

Activity Analysis – Applying Activity Theory to Analyze Complex Work in Hospitals

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ABSTRACT

This paper presents “Activity Analysis” as a method for conducting and analyzing field studies based on Activity Theory. Two cases of activity analysis of work in a hospital ward and inside an operating room are presented. Guidelines for moving from Activity Analysis to systems design is presented and illustrated with the design of a context-aware system for hospitals.

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation: User Interfaces—*Evaluation/methodology*; J.3 Computer Applications: Life and Medical Science—*Medical information systems*

General Terms

Design, Human Factors

Author Keywords

Activity Analysis, Activity Theory, Hospitals, Surgery, Activity-Aware Computing, Context-Aware Computing

INTRODUCTION

The issue of how to deal with complex, detailed qualitative data from observational studies is still an open challenge for CSCW practitioners, despite much work in this space. One approach to studying and analyzing human (work) activities within CSCW has been ethnomethodology [10, 9], which has been applied quite extensively. Based on such studies, implications for the design of collaborative technologies have been drawn. As a subfield within sociology, ethnomethodology takes an anti-theory position and argues that orderliness is enacted as people draw on resources in their environment; actions cannot be described by anything that can be reduced to theoretical principles. Consequently, the key task for ethnomethodologists is to study and recover specific instances of organized practical actions in all endless details [18], and use this information as input to the design process.

Another approach to understanding cooperative work and to designing systems has been based on Activity Theory [13, 14], and some studies applying Activity Theory as theoretical frame have been presented in the CSCW literature [1, 2, 4, 16]. In contrast to ethnomethodology, Activity Theory is a theoretical framework which can be used to study, analyze, describe, and understand human activity, including collaborative activities and the use of technology. And in return, this theoretical framework can help predict and describe human activity, which again helps in the design of technology for mediating human activity.

However, it has been difficult for researchers and practitioners to see exactly how Activity Theory can be used as a method for studying and understanding the details of collaborative work. Compared to approaches based on ethnomethodology, Activity Theory has been less “operational”. The original proposal for using Activity Theory within CSCW draws on the model from Engeström’s approach [6]. This model is used to describe and understand overall organizational activities and how they evolve and expand during contradictions within a large organization, like a hospital. This model is hence well-suited for understanding human activity from an organizational perspective. It is, however, less suited for understanding the details of collaborative work in smaller groups in a more localized physical context. For this reason, it has been less obvious how Activity Theory can contribute to the understanding and design of computer systems for collaboration in smaller groups as it unfolds in the practical reality of everyday work.

The aim of this paper is to show how the theoretical framework of Activity Theory can be used for detailed analysis of collaborative work as proposed in ethnographically-inspired approaches. The paper presents the method of “Activity Analysis”, which is targeted at analyzing human collaborative activity as it unfolds in practice. In comparison to previous work on applying Activity Theory to CSCW, this method suggests and handles much more detailed analysis of the activity as enacted by humans and adjusted to the specific conditions of their work environment. As such, Activity Analysis is targeted to help bridge between detailed field studies of work to an analysis based on Activity Theory.

The paper starts by presenting the Activity Analysis method. Then the method is used to analyze work at a hospital. Two cases are provided: one focusing on the mobile and collaborative work at a medical ward; the other focusing on the

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details of co-located collaboration inside an operating room. The Activity Analysis method has been developed as part of our effort of designing context-aware systems for hospital clinicians, and we discuss how findings from the two cases can be used in systems design. This illustrates how systems design can be linked to findings from an Activity Analysis specifically, and to Activity Theory more generally.

ANALYZING HUMAN ACTIVITY

Theoretical Background

The analysis of activities is theoretically and methodologically rooted in Activity Theory (AT)¹. In AT the core tenet is the dialectical relationship between consciousness and activity, i.e. that human cognition is a reflection of its activity, and vice versa. AT argues that human activity is always directed towards an object that exists outside of the human. The person's motive is then a reflection of this object.

Human activity is executed in a hierarchy of three levels: activity-action-operation. An *activity* is always directed towards a motive; an activity is divided into a series of *actions*, each of which are directed towards more specific goals. Goals are conscious; humans are aware of the goals we want to achieve. Actions, in turn, are decomposed into lower-level units of execution called *operations*, which are executed in accordance with, and adjusted to, the specific conditions of the context, in which the operation (and hence the action) takes place. Operations are often automated (internalized) and people are typically not aware of how operations are performed – they become routine.

Humans seldom interact with the world and the object of the activity directly, but the activity is mediated by a number of artifacts developed over time in a specific cultural and physical context. Physical artifacts like tools and instruments are easy to recognize, but so-called 'psychological tools' like signs, languages, concepts, maps, etc. are also used to mediate human activity. Human activity is collaborative; AT does not view an activity as something 'belonging' to an individual, but as a collective process shared amongst several people. Collaboration is achieved by distributing the actions of an activity amongst different persons, who align the goal of each action according to the objective of the overall activity. This alignment is mediated by shared communicative artifacts, such as language, signs, documents, contracts, checklists, etc. Finally, Activity Theory puts emphasis on the developmental nature of human activity and its constituents; the configuration of the activity-action-operations hierarchy changes constantly; the mediating artifacts evolve and are replaced; the socio-cultural context changes; and the activities and their interrelationships constantly evolve.

