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Coordinating Heterogeneous Work: Information and Representation in Medical Care

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Medical care involves intense collaboration amongst a number of practitioners including physicians, nurses, and pharmacists Their work is concentrated on a single patient, and yet their activities, motivations, and concerns are very different We explore the use of a shared information system in helping these individuals coordinate their work In particular, we use the idea of a common information space to explore how the shared information is incorporated into the diverse work practices of an intensive care unit In addition to physical co-location, we found that providing information in many specialised representations is critical to managing their coordination. Unlike paper records, computer systems offer the ability to decouple information from its representations. This decoupling opens up a rich design space for systems that allow people with different interests, concerns and work practices to work together effectively.

Introduction

The concept of a common information space, or CIS, has become an influential way to think about the use of shared information in collaboration. Originating in the work of Schmidt and Bannon (1992), and further explored by Bannon and Bødker (1997), it was designed to extend then-current notions about the role of technology and shared information.

At the time this was originally proposed, a great deal of technical attention was being paid to the development of "shared workspace" systems (e.g. Lu and

Mantei 1991; Ishii et al. 1992) These systems attempted to extend the workspaces of conventional single-user applications such as word processors and drawing tools, allowing synchronous or asynchronous collaboration across digital networks. Designing effective shared workspace systems presented a range of technical challenges concerning appropriate network protocols, synchronisation, concurrency control mechanisms, and user interface design. Still, over time considerable progress was made, resulting today in the widespread use of systems such as Microsoft NetMeeting that emerge directly out of the "shared workspace" tradition

However, by introducing the concept of common information space, Schmidt and Bannon sounded a note of caution about the technological conception of shared information. They pointed out that information is not shared unproblematically. It has to be explicitly *placed* in common – extracted from one person's work context, and reformulated in some way that displays its relevance to others (by being related to some common conceptual scheme, for instance). Similarly, when individuals come to examine shared information, they need to recontextualize it, making it relevant for their immediate needs. Further, the same information may be relevant to two people in quite different ways, for instance, a purchase order has different consequences for the person who must process the shipment and the person who must balance the budget. A common information space according to Schmidt and Bannon incorporates not only a repository of information held in common amongst different parties, but also the work practices surrounding that information – how it is used, managed and integrated into the work of those who share it. The practices by which information is placed in common, and then made relevant to individuals' activities, make the information meaningful in the context of their work.

The value of the common information space concept, then, is that it relates shared information to the activities that are conducted over and through the information. While the precise formulation has, lately, been subject to a certain amount of critical scrutiny (see, for example, Bannon 2000; Randall 2000), there is still considerable value in the perspective that it offers on how shared information is incorporated into daily work practices.

In this paper, we report on a field study of the use of a shared information repository in medical work. In particular, we describe the challenges to using a computer-based patient record system as a CIS in an intensive care unit. The paper is structured as follows: in the following section we discuss in greater detail the CIS concept and related work. Next, we present our field study: the research site, staff, and technology as well as examples of daily work activities in the unit We then discuss the implications of our findings for the construction and use of a CIS, and finally, present some design considerations for CIS systems followed by some concluding remarks.

Background

Schmidt and Bannon (1992) introduced the concept of common information space by contrasting it with technical conceptions of shared information:

> Cooperative work is not facilitated simply by the provisioning of a shared database, but rather requires the active construction by the participants of a common information space where the meanings of the shared objects are debated and resolved, at least locally and temporarily (Schmidt and Bannon, p 22)

A CIS, then, encompasses not only the information but also the practices by which actors establish its meaning for their collective work. These negotiated understandings of the information are as important as the availability of the information itself·

> The actors must attempt to jointly construct a common information space which goes beyond their individual personal information spaces The common information space is negotiated and established by the actors involved (Schmidt and Bannon, p 28)

This is not to suggest that actors' understandings of the information are identical; they are simply "common" enough to coordinate the work. People understand how the information is relevant for their own work. Therefore, individuals engaged in different activities will have different perspectives on the same information. The work of maintaining the common information space is the work that it takes to balance and accommodate these different perspectives A "bug" report in software development is a simple example. Software developers and quality assurance personnel have access to the same bug report information. However, *access* to information is not sufficient to coordinate their work. Instead, it is their more or less shared *understanding* of the record's organizational structure that allows developers and quality assurance personnel to coordinate their activities They know where to find certain information, what it means if the information is not present, and what implications this information carries for their own work

The distinction between access and practical understanding is at the heart of the CIS concept. Moving from one to the other is not straight-forward. Schmidt and Bannon discuss potential problems actors face in interpreting information when the information's creator, the context of its creation, or politics of its use is unknown to the actors involved. They provide examples of what occurs when this contextualizing information is not present and discuss how common information spaces are created in different work situations.

In many work settings, a CIS involves not only local work practices but also crosses group boundaries. The information artifacts at the heart of the space are the focus of heterogeneous workgroups and have characteristics of "boundary objects" (Star and Griesemer 1989). Boundary objects are information artifacts flexible enough to fit local work practices but also stable enough to convey information across group boundaries, enabling them to act as coordinating mechanisms for interactions between diverse workgroups. For example, Berg and

Bowker (1997) examine the medical record as "an organizational infrastructure...[that] affords the interplay and coordination between divergent worlds." They argue that the patient record is both a representation of the patient as well as a representation of the *work being carried out* on the patient. The record is used by different groups (e g physicians, nurses, administrators, etc.) in their own local work context. To each group, the record has a localized meaning, but it also serves to coordinate the different activities of these groups. The patient record functions as a boundary object, spanning the borders of a number of different groups.

