Characterizing Modes of Coordination

A comparison between oral and artifact based coordination

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ABSTRACT

The choice of communicative modality will greatly affect the way cooperative work is coordinated. Computer supported coordination brings about changes to communicative modalities—often the change is from oral to artifact based coordination. In order to inform the designed changes in modality we need to understand the characteristics of individual modes of coordination, and we need to compare modes before changes are implemented. Within this context the paper has two objectives: (1) to characterize oral and artifact based coordination, and (2) to establish an initial set of dimensions which will support a comparison between the two modes of coordination. The basis for both points is empirical: a field study of oral coordination in maritime operations, and a study of artifact based coordination in software engineering.

Keywords

Coordination modes, maritime operations, software testing.

INTRODUCTION

The coordination of complex cooperative work is an intricate matter that can impose a severe workload on the cooperating actors—so much so, in fact, that the magnitude of coordination work becomes an obstruction to work effectiveness, flexibility, and safety. Coordination support systems are aimed at reducing the coordination workload within the cooperative ensemble. In order to achieve this goal the redesign often involves radical changes in the way coordination is performed, and radical changes have a tendency to yield unforeseen phenomena.

A striking illustration of this problem has been provided by a study by Kasbi and Montmollin [13] which explores the impact on cooperative work practice of the planned radical computerization of control room design for the French 1500 MW power plants of the N4 PWR series. In order to study the impact of this putative 'technological leap', it was decided to connect a prototype of the advanced computer based control room to a 1300 MW PWR process simulator called S3C. Operators running the S3C were observed and their performance was compared with field study findings from conventional control rooms.

Part of the redesign consisted in eliminating the large overview panels known from traditional control room settings, and instead provide the plant information on computer monitors—one monitor for each of the two actors operating the plant. When the proposed design was tested in the simulator it turned out that the actors experienced significant problems related to coordinating their work. In short, one of the problem was that monitors did not facilitate the same degree of reciprocal awareness between the actors as did the traditional overview panels mounted on the wall. The traditional design allowed the actors to monitor each other as they moved around in the control room in order to check information located in different places on the large panels. One actor knew what the other was doing, e.g. what parts of the plant was being monitored by his colleague. The monitor based design prevented this kind of awareness, partly because the actors could not see both monitors at the same time, and because the interface involved a number of windows. One actor had no chance of knowing what the other was looking at, and as a result the actors experienced a rise in the coordination workload rather than a reduction: Earlier the actors could silently monitor each other but with the monitor based design the needed mutual awareness had to be achieved via explicit oral interaction.

If we compare the proposed redesign of the power plant to the changes in modes and media enforced by many contemporary coordination support systems we find that the latter implements the most radical changes since they implement changes in both mode and media of communication. In many cases the change is from oral to artifact based coordination—and thus a change from the acoustic to the graphical medium.

The motivation for the introduction of coordination artifacts is that our everyday modes of interaction, (speech, gesture, etc.) are limited in respect to their coordination capabilities [19]. Thus, above a certain level of work complexity artifact based coordination support is needed in order to maintain satisfactory levels of effectiveness, flexibility, and safety.

As indicated by the power plant example, a radical change in coordination practice is not a trivial design objective—not at least because the similarities and differences between various modes and media of coordination are poorly understood.

The objective of this paper is to characterize and compare the modes of *oral* (spoken) and *artifact based* (objectified) coordination. We will report from two field studies of coordination practice: a study of maritime operations, where focus is on oral coordination, and a study of software engineering, where we will focus on the use of coordination artifacts.

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After having characterized oral and artifact based coordination based on the observations from the two studies we will perform a comparison along the following dimensions:

- Persistency of coordination information
- Dedicated and non-exclusive modes of coordination
- Degree of automation
- Stipulation
- Direct and indirect referencing
- Dynamic and static means of coordination
- Coupling and detachment between work and coordination
- Flexibility and the reduction of coordination workload

The dimensions are not orthogonal in as far as certain aspects of coordination may be significant within several dimensions. Neither do we propose that this initial list of dimensions is exhaustive.

Related work

The coordination of cooperative work has long been a core issue within the CSCW literature, and the body of seminal work is significant. Several in-depth studies have illustrated how co-located actors coordinate their individual yet interdependent activities by means of our everyday modes of interaction [10, 12, 21, 22], while other studies have focused in particular on the role of artifacts in cooperative work [8, 9, 11, 16]. A number of experimental coordination support systems have been developed, e.g., [1, 18, 23] and conceptual frameworks have developed in conjunction with the field studies and design efforts [15, 19, 20].