These basic theoretical concepts can be illustrated with an example from the hospital: A physician (AT: human) is in charge of the treatment of a patient for leukemia (AT: object), and when interviewed, he explains how he is devoted

¹It is impossible to make a decent resume of Activity Theory in this paper. We can only encourage interested readers to read the book "Acting with Technology" [11], which gives a good introduction to Activity Theory and Interaction Design.

to trying to help this rather ill patient as much as possible (AT: motive). The overall course of treatment is specified in the department's clinical guidelines for leukemia (AT: a culturally developed artifact), which is a synthesis of the international medical research literature on best practice within the treatment of blood related diseases (hematology) (AT: the socio-cultural context). The treatment involves a range of tasks (AT: actions), including initial interview, blood and tissue analysis, radiology examinations, prescription of medication, etc. All of these actions are distributed to collaborating clinicians within the hospital, such as pathologists, laboratory technicians, radiologists, nurses, etc. Each of these actions – like the blood analysis – is performed by a wide range of manual procedures (AT: operations), such as adding the blood to a test tube, inserting it into an Optical Spectrum Analyzer, etc. Different parts of the activity are mediated by different artifacts: the clinical guideline helps the physician in the interview; the medical record is used to seek and store patient-related medical documentation; and the radiology examinations are done using Xray machines.

Activity Analysis

The purpose of the Activity Analysis method is to provide a detailed account and understanding of human activity as enacted collaboratively within the resources and constrains of a real-world setting. An Activity Analysis consists of two basic parts. First, detailed studies and observations of a particular setting with a focus on a specific set of overall activities. Second, a detailed analysis of selected activity patterns based on concepts from Activity Theory.

The *first part* applies traditional qualitative sociological methods of study, including participant observation, interviews, artifact studies, and video recording. Such studies can focus on different parts of the activity system, but a typical Activity Analysis would start out by collecting detailed data focusing on the following:

Activity – one particular activity, and the actions, people, artifacts, etc, which are involved. For example, the activity of treating a specific patient.

Person – activities and actions of an individual person. For instance a surgeon.

Place – a specific place or location, and the kinds of activities and actions taking place there. For example the operating room.

Artifact – the use of a specific artifact for mediating activities and actions. For example, a medical record in a hospital.

These are the typical starting points, but other studies of e.g., the socio-cultural context of the work or the historical development of an artifact, may also be relevant according to AT.

The *second part* of Activity Analysis focuses on analyzing the collected data in terms of Activity Theory. Activities are recorded (e.g., using video), transcribed, and coded using the Activity Analysis coding schema illustrated in Figure 1.

The schema identifies the following information and characteristics:

Activity – The identification and labeling of each unique activity. According to Activity Theory, an activity is identified based on its unique motive and object of work.

Image – A still image e.g., taken from the video recording. This is not theoretically relevant but useful in recognizing the work activity being transcribed.

Action – The action performed as part of an activity. In this schema, each row contains one action only.

Operations – The set of manual (or mental) operations that compose an action. Also enumerated are the instruments (artifacts) mediating the action and its operations.

Context – The context of the action, including time, place, material, and patient involved in all operations that make up this action.

Actors – The human actors involved in an action. Actions are often conducted by one actor alone, but in cases where people work closely together, more people can cooperate on an action. For example, two nurses lifting the patient onto the operation table.

Based on this coding schema, it is possible to identify the different activities, the start time and duration of engaging in an activity, the shift between activities, the different actions making up an activity, the details of the operations, the mediating artifacts, and the context in which all of this takes place. A core question in this method is, however, how to distinguish activities – i.e. how to separate one activity from another, and how to separate an activity from an action. According to Activity Theory, the activity's objective and hence the personal motivation, is what distinguishes one activity from another, and an activity from an action. In principle, therefore, we would only be able to establish the real activity during the activity analysis, if we were constantly asking the person why he is doing what he is doing right now. Hence, a good strategy when detailed video recording of a person is to constantly prompt him or her about the overall purpose of work. This approach is, however, not always feasible – for example, it is not appropriate for the observer to interfere during conversations between a patient and the physician. Therefore, the activity may instead be established by looking at the object of work, which may reveal the activity. For example, in a hematology department which focuses on individual patient treatment, each patient is a good candidate for an object of work. But in the blood test laboratory, the task of running a certain type of blood analysis for a whole range of patients is a better suggestion for an activity.

This coding schema has been designed to help analyze activities both on a higher level focusing on activities, actors, and general context, e.g., different locations, as well as on a more detailed level focusing on the meticulous operations involved in executing an activity adapted to the conditions of real life. An example of the former is an analysis that provides an overview of the number of activities that a physician

is engaged in during the day, the temporal pattern of these activities, the frequency and nature of activity switching, and the context of the physician's work. An example of the latter is a detailed study of the tangible interaction and instrumental coordination during surgery, and how different medical instruments and clinical guidelines are used during the procedure. In the next section, we shall provide two cases of how Activity Analysis was applied.