Bannon and Bødker (1997) use boundary objects as a lens for viewing common information space. They contend that, as with a boundary object, the dialectical nature of the common information space is an important characteristic:

> It is this tension between the need for openness and malleability of information on the one hand, and on the other, the need for some form of closure, to allow for forms of translation and portability between communities, that we believe characterizes the nature of common information space (Bannon and Bødker, p 86)

Resolving the tension between the need for both openness (supporting diverse work practices) and closure (supporting coordination) depends on features of the work and work setting. Bannon and Bødker use a variety of examples to discuss CIS construction in different settings, and suggest that physical co-presence plays an important role in making it easier to construct a common information space:

> In the case of physically shared workspace, due to the common work setting and exposure to the same work environment, actors are able to co-operate with each other, both in the production and reception of utterance and information, without having to resort to extended descriptions or elaborated codes, due to their understanding of the shared context within which they work (Bannon and Bødker, p 83)

The physical co-location of the workgroup members provides a number of benefits. First, the work related to the information is highly visible. Participants can see not only what other individuals are doing, but also when and how they are doing it. Second, in a physically shared space, individuals can easily ask other individuals for explanation of something they do not understand – "popping your head over the cubicle wall." Participants can ask their neighbors questions about the work before looking elsewhere for the information. Finally, a shared workspace allows human mediators to play a more effective role in sharing and communicating knowledge about the artifact. Blomberg and colleagues' (1997) study of attorneys in a law firm highlight the role of human mediation of an artifact. Over a period of time, M, a firm attorney, had amassed a large collection of legal documents that he deemed potentially useful or reusable. These documents were available to all, but stored in a filing cabinet in his office When other attorneys wanted to find a document in the cabinet, M acted as gatekeeper, helping them locate and interpret the needed documents:

> The utility of M's file for other attorneys depends on his knowledge of its contents and organization, derived in turn from his creation, maintenance, and regular use of the file Other

> attorneys rely on M to help determine whether the form file contains documents relevant to the transaction on which they are working, to point them to likely places in the file where relevant documents might be found, and to justify the choice of particular documents (Blomberg et al , p 195)

M mediated the other attorneys' search for documents in the filing cabinet. This was successful because he was physically available along with the files.

Although physical co-location provides a number of benefits, how much of a role it actually plays in the creation of a common information space remains unclear. We know that when the work of the participants is similar (e g. as with the attorneys using M's filing cabinet), the physical co-location of actors helps them to create a usable common information space This depends, though, on some mutual intelligibility of action, so that when participants observe each other at work with the artifacts, they have some understanding of what work is being carried out. However, what if the work practices are so heterogeneous that the work of different actors is no longer intelligible to others? What role does physical co-location play then? And what other elements can be brought to bear in order to resolve the tensions of openness and closure?

A Common Information Space in Medical Work

We explore these issues by looking in detail at an example of a common information space supporting divergent forms of work. We focus on medical work in an intensive care unit (ICU) supported by a shared patient record system called HealthStat.[1]

Research Site and Methods

The surgical intensive care unit (SICU), where we conducted our fieldwork, is one of nine ICUs of a large urban teaching hospital. The majority of participants in this study worked in the SICU. The research team had access to the SICU staff. In addition, we observed and interviewed the HealthStat technical team members from the hospital's information systems department. The first author observed work in the SICU for approximately three months during summer 2000. He collected data through 30 formal interviews, as well as a number of informal interviews, and observations. The formal interviews were taped and transcribed. The research team had access to the HealthStat application and internal communications, including written policies, procedures, and meeting notes.

Each ICU provides rigorous invasive and non-invasive care-monitoring for patients requiring special attention due to a critical medical condition. Specifically, the SICU is a 20-bed unit that treats the most seriously ill surgical

1 A pseudonym

patients, including those who have undergone liver transplant, major trauma, or major elective surgery It is equipped with sophisticated equipment including digital physiological monitors and a fully computerized patient record system. The SICU is an extremely busy unit with 15 out of 20 beds occupied on a daily basis Patients usually stay in the unit for 5-6 days and are the focus of a team of health-care workers. In most cases, patients are in such critical condition that any minor change in their condition could have rapid and severe implications. Therefore, the specialised equipment and staff in the SICU allows even small changes in a patient's condition to be detected early, thus permitting rapid changes in treatment to prevent problems from developing.

SICU Staff

The SICU staff includes surgical critical care nurses, physical therapists, social workers, respiratory therapists, surgical residents, critical care fellows and faculty. We focus on three SICU work groups physicians, nurses, and pharmacists because these groups interact with each other and the computerized patient record system on a daily basis. We will now briefly discuss each group.

Physician Staff

The physician staff is organized hierarchically and consists of three rotating surgical residents, two critical care fellows, and four attending physicians. At the bottom of the hierarchy are residents. They are considered physicians-in-training and provide the most hours of patient care in the unit. The fellows are in the middle of the hierarchy. They have completed their residency and are undergoing specialized training in intensive care. Fellows supervise and monitor residents' activities on a day-to-day basis. They resolve a majority of problems that residents cannot handle. If a fellow cannot resolve a problem, an attending physician is notified. The SICU has four attending physicians, each with many years of experience in intensive care The attending physicians supervise fellows and residents to ensure that they receive proper training as well as maintain a high standard of patient care The ultimate responsibility for success or failure in the unit lies with the attending physicians.

