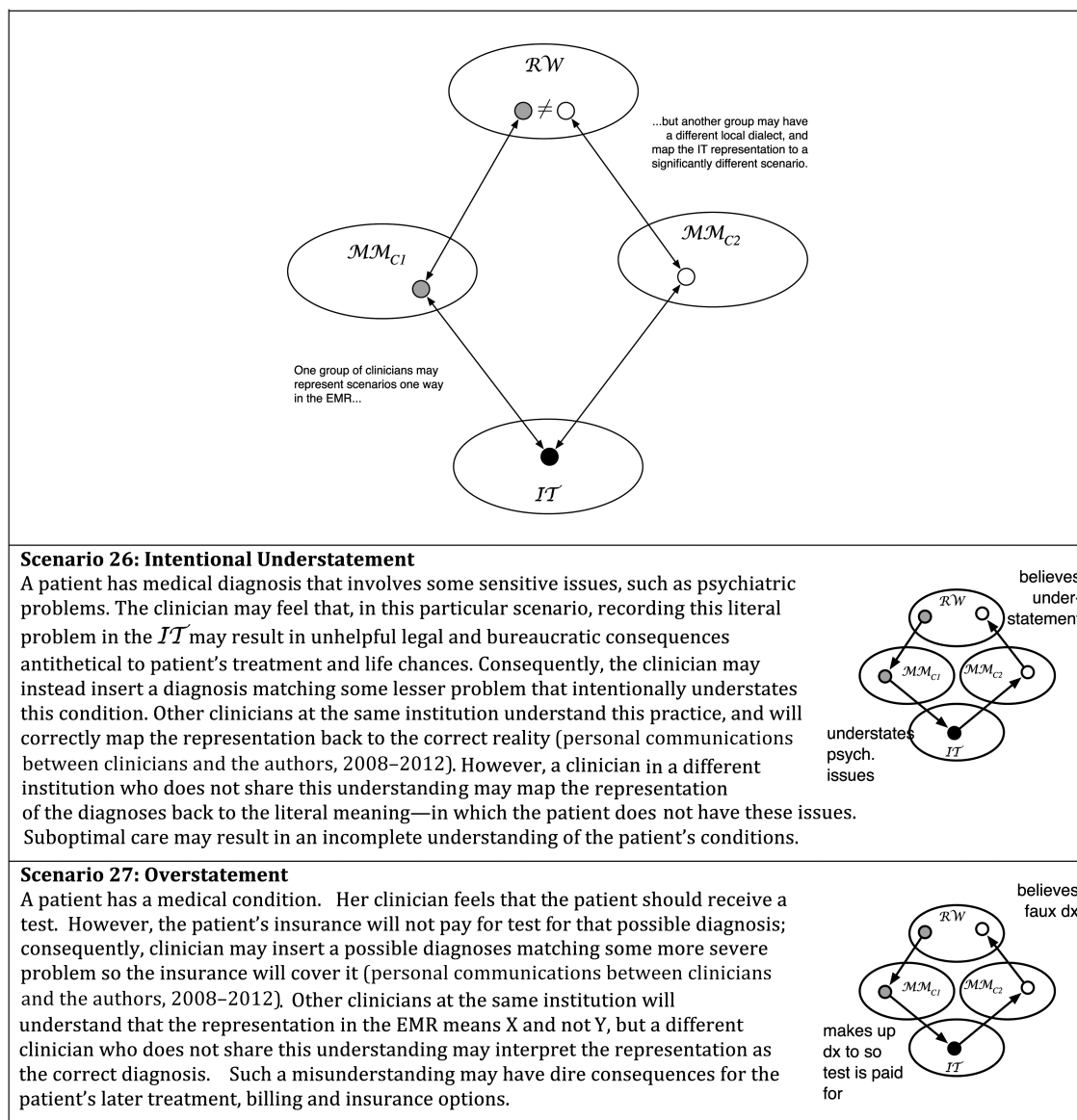


Figure 5 Representing type IV problems in which ambiguities arise because of multiple communities. Local user cultures apply implicitly understood distortions to their use of the system language, which causes users who do not share that understanding to draw significantly incorrect conclusions about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

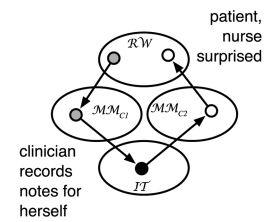
As discussed above, we also need to recognize and address the role of the myriad other IT systems that interact with each HIT system. Problem solving often requires understanding how several IT systems work together, or do not.

