Temporal Cognitive Work:
Discovering Requirements for Digital Artifacts

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Abstract

Effective clinical decisions rely on the ability to synthesize many different streams of data to manage individual patient care and acute care units. Recent developments in information technology (IT) have made more of the kinds of data that are related to patients available to clinicians. Data availability, however, does not equal data utility. For data to be useful, they must fit clinician cognitive work. *Representations* can be used to assist clinician judgment through the use of symbolic visualization. Representations assist human skills such as pattern recognition by synthesizing different types of data in a diagrammatic manner. *Patient-level* representations can be used to support crucial tasks such as the comparison and contrast of various data, and trend assessment. *Unit-level* representations can assist decisions on patient care strategies and resource allocation, and can demonstrate the newly-evolving notion of technical work. Representations would support clinicians in the operating room (OR) and ICUs, where data change most often and are used most often to make crucial decisions. They would be of particular help in the rapidly-developing setting of remote telemetry ICUs and would also support the hand-off of patient and unit-level information between shifts.

1. Introduction

As two of their strategies to improve patient safety, the Institute of Medicine (IOM,1999:177,183) recommended improving access to accurate, timely information, and making relevant information available at point of patient care. Previous research (Nemeth, 2003) demonstrated the use of cognitive artifacts to understand how clinicians plan for and manage the uncertainty and complexity of acute care technical work. *Cognitive engineering methods* (Woods and Roth, 1988) can yield further insights into the nature of individual and group cognitive activity. This paper examines the role of representations to support cognitive work in the clinical settings that require the greatest information flow per patient: the intensive care unity (ICU) and emergency department (ED).

Air and ground transportation, nuclear power, the military, and healthcare are all high hazard, complex, uncertain environments. Operator performance in these settings requires the ability to appreciate previous and current states of the system in which they work, and to foresee the implications of previous and current circumstances for what is to follow. In complex systems, these activities rely on the use of one or more displays. By *display* we mean a visual or auditory representation of information, which can include many different kinds of media such as paper copies of photos, diagrams, tables, maps, and electronic versions of these items. An anesthesia coordinator workstation could be considered a display, as it incorporates all of these items to support the daily cognitive work of managing anesthesia assignments. Representations are presentations to a viewer or listener in the form of an idea or image. Representations are embodied in cognitive artifacts (Hutchins, 1995) that are intended to portray an abstract or physical concept for the purpose of explanation. The more clearly one understands a concept, the better the representation.

2. Cognitive Work in Healthcare

The coordination of anesthesia assignments at a major urban teaching hospital spans 50 to 80 cases a day and requires the orchestration of multiple departments. A few of the senior anesthesiologists serve in the role of daily coordinator, assigning staff members to perform a full schedule of anesthesia, sedation or pain management procedures each weekday. To do this, the coordinator must evaluate the number and types of procedures, determine the number and types of staff members who are available, assign individuals to perform procedures, and evaluate the balance between procedures and assignments. This planning process requires deep domain knowledge and deft diplomacy. It also requires the ability to exploit opportunities, to create trial solutions and to assess their possible consequences. Until recently, the coordinator would use only hard copies of the artifacts to develop the master schedule. During the day the coordinator would track and update case status by making marks on the master schedule hard copy that was posted at the operating rooms (OR) coordinator station. Team members also used the OR Board, a white marker board with magnetic plaques, as a platform to discuss assignments, negotiate trade-off decisions, plan and re-plan assignments, speculate about how to re-balance changes in demand and staff.

Both hard copies of the master schedule and the computer-based system that replaced it were organized according to room locations for procedures. However, neither reflects the time-related requirements and complexity that are the primary drivers in this environment. Requirements are the objects of coordinator cognitive work, such as showing conflicts and gaps in timing, and constraints on schedule management such as room clean-up and restocking. Because time is the key aspect here, organizing display design according to time allows users to easily track changes, to anticipate future events, and to respond to emerging situations. By using a graphic representation that is organized according to time, the team can review the entire day’s activities while they are still underway, and understand and evaluate relationships among events as they evolve.