Nursing Staff

The nursing staff has more than fifty registered nurses certified in critical care, supervised by a SICU nurse manager. Depending on the number of patients, there are 10-12 nurses on each 12-hour shift. The nursing experience in the unit varies; some nurses have more than 20 years of experience but the majority of nurses have been in the unit less than five years. The nursing staff has experienced high turnover due to the stress of ICU work. The nurse's responsibilities range from patient assessment and monitoring to medication administration. Because of the serious condition of the patients in the unit, each nurse is responsible for only 1-2 patients per shift. (In the non-ICUs, the nurse-to-patient ratio is 1:6.) Therefore, SICU nurses can provide more focused care for their patients.

Pharmacist

A pharmacist is assigned to the SICU on a regular basis. She spends 3-4 hours per day in the unit. The medical staff, especially the residents, rely heavily on her knowledge to help them make the appropriate medication decisions. She is also the primary resource for the nurses on any questions concerning drug dosage or usage. The pharmacist participates in the SICU team's rounds each morning and is familiar with the conditions and medications of all the SICU patients.

Diverse Work Practices

The patient is the center of the work activities in the SICU. The primary goal of the SICU staff is to stabilise patients so they can be safely transferred out of the unit. On a daily basis, physicians, nurses, and pharmacists successfully coordinate their patient care activities. However, although patient care is the central focus, the various groups have their own work to do; their motivations, concerns, and activities are quite different (Strauss et al. 1985).

Consider one case that we observed. A nurse noticed that her patient's fingers were turning blue. She knew that blue fingers were an indication of blood vessel constriction and correctly attributed the condition to the medication. The patient was in obvious discomfort. The nurse did not understand why this medication was being administered since it clearly caused so much distress to the patient. She asked the physician if they could stop the medication. However, he insisted that, despite the discomfort that it might cause, the medication was necessary to improve the patient's overall medical condition.

This example highlights the distinct roles and concerns of the physician and nurse. To the physician, the patient's discomfort was not as important as treating the other medical problems. On the other hand, the nurse was primarily concerned with the patient's comfort and well-being. The different emphases of their work continually feature in the life of the unit; with their different concerns, physicians and nurses frequently do not understand the details of each other's work. As one SICU physician stated,

> There is a scope of practice for nurses There are certain nursing actions,[but] they are not the same as my actions They are involved with patient care and they make patient care decisions on a routine basis. It is true that they cannot do what I do They cannot order medications, [but] when I order it they administer it That is her job But they make nursing care decisions. I am not minimizing them. It is a different sphere of things For example, patient comfort measures. I don't prescribe that I don't tell them when to clean a patient, when to put a pillow here or there, and yet they are important to the patients Patients remember that Nurses are the ones

who make those decisions and decide that care I think that they have a very specific sphere of care, just different from mine

If physicians view their activities as distinct from nurses' activities, then nurses too view their work as differing from that of other groups (e.g. physician, pharmacist). Berg and Bowker (1997) and Bowker and Star (1999) discuss the creation of the Nursing Interventions Classification, a classification of nursing work that was developed by nurses as a way to describe their activities independently of other groups' work. Nurses created this classification as a means to legitimate their activities and make them visible to physicians and other hospital staff who otherwise neither recognized nor understood their work

While their work practices may be quite diverse, effective and timely coordination between physicians, nurses, and pharmacists is critical otherwise the patient will suffer In one example we observed, a nurse failed to notify the physician that the patient's sodium was raising to dangerous levels. If the physician had been notified quickly, he would have been able to give the patient medication to lower the sodium. However, the physician only found out about the sodium levels six hours later, by which time the patient's condition had deteriorated so far that the physician had to intubate the patient to protect her airways. As the example highlights, these groups work under constant time pressure that can effect patient care They do not have the luxury of waiting an extended period of time for important patient information.

HealthStat: A Common Information Repository

Information technology plays a crucial role in the SICU. A computerized patient record system, HealthStat, mediates much of the work among the physicians, nurses, and pharmacists. The staff has used HealthStat for more than nine years and is well acquainted with its functionality. Originally implemented in the SICU, the system is now in use in eight of the other nine ICUs in the hospital.

Almost all patient information is in the computerized record Since the patient's bedside monitoring systems are linked to HealthStat, physiological data such as temperature, blood pressure, heart rate, and fluid levels are downloaded automatically into the patient's HealthStat record However, before the information is permanently entered into the record, the patient's nurse ensures the validity of the data by cross-checking the data in the record with the displays on the bedside monitoring systems. The record also contains medication information, progress notes, and laboratory results.

Most of the data that is not automatically downloaded into HealthStat is entered by nurses. They can spend up to 15 minutes every hour entering data into the system. In a busy ICU, this is a great deal of time but is still shorter than the time that would be spent entering the same information on a paper chart. Physicians, by contrast, do minimal data entry; they largely use HealthStat to monitor the patient's status and to find needed patient information. Finally, pharmacists are interested in ensuring that the patient is receiving the appropriate medication and that all the information related to the patient's medication is correct; the SICU pharmacist spends a couple of hours each day using HealthStat

The Work of the SICU

We present three examples of activities related to patient care in the SICU. These activities highlight the collaboration required for successful completion of work tasks.

