

Discovering and Supporting Temporal Cognition in Complex Environments

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Abstract

Building new information tools to support cognitive work requires research at a level that, within the constraints of time and resources, will reveal higher-order cognition among practitioners. Practitioners develop cognitive artifacts in order to perform technical work. As densely encoded representations of work domains, their artifacts embody the most meaningful information in the task setting. The study of cognitive artifact development and use makes it possible to study individual and team cognition. This approach reveals what information is important, and how practitioners capture and use it. As replicas of physical artifacts, digital cognitive artifacts often amount to only meager representations of what matters in the work environment. This clumsy automation imposes a burden on practitioners by forcing them to cope with its shortcomings. In this setting, user-centered automation must support reasoning through time. The study of physical artifacts indicates ways that digital artifacts might better support temporal reasoning.

Use of Cognitive Artifacts to Understand Technical Work

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 including anesthesia, surgery, nuclear medicine, obstetrics and gynecology, gastrointestinal endoscopy, diagnostic and interventional radiology, and psychiatry. This activity involves a distributed cognition (Hutchins, 1995), that is comprised of the shared awareness of goals, plans, and details that no single individual grasps. Through socially distributed cognition (Perry, 1999), individuals cultivate the mutual awareness and understanding that is needed to collectively accomplish shared goals.

Surgeons, anesthesiologists and the others at the hospital work to a Standard of Medical Expertise (SME). Resources among care settings, patient populations and system are constrained and must be allocated prudently in order to meet a Standard of Resource Use (SRU). (Sharpe and Faden, 1998). A few of the senior anesthesiologists serve in the role of daily coordinator, assigning staff 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 available, assign staff to perform procedures, and evaluate the balance between the two. The coordinator typically manages the execution of that schedule on the following day. Management of this process involves the synchronization of complex, changing activities through time. This requires an accurate grasp of the number and nature of available staff as well as an accurate, up-to-the-minute account of procedures that have been performed so far, are underway, and have yet to be performed within work setting constraints.

Research into cognitive activity in this setting is challenging for a number of reasons. Healthcare practitioners may have little insight into how their work is organized. Information and interaction at the sharp (operator) end is dense, complex, varies widely, and changes rapidly. (Cook and Woods, 1994)

In order to understand cognition in this environment, the researcher needs to employ a number of methods. Woods and Roth's (1988) cognitive engineering approach studies behavior in actual environments in order to change behavior and to improve performance. Klein's (2000) naturalistic decision making (NDM) approach accounts for the performance of decision makers in actual settings. Hutchins' (1995) ethnomethodology describes how distributed cognition includes artifacts that make it possible for a group to accomplish shared goals.

The development and use of cognitive artifacts makes it possible to perform the otherwise impossible process of assignment coordination. Cognitive artifacts are an efficient representation of what matters here because they represent only the information that is critical in this work domain. Previous work (Nemeth 2002, 2003a) describes the use of observational studies to discover how the acute care team uses cognitive artifacts to make the plan for the day's work. It also explains how controlled study of artifact creation reveals the strategies that coordinators employ in order to create a feasible future for the next day of procedures. Two artifacts are essential to the coordinator while developing a plan. The Daily Availabilities sheet is used to account for the status of each of the members in the department who are available for assignment. The preliminary copy of the Master Schedule lists all procedures that are scheduled to be

performed the following day that will require anesthesia, sedation or pain management. These two artifacts are the tools that are used to create the Master Schedule.

An example shows how one coordinator uses the Daily Availabilities sheet and the preliminary copy of the Master Schedule to build a final version of the Master Schedule. Figure 1, from Nemeth (2003b), represents the schedule development process in three ways. The left column shows the verbatim transcript of how the coordinator describes his deliberations using Verbal Protocol Analysis (VPA). The Daily Availabilities

and Preliminary Copy that he refers to are shown at center, along with indications of where he is paying attention. A diagram and comments at right show the analysis of his cognitive activity as he assigns available attending and resident anesthesiologists to cover procedures in eight outpatient clinic rooms. After scoping the supply of staff resources and evaluating the type and number of procedures, the coordinator assigns staff to particular procedures and then assesses the assignments. In eleven minutes, he has assigned attending and resident anesthesia staff to perform a day's