ACTIVITY ANALYSIS OF MEDICAL WORK IN HOSPITALS

In order to design activity-aware computing systems – i.e. systems which somehow try to adapt to, and take into account, the activity of the user – we have been undertaking a series of activity analysis studies. This section provides two such cases which show how the method of Activity Analysis can be applied in different ways.

Case A: Mobility and Distant Collaboration

The first case focuses on the collaborative work of patient treatment in an internal medicine department which specializes in hematology at a large metropolitan teaching hospital. Hematology is the branch of internal medicine that is concerned with the study of blood, the blood-forming organs, and blood diseases. The medical doctors who work in hematology are known as hematologists. Hematologists treat bleeding disorders such as hemophilia, hematological malignancies such as lymphoma and leukemia, and hemoglobinopathies. The work at a hematology department is highly collaborative and involves a wide range of specialized doctors, like pathologists, hematologists, radiologists, and hematopathologists, as well as lab technicians, nurses, and care assistants.

The activity analysis was done as part of a long-term study of the hematology department involving several periods of ethnographic field work over a two-year period. The activity analysis is based on a person-oriented record by shadowing and video-recording a senior hematologist for a whole day-shift (i.e. from 07:30 to 15:30), which was encoded as described in previous section. The following outline of the dayshift for a hematologist is intended to provide a frame of context for the analysis.

At the hematology department, the morning conference starts at 07:30 in the large conference room where the day-shift physicians meet. Each physician presents his or her patients in order to inform everybody about their status and receive any input from more senior physicians. After the morning conference, the physicians move on to their individual duties. Some go to the patient wards in order to do the ward round, some go to the out-patient clinic, and yet others have teaching obligations. At the ward, the physician meets with the nurses in the ward office. They go over each patient again – this time, however, focusing on care, exercises, examinations, and social issues. Every time a patient case is reviewed, the paper-based medical record, medicine chart, etc. have to be located, and browsed for information.

After this ward conference, department's physicians move to the radiology department and attend the radiology confer-

Activity	Image	Action	Operations	Context	Actors
Surgery of Mrs. Pedersen		Discussion of Mrs. Pedersen at morning conference.	- look up patient in Medical Record - present case - look up patient in PACS system - ...	Location/Place: Anesthesiologist conference room Time: 08:32	Anesthesiologist at department
Surgery of Mr. Hansen		Presenting Mr. Hansen	as above...	Location/Place: Anesthesiologist conference room Time: 08:37	do.
Surgery of Mrs. Pedersen		Starting surgery	-surgeon connects the tubes to the patient's body -op nurse hands the surgeon the laparoscopic instrument1 - surgeon presses the laparoscopic instrument1 to the patient's body -op nurse hands the surgeon the syringe - ...	Location/Place: operation room- at patient bedside and the surgery device Material: surgery device, the surgery application AIDA II, surgery instruments1,2,3 Time: 9:18-9:23 Patient : Mrs. Pedersen	operation nurse, 2 surgeons
		The nurse anesthetist checks the drug device		Location/Place: operation room Material: drug device (painkiller + anesthesia drugs) Time: 9:18 Patient : Mrs. Pedersen	nurse anesthetist

Figure 1. Activity Analysis coding schema showing the transcript along the vertical axis and the different aspects of an activity along the horizontal axis. The activity is listed on the far left, and each row in the table is a transcript of an action within this activity, describing the operations, context, and actors of this action. This example shows a transcript of a person-oriented record where a specific person – in this case an anesthesiologist from case B – has been followed during a work day.

ence in their conference room. During the radiology conference, the radiologist explains the result of each examination, using the radiology images to point out relevant issues, like cancer tumors. After the radiology conference, the physician moves back to the patient ward and starts the ward round. The ward round is where the physician and one or two nurses takes a tour on the ward and pay all patients a visit at their bedside. Each time, the medical record is consulted and the nurse is taking notes regarding the physician's prescriptions of medication, examinations, and physical exercises. The ward round takes all morning and when finished, the physicians meet again for a conference at 13:00. After this conference, they attend various duties like dictating the medical record, visiting specific patients, or having consultations in the out-patient clinic.

Case A: Results

By transcribing the work day of the hematologist according to the coding schema illustrated in Figure 1, we were able to analyze how many activities he managed during a work shift; how frequently he shifted between activities; his patterns of mobility; and the temporal and collaborative patterns of these activities.

The results of this analysis are illustrated in Figure 2, showing the temporal pattern of the activity analysis of the hematologist. During this particular shift, the hematologist was engaged in 14 unique activities: 11 unique patient cases (labeled '1'-'11' in figure 2), a coordination activity regarding shift scheduling (labeled '-1'), an information management activity ('-2'), and a quality assurance (QA) activity regarding the development of a certain procedure in the department ('-3').