SICU Morning Rounds

SICU morning rounds play an important role in the unit's patient care process A multi-disciplinary team led by a fellow and consisting of three residents, attending physician, pharmacist, and nurse visits each patient. The goal of morning rounds is to discuss and decide upon a plan of care for that day for each patient. The team uses HealthStat workstations outside patient rooms to find patient information. The team begins by viewing x-rays of all the SICU patients. After examining the x-rays, the team "rounds" on each patient. Each of the three residents are responsible for a certain number of patients in the unit. During rounds, the residents "present" their patients to the team As a resident outlines the patient's current condition, vitals and other information, the fellow and other team members view the patient's record on the HealthStat workstation. They do this both to verify the resident's information and to gather other pertinent information. As one fellow stated, "It is much easier for me to find the information in the system than to wait for them [residents] to give it to me." After the resident presents, the fellow examines the patient. The team then discusses the patient's condition and decides on the plan of care for the day. After all the decisions are made, a resident writes a progress note in the patient's HealthStat record. The following vignette presents a typical patient round.

> MC, a resident, presents the patient to the team The patient has recently undergone a male to female gender change operation She was admitted to the unit because of complications from the administration of high levels of progesterone and estrogen TK, a fellow, suggests that the hormones be discontinued However, MC argues that the patient needs them for the gender change WK, another fellow, looks at HealthStat and asks MC whether the patient is getting both Heparin and TPA (both drugs prevent blood clotting) MC tells WK that the patient is only receiving Heparin AL, an attending, asks whether estrogen and progesterone have a dose response level None of the residents know the answer to this question. Later, TK asks the JC, the pharmacist about dose-related complications for estrogen and the relationship between estrogen and progesterone JC tells TK and WK that the drugs are dose independent of each other After a discussion, the team decides not to discontinue the progesterone and estrogen

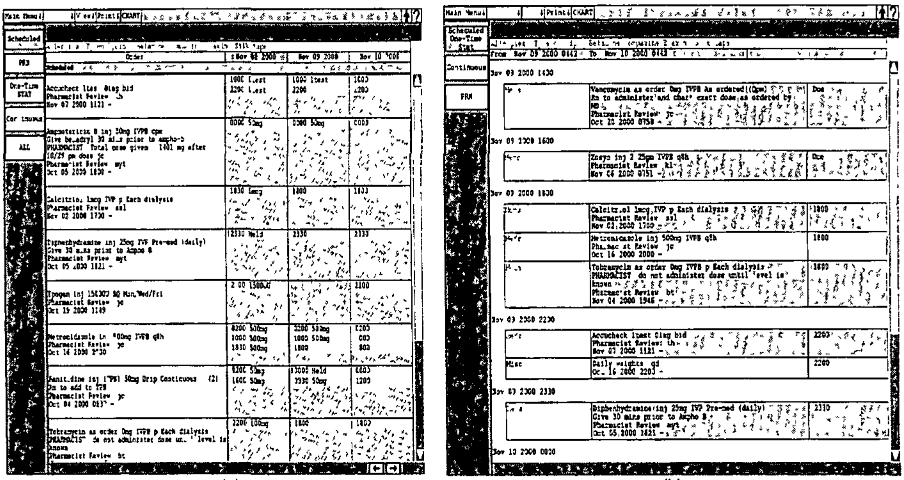
As the example illustrates, rounding involves a collaborative dialogue among physicians, nurses, pharmacists and the patient record system. Different questions were raised during the interaction: Should the estrogen and progesterone be stopped? What other medications is the patient receiving? Are there dose level concerns between estrogen and progesterone? HealthStat provided some information, but the different team members brought their individual perspectives to understanding the information so the questions could be answered. MC gave the context of the case and explained the need for the high level of estrogen and progesterone. She also answered WK's question about the patient medication. JC answered the question about the drug interaction. HealthStat played a role in answering questions, but only as a component of the entire collaborative process. For instance, WK raised the medication question after looking at the patient's physiological data in HealthStat. Instead of asking the resident, WK could have also looked up the medications in HealthStat. However, she was interested in not only the patient's medication but also the rationale for giving the medication. MC was in the best position to provide that information. The information itself, in HealthStat, does not tell the complete story. During rounds, team members actively collaborate to integrate that information into the context of their work

Medication Administration

Ordering and administering medication requires collaboration between physicians, nurses, and pharmacists In routine situations, most surgeons use a standard set of drugs. However, for complex cases, nurses and pharmacists often provide information that help physicians tailor the medication prescription. Since nurses are constantly by the bedside, they can inform physicians about the patient's physical and mental state. This information can help physicians to decide whether a current drug and dosage are appropriate If physicians need to prescribe a drug for a problem with which they are not familiar, pharmacists can provide a list of appropriate medications

Nurses must collaborate directly with both physicians and pharmacists When ordered to give an unfamiliar drug, nurses commonly ask the physician why it is being given, especially when the drug causes discomfort or pain to the patient. Most physicians want the nurse to understand the plan of care and will answer such questions readily. The nurses also ask the pharmacist questions concerning the medication and dosage administration. For certain kinds of drugs, such as pain relievers, it is the nurse who observes the patient's response most directly, and whose opinion is usually given high regard by physicians for subsequent pain medication orders.