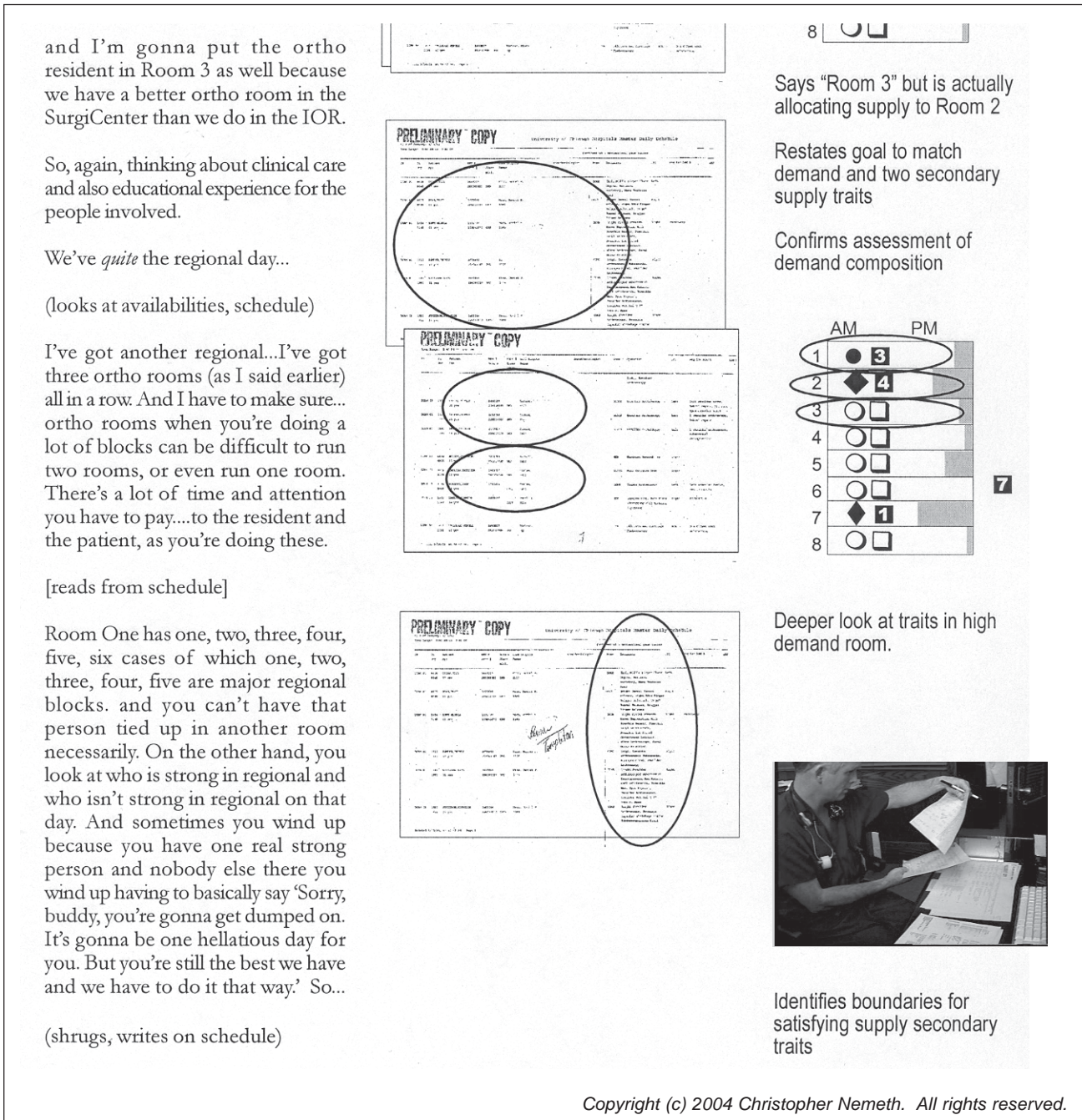


Figure 1: Anesthesia Coordinator Schemata Analysis (selected portion)