3. Ecological Displays for Healthcare

Beyond the OR, the intensive care unit (ICU) and emergency department (ED) require the greatest information flow per patient. Understanding of how clinicians plan for and manage the uncertainty and complexity of technical work in the OR can provide a foundation to understand the cognitive demands of clinical and technical work. Rather that direct clinician decisions, skillfully crafted representations make clinician judgment easier and more efficient. They do so by portraying the relationships among domain semantics in the actual acute care setting at the level of an individual patient, or at the level of the unit. *Patient-level* representations synthesize different types of data through the use of diagrams that leverage human skills such as pattern recognition. Patterns and symbols can be used to support crucial tasks such as the comparison and contrast of various data, and the assessment of trends. *Unit-level* representations reflect the newly-developing understanding of *technical work* (Cook, Woods, and Miller, 1998). Such information spans groups of patients, the current number of patients on the unit, their locations and condition, pending and in-progress diagnosis and treatment, current care providers, and prospective transfer in or out of the unit. Clinicians compare both patient and unit data in many instances. For example, they make comparisons when considering which patients should remain in an ICU and which should be "bumped" to the patient floor to make way for more acute patients. (Cook, 1998)

Representation assemble scale, relationships, history and trends to evoke meaning from information. A computer-supported cognitive artifact's design must represent the constraints and opportunities that are relevant in this work domain. To be effective, displays (which can contain many representations) must reflect the work domain's elements. Representations synthesize pertinent elements including scale, relationship, and other aspects of cognitive work that clinicians would otherwise have to combine on their own. They also offer the potential to refine the way that data and information are presented. For example, uncertainty and contingency are inherent in the ICU and ED setting but current information displays are blind to these issues. Representations that reflect variations in certainty such as low or high confidence in a data source would better reflect domain semantics. Effective representations *spare operators the task of data synthesis* by accounting for a wealth of discrete elements through summary, or abstraction (Rasmussen and Pjetersen, 1995). They also *enrich operators' ability* to contemplate problems and to envision opportunities. Because of this, effective ecological displays and the representations that they convey offer substantial potential to benefit clinical care and to improve patient safety.

Clinicians develop their own intrinsic mental models of patients and of unit activity in high tempo settings such as the ICU and ED. They rely on discrete cognitive artifacts as part of the *distributed cognition* (Hutchins, 1995) that is required to operate in the unit's uncertain, contingent, tentative and fast-changing circumstances (Figure 1). The left panel in Figure 1 suggests how these elements relate to each other. The left panel portrays the current circumstance in which clinicians develop their own mental model of each patient and of the unit as a whole. Data sources are separate and vary widely. Sources include a unit status board that shows planned procedures and staff assignments, a monitor that shows vital signs telemetry for each patient in the unit, patient chart information, and more. The task of pulling together all of the individual elements of data