The activity analysis revealed 86 activity shifts during the 5 hours of work. Figure 2 illustrates the temporal distribution of these activity shifts. The three conferences in the morning are labeled A, B, and C for the morning, ward, and radiology conferences respectively. We notice that during all three conferences there is a fast pace in activity shifting – each patient is briefly presented and discussed. During these conferences, the patient is not present, but, instead, intensive information management is taking place. For example, in order to present a patient during the radiology conference, the radiologist shows 2-10 Xray images and consults both the written request as well as his written analysis. Similarly, during the ward conference, medical records, medicine charts, care records, etc are used for information management.

After the morning conferences, the ward round starts. This is labeled with the first patient (2) in figure 2. During the ward round, each patient is visited at the bed side and attended for a longer period of time. Even though figure 2 illustrates that the physician is engaged in the different patient related activities for a longer period during the ward round, the figure also shows that these activities are frequently interrupted, and that the physician attend the same activity many times during the day. For example, activity no. 8 is attended several times during the later part of the ward round and is interrupted a couple of times, e.g., when the physician needs to briefly attend activity no. 4 again. This very clearly illustrated the kind of multi-tasking taking place in a hospital.

Table 1 illustrates the temporal distribution of activities during the shift. We see that the physician is engaged in patient related activities (1–11) 63% of the time; coordination of shifts takes up 5% of the time; general QA 9% of the time;

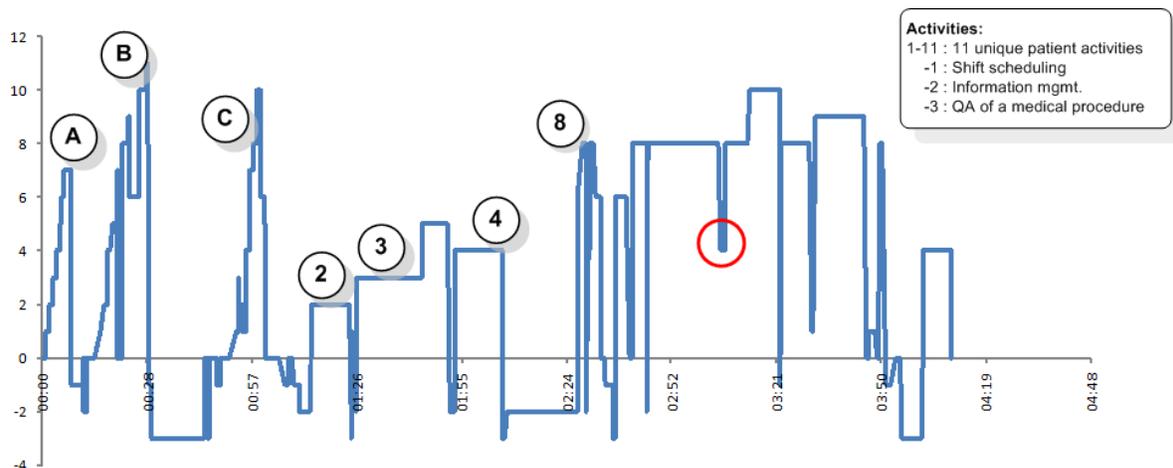


Figure 2. Activity Analysis of a day shift for a senior hematologist during a day shift. All patient related activities are above the timeline (labeled 1–11), whereas more administrative activities are below the timeline (and hence labeled -1, -2, and -3). A, B, and C are the morning, ward, and radiology conferences respectively.

Activity	% of entire shift
Patient related (1–11)	63%
Shift Scheduling (-1)	5%
Information Mgmt. (-2)	10%
QA of procedure (-3)	9%

Table 1. The temporal patterns of the physician’s activities.

and information management 10% of the time. We also investigated how much time the physician was physically co-located with the patient. This added up to 33% of the shift, which is 53% of the time spent on patient related activities. Hence, physicians are with the patients approximately half of the time they are performing patient related activities.

Case B: Co-located Collaboration in ORs

The second case illustrates how Activity Analysis can be used to analyze the detailed interaction taking place inside an operating room (OR) during surgery. In this case, special emphasis was on understanding issues of co-located collaboration, use of instruments, coordination with people outside the OR, and the temporal unfolding of activities during surgery. In this case, the detailed activity analysis is based on video recordings of 5 different laparoscopic operations at a gastric-surgical department of a large teaching hospital. The general scenario for most types of surgeries in this department is as follows:

Half an hour before the operation is scheduled to start, the nurse anesthetist starts to prepare for surgery. She checks the anesthesia devices and prepares the medicine and instruments that are to be used. When the patient arrives to the OR, he/she is prepared for anesthesia. Meanwhile, the scrub nurse and the circulating nurse are preparing the surgical instruments and devices by putting them on the operating trolley next to the operating table. When the surgical instruments are ready and the patient is anesthetized, the surgeon(s) enters the OR, and the operation starts. Dur-

ing the operation, the nurse anesthetist constantly monitors the patient’s condition, and transfuses blood and medicine as needed. The scrub nurse assists the surgeon by giving him/her the instruments and material he or she might need. When approaching the end of the operation, the nurse anesthetist starts the process of waking the patient, and the scrub nurse starts to gather the surgery instruments. After the surgery is finished, the patient is transported to the recovery room.