While being generally concerned with design issues, the present paper is in particular related to the empirical studies that have shed light on our everyday modes of interaction and artifacts in coordination. Many of these studies have illustrated multi-modal coordination, but none have, to our knowledge, focused explicitly on a structured comparison between oral and artifact based coordination.

ORAL COORDINATION ONBOARD THE SALLY MÆRSK

The M/S Sally Mærsk is the largest container carrier ever built. She is 347 meters long, 48 meters wide, and carries more than 7000 containers when fully loaded. It is 104750 ton driven to a max of 25 knots by an engine in excess of 74000 horsepower (BHP metric).

Figure 1. The slightly smaller sister-ship M/S Knud Mærsk.

Our studies of cooperation and coordination in maritime operations have been ongoing for more than five years. We started out in 1996 by observing mariners training in high fidelity full-mission ship simulators. A year later, we performed our first real-world study onboard the container carrier M/S Majestic Mærsk. Later followed the M/S Knud Mærsk, and during the summer of 1999 we conducted our latest study onboard the M/S Sally Mærsk. In total we have been fortunate to spend more than four months—around the clock—doing field studies onboard some of the most impressive vessels in the merchant marine.

Our aim has been to understand cooperation and coordination as seen from the perspective of the actors on the command bridge (from where the vessel is commanded when at sea). The constellation of the cooperative ensemble is highly variant according to different operational phases. In open sea (from sunrise to sunset) there will be only one actor on the bridge—and the work is only temporarily cooperative when foreign vessels enter the sphere. Things start happening when the vessel moves from the ocean into coastal waters: First the bridge will be manned with two actors, then three. A pilot will embark. Lookouts will be positioned on deck. Tugboats will arrive. The Vessel Traffic Control will enter the scene, and when the vessel is within the actual harbor area the cooperative work arrangement will have grown to 20 or more actors directly engaged in the operations.

Field data have been collected via first hand observation, and a technical setup which allowed us to capture a relatively full and coherent picture of the activities on the bridge, the performance of the vessel, the weather conditions, foreign vessels, activities on deck, etc.

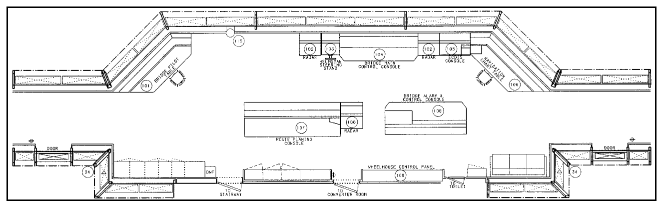

Figure 2. General bridge layout.

During latest study onboard the Sally Mærsk we had six video cameras mounted on the bridge: four on the central bridge and two (mobile) cameras mounted in the bridge wings. The actors carried wireless microphones, and all communication between the actors on the bridge along with intercom, walkie-talkie, and VHF communication was captured and synchronized online with the video recordings. All the Sally Mærsk's and actual tracks were plotted in sea charts. The paper charts, along with video recordings of the vessels digital replay system, created an important basis for detailed discussions of individual maneuvers and the mariners' explanations on what a particular actor said or did in a certain situation. It is this material that we will draw on in the following.

Silence is gold

Any communicative situation involves explicit and implicit elements. When observing the mariners at work, it soon becomes clear that the implicit plays a prominent role within this work domain. Consider the following example.

The Sally Mærsk is inbound for Rotterdam. There are four actors on the bridge: master (captain), chief officer, pilot, and helmsman. The auto pilot has been switched off and steering is now performed manually. All are silent. Then the pilot speaks: starboard twenty. The helmsman speaks: starboard twenty. And all are silent again.

1	Pilot	Starboard twenty

2	Helmsman	Starboard twenty

Fragment 1. Rudder command.

The communication between the pilot and the helmsman is characteristic of high workload situations; such as an approach to port. Only the rudder command is explicitly spoken. Other elements like receiver, the status of the message (command), desired time of implementation, etc. are left out. Following Andersen [2] we will say the explicit elements constitute the *focus*, while the implicit form the *background* for the communication.

The distribution between focus and background in the communication between the pilot and helmsman can be illustrated by means of a typical sentential schema.

Subject	*TAM*	*Verb*	*Object*	*Manner*	*Time, place*
Someone	Do	Acting on	Something	In some way	Somewhere

Table 1. Sentential schema. TAM is short for tense, aspect, modality (adapted from [2]).

A sentential scheme consists of a set of slots following one another in a more or less fixed sequence. Each slot can be filled with a particular kind of linguistic material, e.g. nouns, verbs or adverbs. Each set of contents elements (each slot in the schema) form a so called paradigm [2].