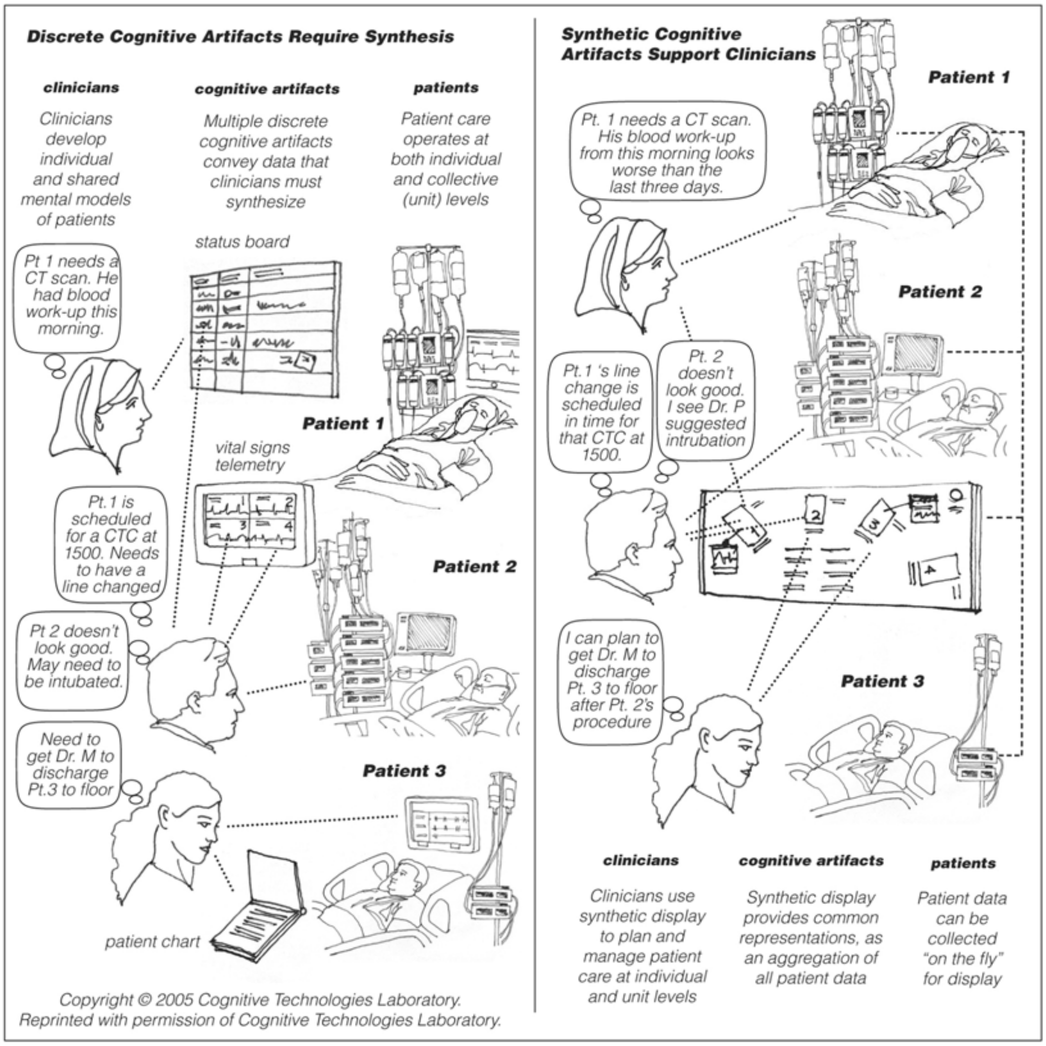

Figure 1: Current and prospective representations affect clinician cognitive work

into a coherent mental model falls to the clinician. Mental models for patients and the unit can differ depending on what artifacts each clinician has seen. The figure's right panel suggests an approach to support for the cognitive work clinicians perform that synthesizes data on behalf of the clinicians. The cognitive artifact at right depicts the entire unit based on the past, current and anticipated data that are related to each patient. As data that is related to each patient changes, the patient's representation changes. As patient representations change, the representation of the unit changes. In the setting that is shown at right, clinicians have the opportunity to probe for more particular data that is related to an individual patient, or to view the unit as a whole. This is not a solution that simply collects vital signs data into one display. Rather, it is an information ecology that is created to assist the way that clinicians work. Such an approach can be primarily graphical with alphanumeric elements, or primarily alphanumeric with graphical elements. However it is configured, the fundamental significance of a representation is not in its visual qualities. Its value lies instead in how well its visual qualities correspond to elements in the work domain that it is intended to represent—what Woods and Hollnagel (1987) refer to as its *domain semantics*. It is the transition between data and task that informs the manner in which representations are developed.

4. Healthcare Representations Shape Patient and Unit Level Clinical Care

Many of the work domains for which cognitive engineering research has been performed are stationary and well-bounded. For example, a nuclear power plant is a high hazard operation, but its condition can be known and its limits can be defined. By contrast, healthcare involves the provision of services to prevent, treat, and manage illness and to preserve mental and physical well-being. The flow of work activities is often much less linear, roles are defined more flexibly and can overlap, and the differences between procedural steps can be less distinct than they are in other sectors. (Ash, Berg, and Coheira, 2004: 110) Clinicians work on compromised systems (patients) who respond in different ways to therapeutic intervention. Healthcare is discretionary, involving the *ad hoc* assembly of information, equipment, and interventions to provide for unique and widely varying patient needs. It is poorly bounded. It is also subject to the influence of many actors among multiple departments and facilities and considerations of technical work such as unit-level planning and management.

As in other high hazard settings, expertise (Feltovitch, Ford, and Hoffman, 1997) in healthcare is the ability to know what is—and what is not—important. Individual elements of information vary enormously in the length of time that they remain reliable, and their weight depends a great deal on their context. The need for accurate, timely information also exists at the unit level, such as the Intensive Care Units (ICU) and emergency department (ED), where the technical work of unit planning and management directs who will get care, what type of care will be provided, and when it will be provided. Healthcare activities rely on the acquisition, portrayal and analysis of therapeutic and diagnostic information as an integral part of individual patient care. The daily work of the clinician requires representations that serve as a map of the ever-changing territory of work that must be successfully navigated. (Rassmussen and Pjetersen, 1995:132) What is represented, and how it is represented, depends on the cognitive work that it is intended to support.