By using Activity Analysis on these operations, we see that the overall operation activity consists of a set of actions, and each action contains at least one operation. For example, the intubation action usually consists of opening the patient’s mouth with the assistance of a laryngoscope and putting the ventilation tube into the patient’s trachea. In order to draw patterns of the surgery activity, we transcribed our video recordings to the coding schema as described in Figure 1. We identified the actions and corresponding operations, actors, physical instruments, and locations in which the actions took place.

Figure 3 shows a temporal diagram of the actions in one instance of a laparoscopic operation². The actions are labeled with A and a number, e.g., A18. The number shows the order in which the action took place, i.e., A18 started after A17. This numbering does not mean that these actions always happen sequentially; actions can take place in parallel, like A16 and A18. The human operations for each action are labeled with *o* followed by the number of the action and the order number. For example, *o181* means the first operation in action number 18. The actors and instruments involved in the action are labeled with *p* (‘person’) and *m* (‘mediator’) respectively. Finally, the location where this operation takes

²Both Figures 3 and 2 show the temporal unfolding of activities. But due to the focus of case B, Figure 3 is tailored to illustrate the detailed unfolding of actions (some of them in parallel), and the mapping of each action to its operations, instruments, location, and actors.

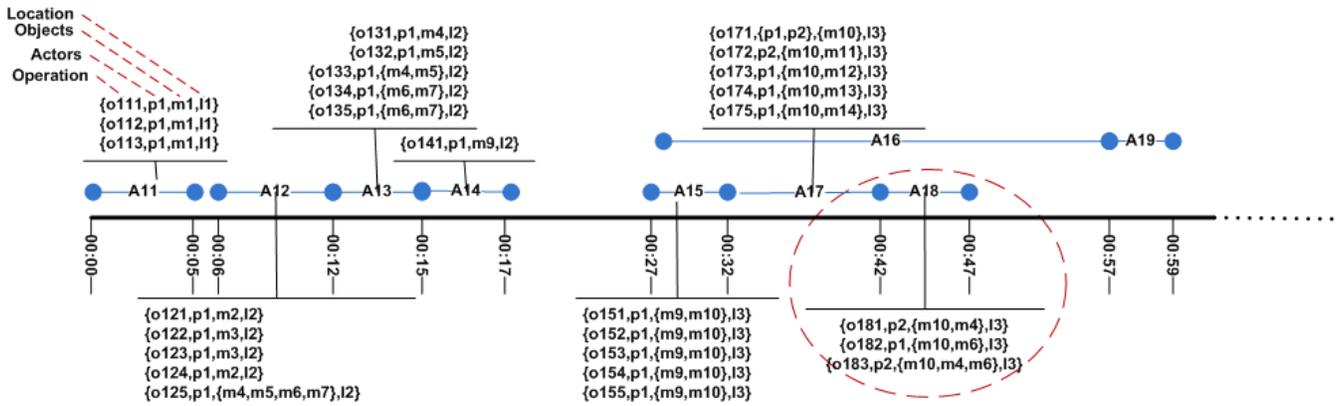


Figure 3. The temporal pattern of activities in a laparoscopic surgery.

place is labeled using an l . Figure 4 shows the intubation action (A18), which consists of three operations:

- o181 – The anesthesiologist holds the patient’s head and opens the patient’s mouth with the assistance of a laryngoscope.
- o182 – The nurse anesthetist gives him the ventilation tube.
- o183 – The anesthesiologist puts the ventilation tube into the patient’s trachea.

The instruments and objects involved in this action include a Laryngoscope ($m4$), a ventilation tube ($m6$), and the patient ($m10$). A nurse anesthetist ($p1$) and an anesthesiologist ($p2$) participate in this action, and all operations take place at the operating table ($l3$).



Figure 4. A snapshot of the intubation action (A18)

Case B: Results

We identified 36 actions and 137 operations in the laparoscopic surgery. The number of (human) operations in each action varies from 1 to 13. Some actions have several actors (33%), and others are done individually. Almost all actions (97%) in the laparoscopic surgery involve using at least one physical instrument, and 78% involve several instruments (see Table 2). Only a few coordination and communication actions do not involve physical tools. We also noticed that there is a direct relation between the physical instruments and the actions; for example, a laryngoscope is

Actions involving several actors	33%
Actions involving at least one instrument	97%
Actions involving multiple instruments	78%

Table 2. Actions inside the OR.

only used in the intubation action. We identified the use of 39 different types of anesthesia instruments and medicine, and 37 different types of operation instruments.

Despite being co-located inside the OR, the actions are performed in certain areas in the room. We identified 4 important zones, i.e., specific areas where collections of actions were carried out. These zones were the anesthesia machine zone ($l1$), the anesthesia cabinet zone ($l2$), the operating table zone ($l3$), and the operating trolley zone ($l4$).