HealthStat plays an important role in supporting the collaborative process of medication administration. The central element that HealthStat provides in this



(a) (b)

Figure 1 Different Representations of Medication Information: (a) Pharmacists use the Medication Administration Record (MAR) to provide them with the more detailed information on each medication (b) Nurses use the Medication Worklist to keep track of their medication administration work activities

process is the Medication Administration Record, or MAR (Figure 1a). The MAR coordinates both the prescription and administration of medication. When the physician writes a medication order, a nurse or pharmacist enters the order into the MAR, recording the details of the prescribed medication. Although the MAR provides the detailed information necessary for the pharmacists, it provides too much detail for the nurses to allow them to plan their medication administration activities for a shift. Consequently, to administer medications effectively and on-time, nurses use another "view" of the MAR, the Medication Worklist (Figure 1b), which provides a time-ordered list of dosages, and administration times for all drugs due to be administered on the current nursing shift. The nurses use the Worklist to plan their medication administration activities for each of their patients.

Each group uses the system to view a patient's medication information, although in different ways. For example, pharmacists check the appropriateness of the medication based on the patient's condition. If they do not believe that the drug is appropriate, they will offer the physician advice about alternative medications. Physicians may consider the pharmacists' recommendations when making their final medication decision, based on the information that HealthStat provides them concerning the patient's response to previous treatments.

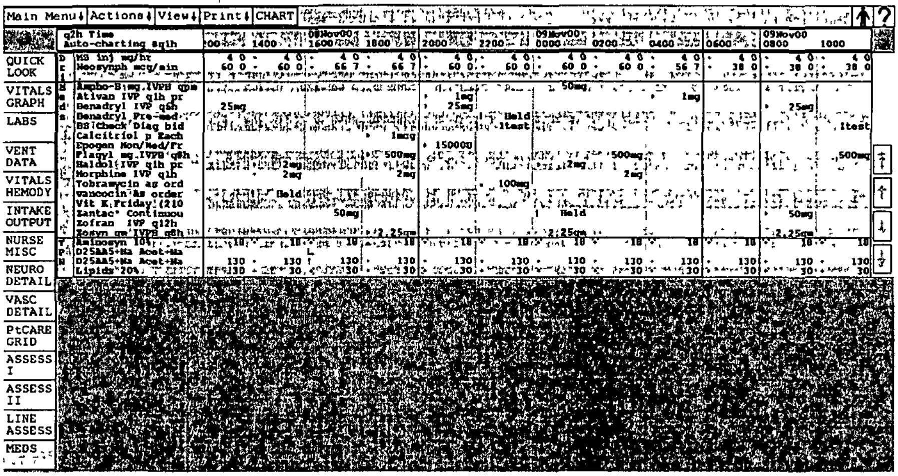


Figure 2 HealthStat Flowsheet's MEDS Section: The ICU staff especially physicians use the MEDS section to quickly check on patient medications

Configuration Group

HealthStat is implemented in eight ICUs in the hospital. Due to technical constraints, any changes to the various interfaces to the system are replicated to only seven of the eight ICUs (the eighth ICU uses HealthStat on an independent platform). Still, coordinating interface changes for seven ICUs is a difficult process. Although all ICUs have some information in common, much is particular to each ICU and its specialized work. Terms used in one unit may not be used in another. To prevent any misunderstandings between the different ICUs, a committee called the Configuration Group was created. The group consists of nurses from the different ICUs, HealthStat programming team members, and the HealthStat director. Any interface changes must be discussed in the Configuration Group meeting. The group then decides whether changes will be implemented.

An important aspect of these meetings is dealing with changes to the HealthStat Flowsheet (Figure 2). In our observations and interviews, nurses and physicians described the Flowsheet as the most widely used interface of the computerized record. Each of its fourteen subsections contains information about the patient. For example, the MEDS subsection contains brief information about the patient medication. ICU staff use the Flowsheet to get a quick overview of the patient's condition.

Since interface changes made to the Flowsheet for one ICU are propagated to the Flowsheets in the other ICUs, the Configuration Group has to mediate the differing requirements of the various ICUs. For example, both the medical and the surgical cardiac units are interested in the section of the Flowsheet dealing with cardiac data. Because HealthStat was implemented first in the medical unit, the nurses there had the data visually arranged in the Flowsheet to fit their work activities. However, when the nurses in the surgical unit began using the system, they complained about this arrangement, arguing that they could not easily find needed information because the data was not arranged according to *their* work activities.

The responsibility for resolving these problems falls to the Configuration Group. The group plays an important role in minimizing friction between different units concerning changes to the system. The Configuration Group meetings also provide a rare opportunity for practitioners to cross organizational boundaries and discuss their work with others from different organizational groups. As such, the Configuration Group engages in an explicit negotiation of the meaning and role of the information in HealthStat.

HealthStat as a CIS

As we have outlined, HealthStat is a shared repository of information used to coordinate the different aspects of medical care in the SICU. However, looking at HealthStat as a CIS leads us to focus less on the idea of shared information, and concentrate more on the practices by which that information is put to use and is made meaningful for the different sets of people who use it. For example, although much information is automatically logged from systems that monitor the patient's vital signs, that information is not accepted into HealthStat until it has been reviewed and approved by a member of the SICU nursing staff. In other words, the information needs to be explicitly "vetted" according to a set of SICU expectations in order to determine its acceptability. In turn, this vetting allows the SICU staff to maintain a common understanding about the appropriateness and accuracy of the information contained in the system. Thus, the notion of "information" here is not uncontested; rather, HealthStat is a repository for approved and trusted information.

Prospective and Retrospective Use

The patient record in HealthStat incorporates a broad set of concerns and a wide range of information about all aspects of a patient's current treatment regime and medical history. The amount of information that it contains about a given patient is potentially overwhelming. One way that the system's design deals with this problem is by providing a range of interfaces tailored to the needs of either the different practitioners who may deal with the patient or the different activities that make up the patient's care.