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.

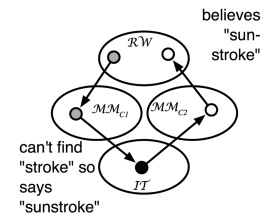
Scenario 28: Multiple Viewers

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.

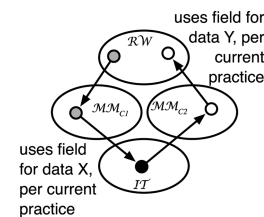
(On the other hand, unfortunately, the natural solution of having different users see different screen views also causes problems: the nurse may see a different screen from the physician, and draw different conclusions about the patient’s condition (personal communications between clinicians and the 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 (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 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 IT to “1L” in RW —but another C_2 (or other modules in 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.

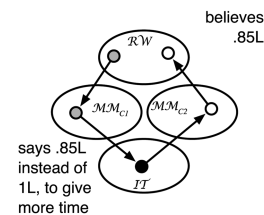


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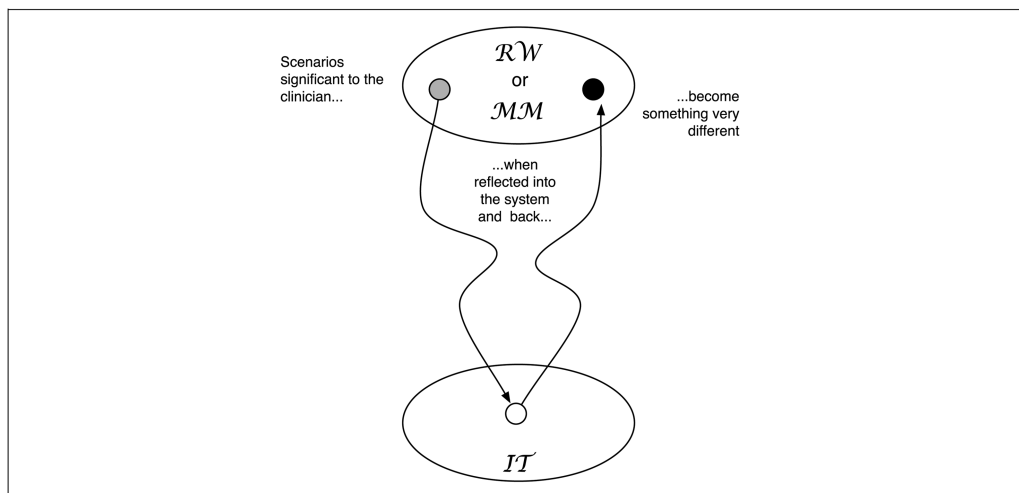


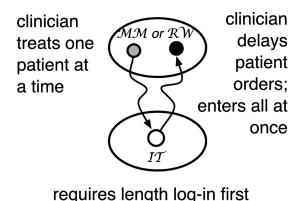
Figure 6 Representing type V problems in which the information technology functions as Alice’s looking glass, reflecting scenarios of interest into a bizarre alternative reality. EMR, electronic medical records; HIT, healthcare information technology.

Research and applications

Scenario 32: User Authentication Too Long

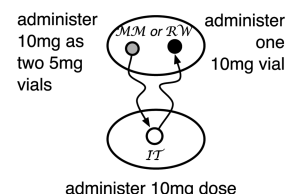
During peak network traffic hours, for instance, authentication of a user can be frustratingly long, forcing certain clinicians to work around the traffic schedule and not around the patient's needs [3]. For example, a clinician may want to enter each patient's orders directly after seeing that patient; 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.

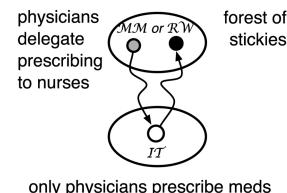
**Scenario 33: Dosage Multiples**

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 dose 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.