Anesthesia related actions are done in $l1$, $l2$, and $l3$; and operation related actions are performed in $l3$ and $l4$. For example, preparation of anesthetic and anesthesia instruments is done near the anesthesia cabinet ($l2$), whereas preparation of operation instruments is carried out in $l4$. The team members move between these zones. For example, depending on the action, the anesthesia nurse switches between $l1$, $l2$, and $l3$. The frequency of movements between different zones depends on the operation phase. During the preparation and ending phases the clinicians move between zones more frequently than during the surgery.

The surgery activity follows a temporal and sequential pattern. It is always started with preparation, followed by the surgery, and ends with cleaning up. We identified three types of actions in the surgery activity:

- Actions that are common in all types of surgeries and are carried out in certain phases of the surgery. These actions are prerequisites for initiating other actions. For instance, anesthetization always takes place during the preparation phase and before the surgery starts. If the patient or the specific area of his/her body is not anesthetized, the surgery usually cannot be started.

- Actions that happen to be performed in some surgeries, and their occurrence is in particular phases of the surgery. For example, the intubation is not necessary for all types of surgeries, but if the patient should be intubed, it will be conducted before starting the surgery.
- Actions that are carried out in some surgeries without being bound to a certain phase. For example, the nurse anesthetist can document the ordering of the blood either during the surgery or after the surgery is finished.

The duration, the type and number of instruments, the number of operations, and the actors involved in an action vary in different surgeries. It depends on many factors, especially the patient's condition and the type of surgery. For example, if a patient has a neck problem, the ventilation should be performed by putting a mask on the patient's mouth instead of sending a tube into the patient's lung.

Some actions do not follow a specific order. For instance, it doesn't matter if the anesthetist checks the devices before or after preparing the medicine. The only thing that matters is that both medicine and devices are ready before the patient enters the OR. The actor of an action or an operation can also change. For example, if during the intubation, the nurse anesthetist does not succeed in putting the ventilation tube in the patient's lung, another nurse or the anesthesiologist will take over.

A typical surgery requires participants specialized in the specific type of surgery and associated type of anesthesia. Coordination and communication happen within and between the anesthesia team and the operating team. The team members usually communicate and coordinate their actions by talking to each other or observing each other's work. For example, the nurse anesthetist can either observe the surgery to find out the remaining time of the surgery, or she can ask the surgeon. Observing the use of an instrument by a team member can be an indicator for other members' actions. For example, the anesthetist always needs to know when the surgery is finished, so she or he can start preparing for the ending phase. If the surgeon starts to use the suture needle and thread, that usually means the surgery is ending, so the anesthetist can start the process of waking the patient.

The only shared 'object' is the patient and information about his/her condition. Hence, the anesthesia team and the surgical team can coordinate their work by shared access to the condition of the patient, including monitoring the patient on the monitors.

About 33% of all actions involve more than one actor. Typically, the nurse anesthetist assists the anesthesiologist in anesthesia relevant actions, and the scrub nurse assists the surgeon in surgery relevant actions. Getting involved in an action usually depends on the participants' roles and specializations. An anesthetist is concerned with the anesthesia and the patient's general condition during the surgery, whereas a surgeon concentrates on the surgery. This division of labour causes the division of tools and instruments used by the members. An anesthetist would rarely touch the

surgery instruments, partly because she or he is not scrub, and partly because there is no direct link between her or his tasks and the surgery instruments.

FROM ACTIVITY ANALYSIS TO SYSTEM DESIGN

Now – how can Activity Analysis be used in systems design? Does Activity Analysis provide more overall guidelines for design, or are the implications for design to be drawn on a case-by-case manner as we see in more traditional workplace studies? The answer is not clear-cut. Activity Theory and Activity Analysis provide us with a set of general theoretical insights, but the specific translation from studying and analyzing activities to systems design is clearly also very dependent on the specific case.

In this section, we want to illustrate how Activity Analysis can be applied in systems design. We will do this by discussing how to design a context-aware system for hospital clinicians. In the nomadic work environment of a hospital, context-aware technologies seem a promising approach. For example, if we think of case A, a good candidate for a context-aware systems for hospital use will be a system that helps the physician to get relevant information on a patient through a portable device when he is approaching this patient during the ward round. And indeed, this has also been suggested [3, 15, 7]. Similarly, providing timely access to relevant medical data during an operation has been suggested to be relevant in case B [8].

From Activity Theory, we are able to draw four more general-purpose design guidelines, which help transform the insights obtained in Activity Analysis into principles for systems design in a specific setting³:

Activity – Focus the design on the (human) activity. In this case rather than creating a system that reacts on 'context' (e.g., location), create a system that react on human activity – i.e., moving from context-aware to activity-aware systems.

Levels – Design for all three levels of human activity. In this case rather than supporting context-aware systems on an action level of e.g. the ward round, incorporate support for the whole patient treatment.

Context – Take into consideration that all human activity is enacted through operations adjusted to the specific conditions of the real world. In this case the operations during surgery are adjusted to specific contingencies arising during the procedure.