For example, physicians interact with the system primarily through the Flowsheet Since they do not have a great deal of time, the Flowsheet provides them with quick information about the patient's condition. Pharmacists have a different set of goals. They are less concerned with the overall medical treatment of each individual patient and more concerned with ensuring proper medication administration. Their interactions with the system consist largely of checking on patient medications through the MAR On the other hand, the nursing staff, who are primarily responsible for the moment-by-moment care of the patients, interact with the system through a number of screens, depending on their particular tasks One of the primary interfaces that they use to coordinate their work is the Medication Worklist.

HealthStat stores information about the administration of medical care. However, the different screens reflect very different aspects of that care. The physicians' primary concern is with diagnosis and monitoring of the effectiveness of a treatment regime. The process of rounding, for example, is about describing how the patient has responded to treatment since the previous round, and on the basis of that, deciding what path should be taken next. So, the physicians' primary use of HealthStat's information is *retrospective*; they want to know what has happened over the last 24-hour period. In contrast, the nurses, who must arrange their activities in such a way as to ensure that each patient receives appropriate attention at relevant points in the shift, look to HealthStat for *prospective* information about the activities which will need to be carried out in order to effect the prescribed regime of care. HealthStat sits at the nexus of these two concerns – retrospective and prospective – both detailing what has gone before and projecting what will come next (See Berg (1999) for a similar argument concerning "reading" and "writing" a computerized patient record).

There are two consequences to this use of HealthStat. The first is the issue of temporal coordination in a CIS. Previous investigations of CIS have pointed out how the activities that surround an information store, and the practices by which information is explicitly transformed in order to "place it in common" are frequently oriented towards the anticipated lifetime of the information. At the most banal level, when information is placed into some form of storage, it is with an expectation that the information may need to be retrieved at a later date. Participants record information in such a way as to anticipate the circumstances under which it might be found again at some time in the future. Discussing the case of the Danish National Labour Inspection Service, Bannon and Bødker (1997) point out that records about encounters with companies may be reused years later, and that inspectors need to be sensitive to the potential future uses of the material they create; while Dourish et al. (1999) discuss how the evolution of a "common" classification scheme presented problems for the long-term storage of engineering documents. In contrast, in the SICU, temporal coordination through the CIS is both much more explicit and much finer-grained. The system not only stores information but also *transforms the information into a hour-by-hour schedule* by which work activities can be coordinated. This mediation between retrospective and prospective information is a key feature of how the different groups within the SICU make use of the CIS.

Our second point concerns the coordination of these multiple representations of information.

Information and Representations

One of the motivating concerns that we have been pursuing through this work is the following problem. if the work practices of the different groups whose work is coordinated through HealthStat are sufficiently diverse that many of the benefits of co-location, as discussed earlier, are effectively lost, then what compensates for this loss? How can coordination be re-established?

The issue of prospective and retrospective uses of information by nurses and physicians offers a clue. Through its multiple screens, HealthStat offers different views of the same information, and these different views are attuned to the needs of the different groups who use them. For the nursing staff, HealthStat transforms information about a treatment regime into a schedule of tasks and activities that will need to be carried out. The information that HealthStat records gives rise to many different representations (Flowsheet, MAR, Medication Worklist), according to how the information is used by the different groups.

This decoupling that HealthStat allows between the information and its representations is unusual amongst the CIS scenarios explored in the research literature. In the case of a CIS that is based on physical records, there is, clearly, only a single representation or physical form for each information artifact. However, even in cases where the information is recorded electronically, a single representation is still the norm (e.g. Trigg et al. 1999). HealthStat, however, expresses the same information through different representations. As we have seen, these representations are crucially integrated into the different working styles and practices of the groups who collectively carry out the work of the SICU. However, this need for *different representations* is balanced by the need for *shared information*. It is not enough that the representations be different, as would be afforded by translation-based approaches (Simone et al. 1999), but that these be different representations of *identical* underlying information, since it is through the sharing of this information that coordination is achieved.

The tension between the need for diverse representations (matching diverse work needs) and common information (for stable coordination) is reflected in the need to coordinate over the forms of the representations themselves. The staff needs to coordinate their activities through more than simply the information; they need to be able to discuss, to exchange, and to compare representations. The work of the Configuration Group reflects this concern. The seven ICUs have varied work practices requiring not only disparate information but also different arrangements of the same information This diversity is a common feature of a

CIS, but one interesting element here is that the diverse needs of the units are explicitly negotiated through the Configuration Group. Here, the issue is not different representations of the same information, but compatibility between the representations used in different places. Since, the ICUs all use the same system, there has to be clear understanding of the representations' meaning to each unit Unlike most CIS negotiations which are informal in nature and carried out during the course of the actual work, the Configuration Group allows nurses from the ICUs to meet and exchange information about their different work practices. The Configuration Group meeting is an opportunity for the group members to find out in *explicit* detail how the same information might be differently used in the various ICUs By exchanging information about each unit's local work practices, Configuration Group members have a better understanding of how making changes to representations can effect each unit.