In the communication between the pilot and the helmsman only one paradigm has focus. The remaining paradigms are backgrounded. Only the manner slot is filled-in explicitly, the rest are left 'blank'.

Subject	*TAM*	*Verb*	*Object*	*Manner*	*Time, place*
Helmsman	should	turn	wheel	starboard twenty	now

Table 2. Focused paradigm is grayed.

The schema provides us with an overview. And we can now, in a more structured way, determine the relationship between focus and background. In earlier works [3], we have used the schema as a means of distinguishing between individual coordination functions, while in the present we will point to focus and background as means of reducing the coordination workload.

The overall purpose of the communication between the pilot and the helmsman is the desired accomplishment of a physical task, i.e., turning the rudder in order to change the vessel's course. Safe operations rely on detailed and specific communication about the vessel, the navigating crew, and the surrounding world—that is, communication about the cooperative work arrangement and the common field of work. Safe operations are not maintained by having someone steer some course somehow—it is achieved by having specific individuals do certain tasks in particular ways. In the present case, having the helmsman turn the rudder to the twenty degrees starboard position.

If we view oral coordination from this perspective it follows that one explicitly filled-in paradigm must at the same time constrain the contents of the other backgrounded paradigms to exactly one member. Rudder commands are examples hereof, and serve to illustrate the principle of focus and background as a means of reducing coordination workload and complexity.

Elaborate use of backgrounding calls for a high degree of flexibility in the communication. Communicating parties must be able to quickly and flexibly change the distribution of focused and backgrounded paradigms, i.e., paradigms initially in the background may suddenly demand explicit focus. Consider the following example.

Still inbound for Rotterdam the Sally Mærsk has been forced to perform a 360° turn in the middle of the deep water channel less than five miles off the harbor entrance. The maneuver is critical because she will block the fairway during part of the maneuver. No vessel will be able to pass during that period, and the maneuver should thus only be performed if no vessel needs to pass. Traffic conditions were clear prior to the maneuver. Yet just after having initiated the turn, the Sally Mærsk is contacted on the VHF radio by the outbound Sealand Atlantic. As it turns out the two giant container carriers will meet in the narrow channel and the VHF communication serves to negotiate the details of the passage. On the bridge of the Sally Mærsk we can observe as the master turns focus on initially backgrounded paradigms, because he realizes that the pilot at his side has misunderstood essential parts of the passing maneuver. The players are: The outbound vessel Sealand Atlantic (Atlantic), and onboard the Sally Mærsk we hear the Rotterdam pilot (pilot).

1	Atlantic	Sally Mærsk, the Sealand Atlantic [VHF]
2	Pilot	Sally Mærsk [VHF]
3	Atlantic	Yes. Good afternoon captain, are you turning to port now? Are you? Over. [VHF]
4	Pilot	Yes I'm turning slowly to port. Yes. [VHF]
5	Atlantic	Okay, we, we are, we will be steering our course of about two nine zero, and we will stay to the north of you – if that is agreeable with you? [VHF]
6	Pilot	Yeah, fine, I'll be following the deep water route outside [VHF]
7	Atlantic	Yeah, and can you give us red-to-red passing, please, port-to-port. [VHF]
8	Pilot	Port-to-port, yeah fine ok. [VHF]
9	Atlantic	Standing by on [VHF channel] one six [VHF]
10	Pilot	Okay.

Fragment 2.

The international regulations state that two vessels meeting head-on should pass port-to-port (red-to-red[1])—exactly like Sally Mærsk and the Sealand Atlantic have to in Fragment 2. Notice that the principal condition 'passing head-on' is not mentioned—it is in the background. A major misunderstanding is building.

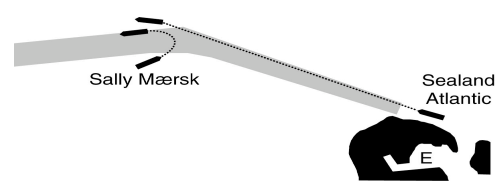

Figure 3. The meeting between Sally Mærsk and Sealand Atlantic.

Figure 3 illustrates the position of Sally Mærsk and the Sealand Atlantic at the point in time when the communication in fragment 2 and 3 takes place. E marks the

[1] The port side of a vessel is sometimes referred to as the 'red' side due to the color of the lights mounted: green on the starboard side and red on the port side.

Rotterdam EuroPort—where Atlantic is coming from and where Sally is going after the 360° turn. The dotted lines indicate the tracks that will lead the Atlantic to pass north of Sally.