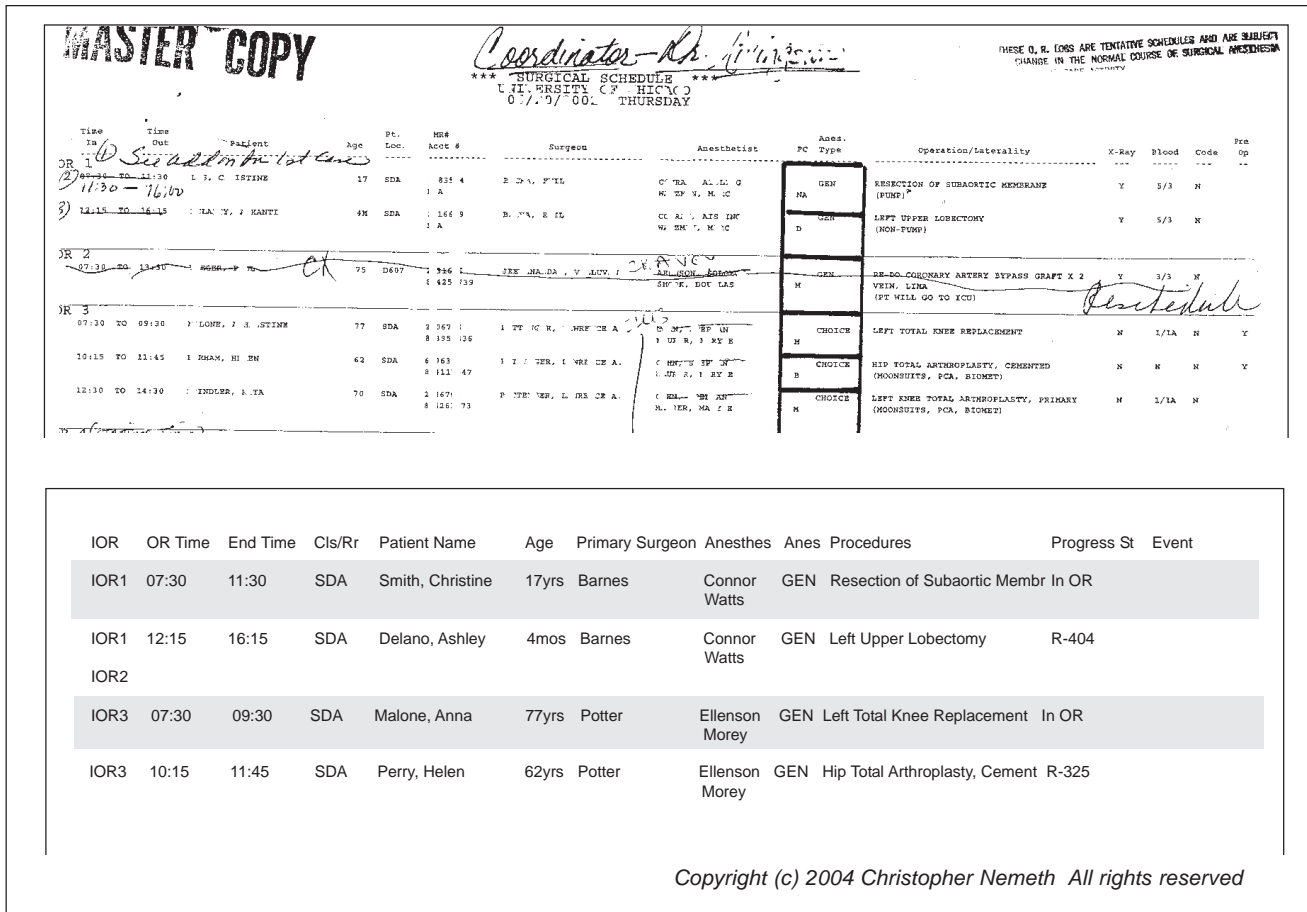


Figure 2: Master Schedule Physical Artifact (upper) and OpAssign format (lower)
All names are fictitious

outpatient procedures. 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. No two coordinators approach the process in the same way. 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 Inpatient Operating Rooms (IOR) 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.

Digital Artifact Concerns

Hard copies of the Master Schedule have recently been replaced by a computer-based system, OpAssign. The Daily Availabilities remains a hard copy report that the coordinator refers to while composing the Master Schedule.

The OpAssign display is an alphanumeric table that is

shown on a flat screen monitor. As a mimic of the physical Master Schedule, OpAssign shows surgical procedures that are organized by room and by time of day within the room. All procedures are represented by alphanumeric characters and each procedure occupies the same amount of space in the layout. Colored bars are intended to indicate case status such as called for, arrived on unit, in OR, in-progress, delayed, and concluded. Procedures appear identical on the display even though they differ as markedly in criticality and duration as a circumcision and a coronary artery bypass graft (CABG).

A number of changes have occurred as a result of the transition from physical to digital cognitive artifact.

- The physical artifact had previously made it possible for the coordinator to control the accuracy of information that was used to make decisions. Only the coordinator would make marks on the one original hard copy that was posted at the coordinator station. The physical artifact also allowed for the coordinator to make margin notes to keep track of unofficial, yet important information such as the name and extension of a staff member who had called with information

that pertained to a case. Now that the Master Schedule is no longer a physical artifact, neither the coordinator nor the acute care team can annotate it.