Discussions in the Configuration Group meetings help overcome the problem that each group has understanding the other's work This problem is manifest in the SICU itself. While previous investigations described in Bannon and Bødker (1997) have suggested that physical proximity is a key feature in allowing different groups to coordinate their work in and around a common information space, our field data suggests that this is true only in the cases where the work of the different groups is sufficiently integrated (or, at least, mutually comprehensible) that the information can have some general relevance. In these circumstances, then, the ability to see how the work of others is being carried out with and through the information allows participants to coordinate their actions In cases where the work is more disparate, though, physical proximity is of less immediate value. Even though they work in the same environment, the different groups in the SICU do not feel that their work is understood by the others. The role of a single information representation as a site of work coordination breaks down. However, electronic information systems allow us to present multiple, coordinated representations of information. When the system can present the same information in ways that are differently attuned to the information needs of different groups, participants see other's work transformed in ways that make sense from their own perspective.

Design Considerations for CIS Systems

Our exploration of the use of HealthStat in the SICU has highlighted a number of interesting issues concerning the role of information in coordinating work. In particular, we have seen that work coordination through HealthStat depends on the separation it offers between the information and its representation (how that information is configured for particular uses). Although the observational material presented in the paper has been very specific, our findings suggest a number of broader implications.

First, the work of the SICU suggests that we should reconsider the role of physical proximity and accessibility in coordinating cooperative work. As we have already noted, previous studies have observed that physical proximity is critically important in a range of collaborative settings, affording participants visual and auditory access to each other's activities and facilitating easy communication. Clearly, this is true, but it rests on a more fundamental assumption that the activity going on in the physical space is intelligible to those who witness it. For example, Heath and Luff's (1992) classic analysis shows how the London Underground control room operators achieve a remarkably smooth and intricate coordination between their activities through a combination of, first, continually monitoring the actions of others in the room, and, second, explicitly organising their actions so as to disclose what is happening to others nearby. However, this depends not only on their proximity, but on their ability to interpret what is going on around them, through their familiarity with the work of the control room and the practices by which their colleagues organise that work It is precisely this in-depth familiarity with the detail, motives and consequences of each other's work that is absent in the case of the SICU. The physicians and the nursing staff have only a limited and superficial understanding of each other's work – certainly not enough to achieve the delicate choreography that Heath and Luff observe So, the observation that physical proximity and accessibility support the coordination of group work glosses over an important detail. More accurately, physical proximity and accessibility afford the mutual interpretation of working activities to those who share a sufficiently detailed understanding of those activities in the first place. In cases such as the SICU, where this understanding is not present, physical proximity is not, by itself, sufficient

Second, the case of the SICU shows us that although participants interact with the information through different representations, coordinating their activities depends on these representations reflecting the same underlying information. Because it is the same underlying information, the different representations are always sychronised; any changes in the underlying information will be immediately reflected in all the different representations. The alternative would be to maintain two different systems in parallel – perhaps an information store that describes medication information, and a separate schedule that outlines nursing tasks, such as that observed by Bardram (1997). However, the possibility for inconsistency and the difficulty of moving information back and forth would compromise the SICU's ability to coordinate activities around the patient; it is important that the underlying information be shared The role of shared information in promoting coordination has been explored extensively in CSCW, particularly in the form of technologies promoting awareness (e.g Dourish and Bellotti 1992; Gutwin et al. 1996; Mark et al. 1997). The effectiveness of most of these approaches, however, depends on a common representation of the underlying information: a common information structure in the case of Dourish and Bellotti or Mark et al. and a common set of spatial arrangements in the case of Gutwin et al. There has been much less exploration of uses of awareness techniques in a coordinated fashion across multiple distinct representations, although an exploration by Greenberg and his colleagues (1996) provides an interesting example of the opportunities. Cases where the different forms of work are highly diverse, such as in the SICU, may require this sort of approach. In turn, our attention to the ways in which information representations can be designed to naturally convey a sense of the activities in which they are involved. This is not, in itself, a new observation (see Nygren et al. (1992) for an exploration of this issue, also in the medical domain), but the separation between information and representation implied in our study suggests that this meta-information must also be coordinated with multiple representations of the information.

Finally, the separation between information and representation also highlights how the same information is enmeshed in a variety of work processes. It serves multiple purposes and enables multiple individuals to carry out their own work. Traditional software architectures, however, typically provide no direct support for this feature of information work. Often, the information is embedded in a structure (such as a schema or hierarchy) that makes it tractable and manipulable by software systems. However, these information structures make it harder to pick information up and move it from place to place, decontexualising it and recontextualising it according to the situation of need; and similarly, they only reflect a single point of view on the role of the information rather than the many different points of view that we see at work in situations such as the SICU. Our fieldwork, then, provides support for approaches to information architecture that separates the information from the structures that surround and describe it (Dourish et al. 1999; Parsons and Wand 2000). By decoupling information from its structure and supporting diverse representations of the same information, these approaches can facilitate better coordination of heterogeneous work.

Conclusion

Common information spaces exist in diverse work environments. In our study of medical work in an intensive care unit, we focus on the use of a CIS in which the actors are physically co-located. The work of the SICU, like that of many other workplaces, is detailed, demanding, time-critical, and involves interaction among many different groups. At the center of the SICU work is the patient whose health is dependent on the effective coordination among physicians, nurses, and pharmacists. However, in many ways, each group's work practices are opaque to others. Although being physically co-located does help coordinate their activities, the diverse work practices of these groups prevent them from receiving the full benefits of co-location. Under these circumstances, our observations in the SICU point to the important role played by specific information representations in coordinating diverse work activities. For example, the system's ability to present both retrospective and prospective representations of the same information is important for coordinating physician and nursing activities. Unlike paper records, computer systems offer the ability to decouple information from its representations to help smooth coordination. This decoupling opens up a rich design space for systems that allow people with different interests, concerns and work practices to work together effectively.