Neither instruments nor the view from the Sealand Atlantic would at present indicate just how much Sally Mærsk will turn to port. Fragment 2 shows that the master of Sealand Atlantic knows that Sally is turning. But he is clearly unaware that she is in a full 360° turn—otherwise, he would have foreseen that the vessels will not meet head-on. By the time Sealand Atlantic catches up on Sally Mærsk she will have turned 180° compared to her position when Fragment 2 was spoken. Thus, the Sealand Atlantic will overtake Sally Mærsk not meet her head-on. In the following we will see that the master of the Sally Mærsk realizes that a misunderstanding between the onboard pilot and the foreign Sealand Atlantic is presently distorting the negotiation. Several new actors enter the scene: The master, chief and first officer on the bridge of the Sally Mærsk, and the on-shore Pilot Maas (PilotM), the chief traffic coordination authority.

1	Master	Who was that?
2	Pilot	The outbound ship, Sealand Atlantic, she wants to pass port-to-port.
3	Master	How can we do that?
4	C.Officer	(…).
5	1st Officer	Yes.
6	Pilot	We are steering around slowly, slowly.
7	Pause	
8	1st Officer	I presume that he means that we will.
9	Master	Yeah, but how can he … (…). **He will overtake us** probably.
10	Pilot	Year – I don't know.
11	Master	… yeah, um, so um, port-to-port.
12	Pilot	Sealand Atlantic, the Sally Mærsk. [VHF]
13	Atlantic	Sally Mærsk, Sealand Atlantic. [VHF]
14	Pilot	Um, You want to pass us on our starboard side – on the north side? [VHF]
15	Atlantic	Roger, I'll like to … I … I hear you were turning to your port to go back in. I (…) in with the derdger, otherwise we are going red-to-red, over. [VHF]
16	Pilot	I think red-to-green with us [VHF]
17	Pilot M	Saeland Atlantic, Pilot Maas. [VHF]
18	Atlantic	Pilot Maas. [VHF]
19	Pilot M	The Sally Mærsk is turning to port, so you can proceed north of her. Over. [VHF]
20	Atlantic	She is gonna turn to port. Okay, thank you Sally Mærsk. [VHF]
21	Pilot	Yeah (…) port-to-port, red-to-red not possible.
22	Master	That is not possible.
23	Pilot	His red side to our green side

Fragment 3.

Line 9 in Fragment 3 illustrates a paradigm being shifted from background to focus. Until this point in the conversation it has been implicitly assumed (by the pilot and Atlantic) that the vessels will meet head-on. The change occurs as the master explicitly questions this assumptions by noting that the Sealand Atlantic will *overtake* Sally.

This small example illustrates common complications in VHF communication. But it also indicates that flexibility is needed in regard to the distribution of focus and background paradigms. A high degree of background is characteristic of the data we have collected. Yet so are the flexible changes from background to focus which often occur when misunderstandings are realized.

The protocol

Oral communication is governed by a protocol of rules and conventions which restrain such aspects as turn-taking, form, and contents. Protocols are observable as communicative patterns. Yet the patterns vary significantly between settings.

Our data suggest that oral coordination in maritime operations is governed by a fairly strong protocol. The communicative patterns are often easily observable and display a common structure, like in the case of rudder commands, where the protocol stipulates that the command is followed up by a confirmation (see Fragment 1).

Protocols are actor or role specific: a different set of norms apply to the master, officers, helmsman or the pilot. The master and pilot often engage in a sequence of questions and answers, while the only messages passed between the pilot and the helmsman are commands and confirmations.

Protocols evolve over time to form a heterogeneous set of general and specific norms. Some norms remain relatively stable over longer periods of time, while others change due to transformations in the working division of labor, or as a result of technological innovation. Traditionally, there has been an extremely strong and well defined hierarchy within the crew. A hierarchy which was rigidly reflected in the communication patterns. No one, not even the second in command, was at liberty to question the actions of the master. Today this is different. The master is—as seen from an organizational perspective—still in supreme command of the vessel, and an order is still an order. But the crew is obliged to monitor the master (or officer in command) actively and to speak up freely.

Relatively few of the norms are publicly available in the form of written instructions. The ship owners' Guidelines for Navigators list a number of directions regarding communication on the bridge, others are found in international maritime regulations, yet most are implicit—most of the time.

One instance where norms will surface and become readily observable is when they are violated. Consider the following example.

1	Master	… and call out when you are on the new course, K [helmsman]. When it is there you say 'one one five' – then we know it's there
2	Helmsman	I did say so last time
3	Master	Well, I just did not hear it then
4	Helmsman	(…)
5	Master	Ok (…) that's fine – keep up the good work

Fragment 4. Norm violation.