Collaboration – Since all human activity is collaborative involving both concurrent and conflicting actions, systems design should take into consideration the way human actions are part of a larger social pattern. In this case actions and operations may run concurrently involving sev-

³This list is not exhaustive. It is merely a list of design consideration drawn from the Activity Analysis. Other design concerns arising from Activity Theory may include e.g., designing for continuous development in use. The Activity Checklist [12] provides a list of related concerns.

eral persons in the operating room, and context-aware information retrieval needs to accommodate this.

We will discuss these implications for design of context-aware technologies in greater detail. Note, however, that the focus is on moving from Activity Analysis to the overall design of a context-aware system for hospitals; the aim is not to provide a detailed description of this system.

Design for Human Activity

The first – and maybe most obvious – design guideline is to design systems while focusing on supporting the human activities. In the case of designing context-aware systems, this design implication helps us to move the focus from “context” to “activity”. This resonates well with the fact that it has proven difficult to deductively move from physical context – like location – to establishing the system’s appropriate course of action. For example, a physician may be in front of a patient in order to prepare some medical equipment, like a catheter insertion, and would be more interested in a clinical guideline for this procedure rather than the patient’s medical record [7]. And – on the contrary – the activity analysis in case A showed us, that the physician is in close proximity to the patient only half of the times he is engaged in a patient activity.

More generally, by moving focus from “context” to “activity”, we move from studying, capturing, modeling, and inferring context to analyzing the activity, and examining what is contextually relevant for the human actors who execute the activity. As argued by Dourish [5] “contextuality is a relational property that holds between objects or activities. It is not the case that something is or is not context; rather, it may or may not be contextually relevant to some particular activity”. As such, context becomes an “interactional resource” in the sense that contextual entities can be used to perform activities. Furthermore, contextual entities play different roles as part of an activity: some are tools and instruments which play an active role in mediating the activity; others are results or outcomes of activities; and yet others are passive and sometimes constraining entities in the physical environment. Depending on the specific activity (or action or operation), a physical object may play different roles. For example, inside the OR the surgical instruments are essential tools for the surgeon, but physical constrains that the anesthesia nurse needs to work around.

In line with other researchers [17, 7], we therefore propose to build activity-aware systems, rather than context-aware systems; i.e. systems which are able to recognize not only the context of the user, but the overall activity that the user is – and has been – engaged in. For example, in case A our system is being designed to continuously collect and manage large amounts of medical information – digital as well as physical – that is used during treatment of a patient. By monitoring the use of medical resources and physical items, the system can gradually build and maintain a set of links to resources which are relevant for this “patient-treatment” activity. Then, timely retrieval of medical information in different situations may be triggered by contextual events. For

example, in the medical ward, access to the patient’s medical data may be triggered by physical proximity to the patient or when a physical or digital artifact related to the patient is used. In the OR, medical information may become available on a large interactive display at the time when the operation for this patient is scheduled to start. In this way, what constitutes “relevant information” is defined through long-term use of various information related to an activity (like treating a specific patient), and access to this collection of information (including historical information) can become accessible based on contextual events (such as approaching the patient). Hence, what is “relevant” information in a specific situation is defined by the activity and its history, and not by the properties of the situation.

Design for Different Levels of Activity

Activity analysis based on Activity Theory helps divide field studies of work activities into its three levels of activities, actions, and operations. For example, case A is mostly concerned with a higher activity level, whereas case B is concerned with the more detailed level of actions and operations. When moving to systems design, we should continuously ask at what level we are creating systems support; are we creating a system which helps clinicians to coordinate and articulate activities across the hospital, or are we creating a dedicated tool for the actions of a surgeon inside the OR. It is, however, important to keep in mind the ‘whole’ activity. In the operating room, for example, it is important that the systems design has some connection to the overall activity of the patient treatment.

The activity analysis of work at the hematology department in Case A shows that clinicians were handling many (14) concurrent activities during a day shift; that they were switching between these activities frequently (86 times), at a fast pace e.g., during the conferences; that activities were unfolding in a changing context due to the mobile nature of the work; and that 63% of their time was devoted to patient related activities. Traditionally, context-aware computing has worked with a one-to-one relationship between context and activity. Our study implies that there is a many-to-many relationship; several activities may be relevant in one context, and the same activity is relevant in several different kinds of contexts. An example of the former is that almost all patients (2–11) in figure 2 are relevant during the physicians’ morning conference, whereas the activity of treating Mrs. Pedersen for appendicitis is relevant both in the conference rooms, the patient ward, and the OR. Therefore, on the overall activity level, the implications of this activity analysis are that clinicians need support for timely retrieval of large amounts of medical information, and frequent and fast switching between multiple activities in different places. We are hence designing activity-aware computing support for fast and frequent activity switching between multiple activities. This is achieved by having the system maintain an awareness of a potential set of relevant activities, rather than just one.