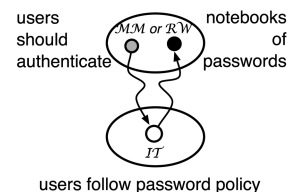


Figure 6 (Continued)

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 aminoglycosides, 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)

Research and applications

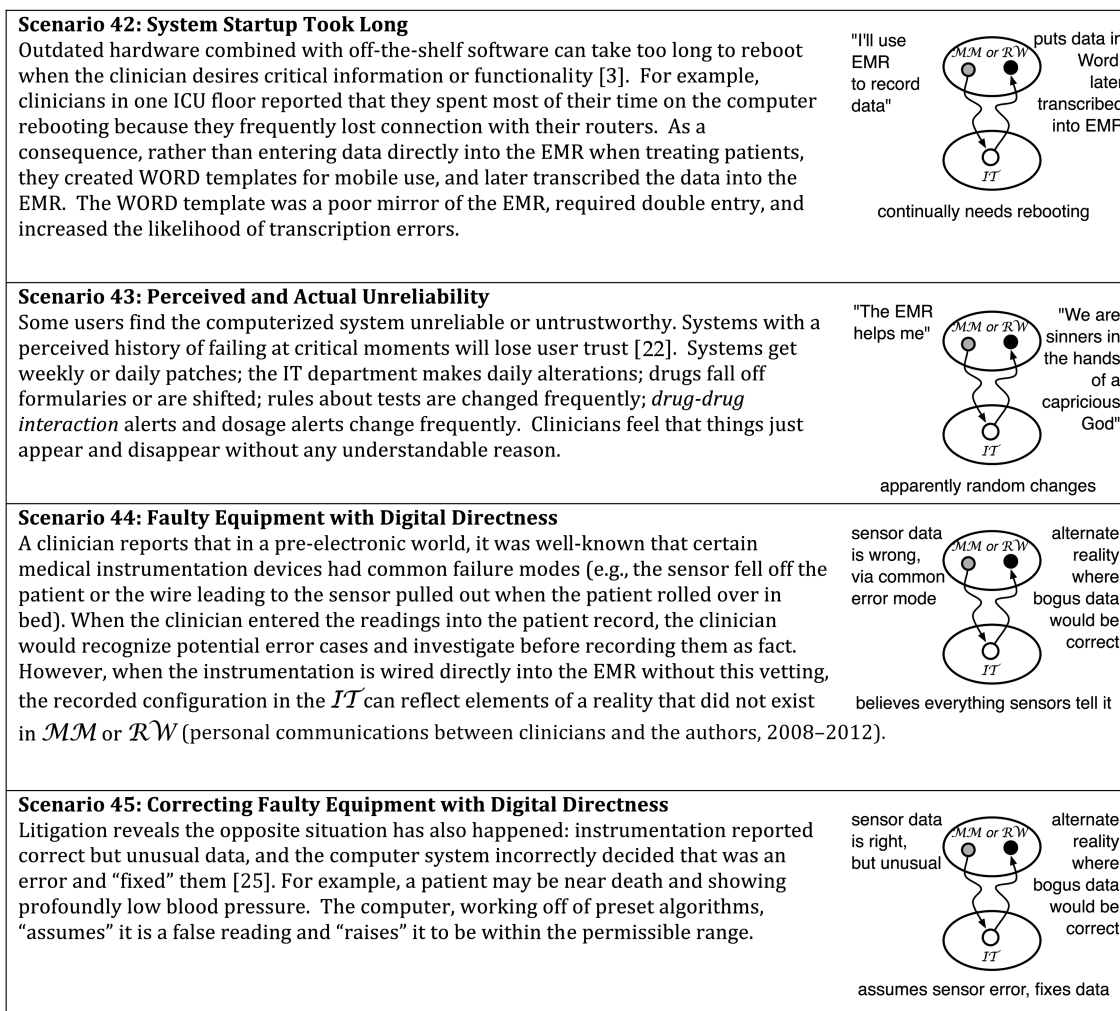


Figure 6 (Continued)

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.