Healthcare relies on the description of process and condition. For each ICU patient, multiple diagnostic and therapeutic processes are underway, about to be started, or being concluded. Each patient’s condition can be accounted for by a spectrum of variables that are interrelated, and their interactions exceed the ability of clinicians to perceive them. The internal processes in a patient and the processes that influence how an acute care hospital unit operates cannot be entirely known through direct observation. Even under the best circumstances, there is an irreducible uncertainty that dogs clinicians’ ability to fully grasp the phenomena for which they are accountable. Recent increases in coordination demands due to staff resource limits place even greater need for reliable exchange of information in instances such as between-shift hand-offs. For these reasons, representations that accurately depict reality are crucial to successful healthcare. The presentation of information bears directly on the clinicians' ability to develop an effective mental representation of past, current and prospective states of patients under their care.

5. Broader Issues for IT in Healthcare

This paper has described multiple examples that need high quality human-computer interaction (HCI) features in order to support clinical work. HCI has long been viewed as a cooperative relationship between user and computer. (Norman and Draper, 1986) While that cooperative notion is widely acknowledged, it is seldom put into practice. Systems will need to perform as a "team player" (Christofferson and Woods, 2000) alongside clinicians if they are to both deliver the improvements that IT makes possible and avoid the introduction of new forms of failure. These issues are particularly acute in healthcare, because this setting is many times more complex than other application areas that are easier to support. Healthcare's variety in demand and practice, time pressure, resource constraints, and uncertainty as well as rapid changes to knowledge, people, technology, and organizational structures demand IT solutions that can evolve easily and quickly. Static, generic, or "homegrown" support tools are a poor fit.

IT systems are often touted as a way to improve patient safety, having attractive user interaction features "will be implemented" once the system has been put into operation. However, the inherent complexity of these new systems and the high cost of integration into existing systems cause managers to delay introduction of added value features. Once in operation, the need for stability, the pressures of high operational tempo, and the lack of resources make retrofitting high quality HCI features difficult or impossible. This forces users to create their own workarounds to compensate for features that never arrive.

IT system research has traditionally disregarded the sophistication that workers use to create success in the face of work environment complexity. (Heath and Luff, 2000:3-4) Failure to understand the work they are supposed to support leads IT developers to make two incorrect suppositions: work is uncomplicated, and workers simply need to be reminded of what is important or how to do specific things.

Our lab studies practitioner cognitive work as it is revealed by their use of cognitive artifacts. Through this approach, we discover situations that are problems for workers. We also discern work domain boundaries and constraints, and how clinicians operate within them. Our understanding of how people do their work in this setting leads us to conclusions that are different than the "blame and shame" accusations that assume individual culpability. We don't view work failures as evidence of deviant behavior. We instead see them as evidence that circumstances have overwhelmed the usually adequate compensations that workers have developed to make up for system shortcomings. We study adverse events as a way to better understand the aspects of work that are problematic. Problems with work, especially the ways that work is organized and the way that tradeoffs are made, point to opportunities to do a better job of supporting work.

This approach makes a difference in what we mean when we discuss representations. Representations are not simply diagrams, any more than work is simply tasks. Representations are assemblies of relevant information that provide a space for clinicians to succeed within existing constraints and boundaries. This is especially true in instances where work is most difficult, as representations expand the variety of options that are available to clinicians to consider. Representations that are conceived at this level make it possible for workers to examine, compare, and contrast various possible solutions. This includes solutions that violate hard boundaries such as the number of available rooms and soft boundaries such as organizational guidelines, because workers must necessarily make trade-offs in the course of daily work.

Our representations assume that IT will necessarily fail in unexpected ways. They incorporate both fallback alternatives and recovery strategies, such as providing paper copy backups in order to run systems in “catch-up” mode after failure. As information assemblies, representations can also be intentionally disassembled in the event of an IT network failure. This makes it possible to deliberately degrade systems as workers make deliberate disconnections to defend against the propagation of failures.

5. Conclusion

Better support for cognitive work makes it possible for clinicians to do better cognitive work. Representations are views of *work* rather than views of *data*. Success in the development of IT systems for healthcare flows from understanding and depicting the work that is done here, rather than the data it produces.

The development of both patient- and unit-level representations relies on the collaboration of healthcare, human factors, design and software professionals that our lab routinely conducts. Efforts such as this and others that are described by Nemeth, Cook and Woods (2004) are intended to help us to begin to understand causes for IT system failure in healthcare and to foresee opportunities for improvement.

Applications that would benefit from this approach to cognitive work representation span all levels of acute care. Carefully developed ecological displays would support clinicians in the ICU and ED, where data change most often and are the basis for crucial decisions. They would be of particular help in the newly-evolving practice of remote telemetry (telemedicine) ICUs. They would also support the hand-off of patient and unit-level information between shifts. Clinical improvements in these activities will benefit both healthcare practitioners and the patients for whom they care.

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