Case B was analyzing a specific surgical activity on the more detailed level of actions and operations. This analysis revealed a tight coupling of 36 actions taking place inside the

OR, and these actions were also tightly coupled to the physical instruments used before, during, and after surgery. 97% of the actions in the operating room involved at least one physical instrument, of which there were 39 anesthesia utensils and 37 surgical instruments. As there is a strong correlation between specific objects and actions, sensing the usage of a small set of instruments may have the potential to reveal the action. In the case of a surgical procedure, there seem to be rather simple associations between the use of instruments, the human operations, and the actions taking place. For example, there is a rather straightforward linkage between the laryngoscope, the ventilation tube, and the action of intubation (A18) in figure 4.

This observation corresponds with the basic principle of mediation in Activity Theory; all human activity (and hence action and operation) is mediated by tools. By observing the use of tools and instruments by a person, we get a very good indicator of what activity is being performed. This fact is being used in the design of our activity recognition system for the OR; we apply a wrist-worn sensor that can detect which tools the clinicians are using. This is combined with a location sensing system tracking objects. In this way, we can sense the relationship between persons, locations, and the instruments used by the persons to manipulate different objects. For example, when a surgeon is holding a scalpel at the operating table to operate on the patient.

Design for Contextual Conditions and Contingencies

Central to Activity Theory is the notion that mental constructs such as motives and goals orient the activity and action, whereas the operations are adjusted to the conditions of the real world [1]. Therefore, system design should take into consideration the enactment of operations as adjusted to the specific conditions of the real world. When creating context-aware systems, this implies that any activity or action detection may be wrong. Hence, identifying the ‘right’ activity or action can only be done by the human actor, and therefore the system design should allow for users to indicate whether the activity-aware system is on the right track. This may, for example, imply that when activities or actions are discovered, they are presented to the user as suggestions for further action. In the ward round scenario (Case A), instead of presenting the medical data for the patient nearby, we are designing the activity-aware system to present a set of patient cases based on some relevancy algorithms. Then the user can select the ‘right’ patient (i.e. activity). In the OR, the system is designed to detect actions and their status, but as a control measure, a clinician will always approve the resulting output.

Design for Collaborative Activity

Activity Theory highlights the collaborative nature of human activity, i.e., collective processes shared amongst several people. For example, in case A, the treatment of a patient involves a range of tasks, including initial interview, blood and tissue analysis, scanning, medication prescription, etc. All of these actions are distributed to collaborating clinicians within the hospital, such as physicians, laboratory

technicians, nurses, etc. In case B, the surgical activity is carried out in a team of surgeons and nurses. While the nurse anesthetist and the anesthesiologist are intubating the patient, the scrub nurse prepares the instruments for the operation.

Moreover, Activity Analysis puts emphasis on the fact that collaboration takes place on the three levels of activity, action, and operation. Collaboration on the activity level is obvious, as visible during the ward round in Case A. But more fine-grained and tacit collaboration can be studied on the operation level inside the OR. Here, surgeons and operating nurses collaborate tightly on the actions involved in surgery, and by just watching the operations of the surgeon the nurse is often able to continuously provide the right instruments in a timely manner. Also, on an operational level, we find collaboration where the operations of the involved actors are mediated by the shared object of work. For example, in the intubation action (A18 in Figure 4), the anesthesiologist and the nurse silently work together in coordinating their operations.

This analytical stance implies that the design of activity-aware systems using activity recognition need not only focus on recognizing the activity of an individual actor – which has been the prevalent approach so far – to consider how activity recognition of collaborative and concurrent activities can be done.

CONCLUSION

This paper has presented the “Activity Analysis” method and provided two cases demonstrating how to apply this method in a detailed contextual analysis of medical activities inside a hospital. The method applies ethnographic field studies by analyzing observations using Activity Theory.

Activity Analysis can provide a detailed insight into many aspects of human activities on several levels. For example, case A provided detailed insight into the activity management of a physician by analyzing the collaborative and mobile aspects of his work during a day shift. Analyzing the details of a surgical operation helped identify the relationship between use of instruments, the location of people in the OR, and the activities of the surgical team.

The question might be whether this detailed analysis is worth it for the insights gained. Our answer is yes, as, for example, using the results of case B, we were able to identify the sensing requirements for building an activity recognition system in the OR, which helped us avoid unnecessary and costly sensors. Without having much quantitative data, we identified the key instruments that needed to be sensed. We confirmed this list in an experiment where we equipped as many instruments as possible with RFID tags and collected data from surgeries. The same instruments were identified as key features by the classification method. The details of this work will be described in an upcoming paper.

We have shown that activity analysis can provide detailed insight into the constituents of human activity. Moreover, based on activity analysis, we provided a set of design guide-

lines, which are useful in the design of systems that have a focus on supporting human activity. The overall idea of these guidelines is to help the designer use activity analysis to focus on important parts of the human activity, including (i) creating a tool for the ‘whole’ human activity; (ii) design for – or at least consider – all three levels of human activity; (iii) design for the contingencies of the real-world enactment of an activity; and (iv) design for collaboration both on a higher activity level as well as the lower level of human operations. We applied these guidelines to the design of context-aware systems for use in hospitals.

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