- Data field limitations force certain compromises in the information that can be shown. Many elements of information are truncated on the OpAssign display. Details can only be found by drilling down through multiple levels of the interface.
- Information on case status was traditionally written onto the Master Schedule hard copy by the coordinator as a patient was wheeled past the coordinator station toward an IOR room. Now, case status must be entered via laptop from a very busy IOR room. This means that information on the Master Schedule display can lag actual events by 30 minutes or more. The lag causes the coordinator to second guess the display and to do additional cognitive work to check on case status. It also erodes the coordinator's ability to manage decisively.
- Case location on the original hard copy remained the same. Team members could use the fixed location for each case to find and refer to it. As case status changes through the day on OpAssign, their location on the screens also changes and team members have to search to find them.

These and other shortcomings have caused team members to do additional cognitive work to cope with limitations of the digital display, impeding team performance. Figure 3 shows OpAssign in use at the coordinator workstation.



Figure 3: OpAssign Display at Coordinator Workstation

Opportunities to Improve Displays

Interestingly, both the hard copy of the Master Schedule and the OpAssign display list scheduled start and end times. However, neither of these two reflect the time-related demands and complexity that are the primary drivers in this

environment. Figure 4 illustrates a conceptual prototype for a digital version of the Master Schedule information that draws on the findings from research into coordinator schedule development and team schedule use. Six of the IOR rooms are shown in the figure. Information on each case is shown in a horizontal bar that is aligned next to the label of the operating room to which it is assigned. A shaded segment follows each procedure to indicate the 45 minute period that is required to clean-up and restock the room. The arrow at top of the display indicates that the time is 0800 on the day of procedures that are being conducted in the Inpatient Operating Room (IOR) unit.

IOR1 shows that a half hour is open after the first procedure and clean-up have been completed. The procedure that is scheduled for 0730 to 1330 in IOR2 has just been cancelled and the display indicates that the room is scheduled and prepared for use. IOR3 shows that cases are scheduled efficiently. IOR4 is available for any general surgery to be added on after 1215. Somehow, the second procedure scheduled for IOR6 has been slated to start before the technicians would be able to finish clean-up. The solid bar can be used to display more information on the cases by choosing it with an input device such as a mouse or touching the screen.

Certain information is crucial in order to optimize assignments. This includes knowing when procedures are likely to finish, which procedures can be moved into another room, and which opportunities (such as Medicare payment) might be exploited. Such information can be made available by polling the database of scheduled cases to see what opportunities may exist.

The example in Figure 4 is based on research into the work domain in which it would be used. Because of this, it avoids many of the shortcomings that the OpAssign display encountered. It may also improve on the OpAssign design in a number of respects.

- The visual organization of the display remains the same as it evolves. By using a graphic representation of time, the team can understand and evaluate relationships among events through time.
- Relevant variables such as age are shown within each case window, which saves the need to locate and assemble information that is related but is displayed separately.
- Cases that were performed remain on the display in sequence, making it possible to review the entire day's activities while they are still underway.
- Aspects of schedule management that were previously hidden are made evident. These include requirements that 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.