REFERENCES

- IT Projects Have a 70% Failure Rate: Don't Let Your Hospital IT Projects Fail. *HIMSS Industry Solution Webinar*. Chicago, IL, USA: Healthcare Information and Management 2012.
- Harrison M, Koppel R, Bar-Lev S. Unintended consequences of information technologies in health care—an interactive sociotechnical analysis. *J Am Med Inform Assoc* 2007;14:542–9.
- Sinclair S. *Behavioral Information Security: Problems With Access Control in the Real World*. PhD thesis, Dartmouth College Computer Science, 2012. Forthcoming.
- Norman D. *The design of everyday things*. Basic Books, 2002.
- Jones SS, Koppel R, Ridgely MS, et al. *Guide to Reducing Unintended Consequences of Electronic Health Records*. Prepared by RAND Corporation under contract no. HHS2902006000171, Task Order #5. Agency for Healthcare Research and Quality (AHRQ). Rockville, MD. August, 2011.
- US Food and Drug Administration. *CDRH reports*. <http://www.fda.gov/AboutFDA/CentersOffices/OfficeofMedicalProductsandTobacco/CDRH/CDRHReports/default.htm>
- US Food and Drug Administration. *Manufacturer and User Facility Device Experience Database—(MAUDE)*. <http://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/PostmarketRequirements/ReportingAdverseEvents/ucm127891.htm>
- Sinsky C, Hess J, Karsh B-T, et al. *Comparative user experiences of health IT products: how user experiences would be reported and used*. Institute of Medicine of the National Academies, 2012.
- Middleton B, Bloomrosen M, Dente M, et al. Enhancing patient safety and quality of care by improving the usability of electronic health record systems: recommendations from AMIA. *J Am Med Inform Assoc* 2013;20:e2–e8.
- Koppel R, Kreda D. Health care information technology vendor's 'hold harmless' clause: implications for patients and clinicians. *J Am Med Assoc* 2009;301:1276–8.
- Culnan MJ. Mapping the intellectual structure of MIS, 1980-1985: a co-citation analysis. *MIS Q* 1987;11:341–53.
- Mingers J, Stowell F, eds. *Information systems: an emerging discipline?* London: McGraw-Hill, 1997.
- Kagolovsky Y, Freese D, Miller M, et al. Towards improved information retrieval from medical sources. *Int J Med Inform* 1998;51:181–95.
- Solskinnsbakk G, Gulla JA. Combining ontological profiles with context in information retrieval. *Data Knowledge Engl* 2010;69:251–60.
- Jansen BJ, Spink A, Saracevic T. Real life, real users, and real needs: a study and analysis of user queries on the web. *Info Process Manag* 2000;36:207–27.
- Kaptelinin V. Activity theory. In: Soegaard M, Dam RF, eds. *Encyclopedia of human-computer interaction*. The Interaction-Design.org Foundation. http://www.interaction-design.org/encyclopedia/activity_theory.html
- Wickens CC, Lee JD, Liu Y, et al. *An introduction to human factors engineering*. 2nd edn. Pearson Prentice Hall, 2004:185–93.
- Koppel R, Wetterneck T, Telles JL, et al. Workarounds to barcode medication administration systems: their occurrences, causes, and threats to patient safety. *J Am Med Inform Assoc* 2008;15:408–23.
- Koppel R, Metlay J, et al. Role of computerized physician order entry systems in facilitating medication errors. *JAMA* 2005;293:1197–203.
- Koppel R. *EMR entry error: not so benign. Technical report*. Agency for Healthcare Research and Quality, 2009.
- Miller RH, Sim I. Physicians' use of electronic medical records: barriers and solutions. *Health Aff* 2004;23:116–26.
- Saleem J, Russ A, Neddo A, et al. Paper persistence, workarounds, and communication breakdowns in computerized consultation management. *Int J Med Inform* 2011;80:466–79.
- Groopman J. *Diagnosis: what doctors are missing*. The New York Review of Books, 2009.
- Wang Y, Smith SW, Gettinger A. Access control hygiene and the empathy gap in medical IT. *Proceedings of the USENIX Workshop on Health Security and Privacy*, 2012.
- Ridgely MS, Greenberg MD. Too many alerts, too much liability: sorting through the malpractice implications of drug-drug interaction clinical decision support. *Saint Louis Univ J Health Law Policy* 2012;5:257–96.
- Cimino J. Improving the electronic health record—are clinicians getting what they wished for? *JAMA* 2013;309:991–2.
- Felten E. "Too Stupid to Look the Other Way." *Freedom to Tinker*, 29 October 2002.
- Cooley JA, Smith SW. Privacy-preserving screen capture: towards closing the loop for health IT usability. *J Biomed Inform* 2013, In press.
- Koppel R. In: Leviss J, et al., eds. *Foreword to H.I.T. or miss, lessons learned from health information technology implementations*. 2nd edn. Chicago: AHIMA Press, 2013.



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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