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References

Bannon, L (2000). "Understanding Common Information Spaces in CSCW," Paper presented at the Workshop on Cooperative Organisation of Common Information Spaces, Technical University of Denmark, August 2000.

Bannon, L. and Bodker, S. (1997). "Constructing Common Information Space," *Proceedings of the European Conference on Computer-Supported Cooperative Work ECSCW'97.*(Lancaster, UK), Dordrecht Kluwer, pp 81-96.

Bardram, J E. (1997) "Plans as Situated Action: An Activity Theory Approach to Workflow Systems," *Proceedings of the European Conference on Computer-Supported Cooperative Work ECSCW'97.*(Lancaster, UK), Dodrecht Kluwer, pp. 17-32.

Berg, M (1999) "Accumulating and Coordinating: Occasions for Information Technologies in Medical Work," *Computer-Supported Cooperative Work* 8 pp. 373-401.

Berg, M. and Bowker, G. (1997). "The Multiple Bodies of the Medical Record. Toward a Sociology of an Artifact," *The Sociological Quarterly* 38. pp. 511-535.

Blomberg, J, Suchman, L. and Trigg, R H. (1997) "Reflections on a Work-Oriented Design Project" in Bowker, G C, Starr, S.L., Turner, W. and Gasser, L. (eds.) *Social Science,Technical Systems, and Cooperative Work: Beyond the Great Divide.* Mahwah, New Jersey Lawrence Erlbaum Associates.

Bowker, G.C. and Star, S L. (1999). *Sorting things out: classification and its consequences* Cambridge, Mass. MIT Press.

Dourish, P. and Bellotti, V. (1992). "Awareness and Coordination in Shared Workspaces," *Proceedings of the ACM Conference on Computer-Supported Cooperative Work CSCW '92.*(Toronto, Canada), New York ACM Press, pp. 107 - 114

Dourish, P, Edwards, K., LaMarca, A and Salisbury, M. (1999). "Presto An Experimental Architecture for Fluid Information Spaces," *ACM Transactions on Computer-Human Interaction* 6 (2)· pp. 133-161

Greenberg, S, Gutwin, C. and Roseman, M (1996) "Semantic Telepointers for Groupware," *OzCHI'96*. (Hamilton, NZ), IEEE Press, pp 54-61

Gutwin, C, Roseman, M and Greenberg, S (1996) "A Usability Study of Awareness Widgets in a Shared Workspace Groupware System," *ACM Computer-Supported Cooperative Work CSCW'96*. (Cambridge, MA), New York· ACM Press, pp. 258-267

Heath, C and Luff, P (1992). "Collaboration and Control Crisis Management and Multimedia Technology in London Underground Line Control Rooms," *Computer-Supported Cooperative Work* 1 (1-2): pp. 69-118.

Ishii, I, Kobayashi, M and Grudin, J. (1992) "Integration of Inter-Personal Space and Shared Workspace: Clearboard Design and Experiments," *Proceedings of the ACM Conference on Computer-Supported Cooperative Work CSCW'92*. (Toronto, Canada), New York: ACM Press, pp 33-42.

Lu, I. and Mantei, M. (1991). "Idea Management in a Shared Drawing Tool," *Proceedings of the European Conference on Computer-Supported Cooperative Work ECSCW'91*. Dordrecht Kluwer, pp. 97-112

Mark, G, Fuchs, L. and Sohlenkamp, M. (1997). "Supporting Groupware Conventions through Contextual Analysis," *Proceedings of the European Conference on Computer-Supported Cooperative Work ECSCW'97*. (Lancaster, UK), Dordrecht· Kluwer, pp. 253-268.

Nygren, E., Lind, M, Johnson, M and Sandblad, B (1992). "The Art of the Obvious," *Proceedings of the ACM Conference on Human Factors in Computing Systems CHI '92* (Monterey, California), New York: ACM Press, pp 235-239

Parsons, J and Wand, Y. (2000). "Emancipating Instances from the Tyranny of Classes in Information Modelling," *ACM Transactions on Database Systems* 25 (2)· pp 228-268.

Randall, D. (2000). "What's 'Common' about Common Information Spaces?," Paper presented at the Workshop on Cooperative Organisation of Common Information Spaces, Technical University of Denmark, August 2000.

Schmidt, K. and Bannon, L. (1992). "Taking CSCW Seriously. Supporting Articulation Work," *Computer-Supported Cooperative Work* 1: pp 7-40.

Simone, C., Mark, G. and Giubbilei, D. (1999) "Interoperability as a Means of Articulation Work," *Work Activities Coordination and Collaboration (WACC'99)*. (San Francisco, California), pp. 39-48.

Star, S L. and Griesemer, J R (1989) "Institutional Ecology, Translations and Boundary Objects Amatuers and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-1939," *Social Studies of Science* 19. pp 387-420

Strauss, A, Fagerhaugh, S., Suczek, B. and Wiener, C. (1985) *Social Organization of Medical Work*. Chicago: University of Chicago.

Trigg, R H., Blomberg, J. and Suchman, L. (1999). "Moving document collections online. The evolution of a shared repository," *Proceedings of the European Conference on Computer-Supported Cooperative Work ECSCW'99*. (Copenhagen, Denmark), Dordrecht Kluwer, pp. 331-50.