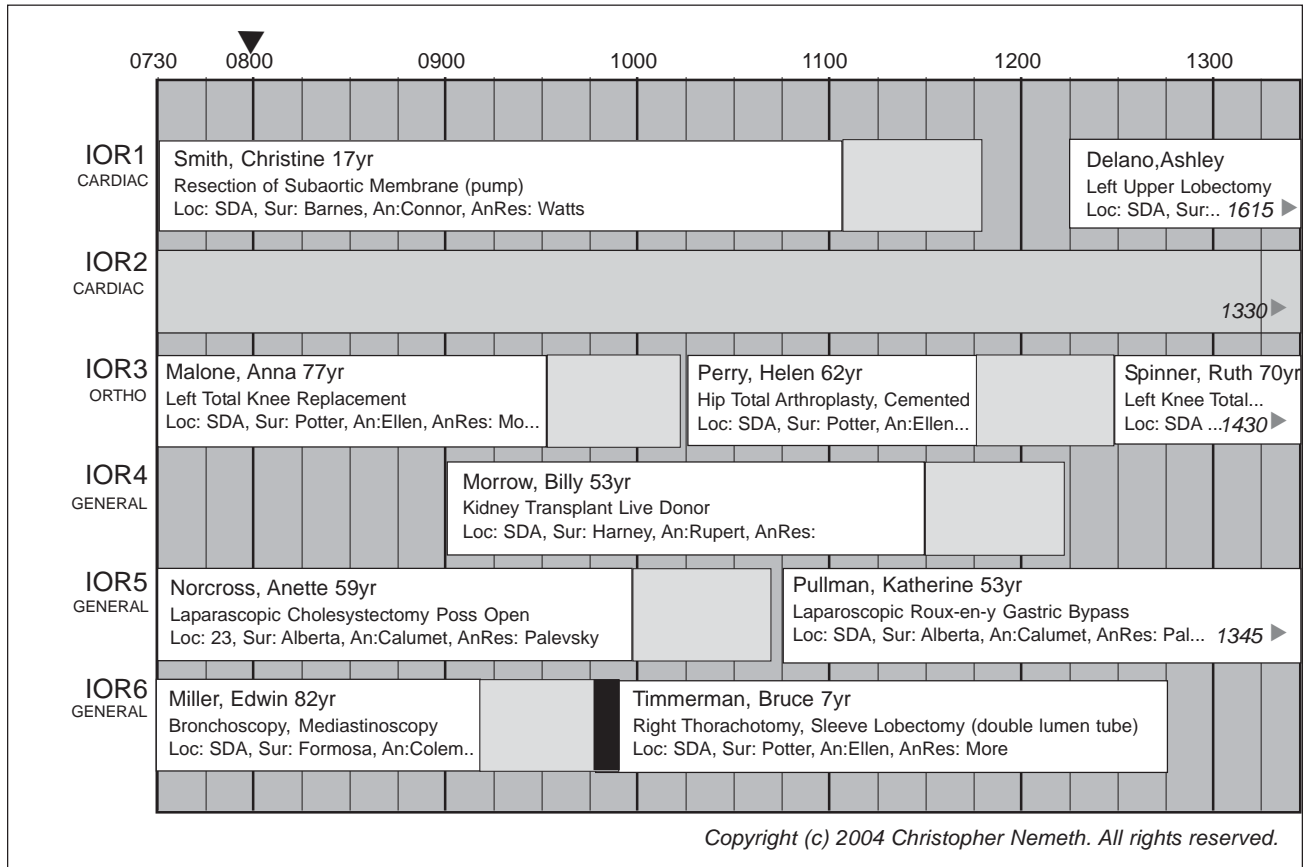


Figure 4: Prototype Digital Display of the Master Schedule
All names are fictitious

Adding Value to Cognitive Tools

Any tools that are created to assist these complex and highly sensitive interactions need to reflect the underlying complexity of the work that is to be performed. A digital version of the Master Schedule might improve team performance by supporting work in ways that the research that was described earlier in this paper demonstrated.

The flexibility that digital representation offers is powerful and can be used to support cognitive work. However, this does not happen automatically. The digital artifact's design must represent constraints and opportunities that are relevant in this domain. 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.

Further features such displays might provide include:

Prompting—Digital artifacts might survey information in the distributed cognition for gaps and inconsistencies that go unnoticed and unaccounted for. Nominating the item(s) for consideration would enrich and improve the cognition.

Speculation—Digital artifacts can enable coordinators to speculate about and choose among possible courses of action. For example, speculation about plans for the afternoon staff is currently limited to the OR Board. Developing potential courses of action would make it possible to evaluate how desirable they might be.

Consequences—Applying evaluation criteria to potential courses of action could make it possible to display the consequences of choices. One example is to show how billing might be increased, or costs might be minimized, by opening one operating room or closing another.

Value-based decisions—Digital artifacts can be used to develop templates of schedule planning strategies. Coordinators could review and use the template that best matches their values and preferences. Such templates can capture scheduling expertise and make it available beyond a single individual. Study of template use through time might open the way to insights about coordinator training and the development of further schedule models that might ease coordinator workloads.

Conclusion

This paper has described a detailed study of the operational aspects in a complex, high hazard work setting, assessed the role and effect of physical and digital cognitive artifacts on cognitive work, and presented a display concept that embodies the task demands that workers confront. Support for the cognitive work of those who labor in this setting is the hallmark of user-centered automation. (Billings, 1997)

As a readily available source of information, cognitive artifacts make it possible to study cognition in complex environments. Because those who work in the environment have created them, artifacts are highly encoded representations of what matters most in complex settings. The creation and use of cognitive artifacts also provide the researcher with a means to understand deeper structure of behavior in the work domain.

Findings from such research can be used to identify the functions of computer-supported displays that are needed to not only support but to improve performance. Validation of those findings and related display designs will come from operator acceptance in actual use. Improving work efficiency and reliability can make it possible for work teams to be more effective, thereby improving medical safety.

Acknowledgements

This work was supported by a grant from the National Library of Medicine.

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