Fragment 4 was recorded during manual steering. Commands are issued by the pilot and implemented hands-on by the helmsman. In the case of course commands (presently a change to course 'one one five') the helmsman should acknowledge the command when receiving it, and report to the pilot when the vessel is steady on the new course. The helmsman in Fragment 4 failed to comply with the protocol and is advised by the master.

Fragment 4 also serves to illustrate another important characteristic of oral coordination, namely that the protocol is self-referential. The protocol stipulates communication related to work and coordination; yet it also provides norms for communication about the protocol itself.

Characteristics of oral coordination

The examples given in the above can be summarized into the following characteristics of oral coordination:

- In oral coordination, the information is distributed in focus and background paradigms—the latter reducing coordination workload and complexity.
- Coordination communication consists in closing the paradigms so that one executable member remains.
- Oral coordination holds smooth changes between focus and background paradigms, enabling speakers to question implicit assumptions.
- The norms constituting the protocol have evolved over centuries. Norms do not form a system but function as relatively autonomous, concurrent, and heterogeneous guidelines.
- Some norms are publicly available as written instructions, while most are implicitly embedded in practice. However, norms are often verbalized if violated.
- The protocol is self-referential.

ARTIFACT BASED COORDINATION

Our second field study addressed the coordination activities in the software development part of a large engineering project: The design of a complex instrument for measuring the quality of raw milk at Foss Electric. It involved more than 50 different people and lasted almost three years. Our study concentrated on the work and coordination activities conducted by the software design group (10-12 people). This group designed and implemented the software to be used for controlling and interacting with the instrument. The software complex contained more than 200000 lines of C-code and was organized in 15 different applications.

Our study was conducted over a period of 8 months, comprising approximately 30 full days of observation and participation. We attended meetings and discussions among the designers, and we conducted about 25 semi-structured interviews (with both designers and others in the project). The documents produced and used by the designers were studied, and much effort was spend on studying and analyzing the different forms, posters, white boards, etc. applied as coordination means. The main purpose of the study was to understand and characterize artifact based coordination mechanisms.

Two is fine—four is a mess

Since the study was conducted towards the end of the project many activities concerned test and correction of the software. It was the first development project at Foss Electric involving more than a few software designers, and early in the project the software designers realized problems in coordinating the testing activities: Problems were solved more than once, nobody had an overview of actual problems, etc., etc. As one of the designers stated: "It has really been problematic that we did not have any guidelines and descriptions for how to produce, integrate and test our things". As a counter measure to these problems the software designers invented and used a standardized bug report form that all testers had to fill in whenever they identified an error (a bug). In addition a standard procedure for handling the forms and a number of new working roles were established, refined and described by the software designers themselves. The following will briefly present the bug report form and the accompanying procedure and roles.

The bug report form

The overall purpose of the bug report form was to establish a means for describing information about an identified problem in the software and distribute this information to the relevant persons involved in software testing and correction. The form with an annotated procedure for its use can be seen in Figure 4 below.

A bug report form could be filled in by everybody involved in testing the software, e.g. software designers, other designers, or people from quality assurance (QA). Whenever a bug was identified, a form would be filled in (in accordance with the prescribed procedure) and forwarded it to the Spec-team. The Spec-team was a group of software three designers established to diagnose problems and ensure that the right persons were requested to fix it.

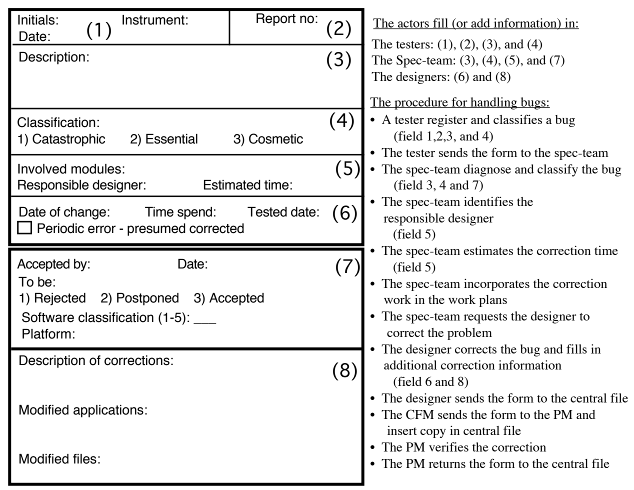

Figure 4. The paper based bug report form and the typical process for its usage. The roles mentioned are described in Figure 5 below (adapted from [4]).

Once or twice a week the Spec-team met and diagnosed the incoming problems, and decided which software designer(s) should fix it. The responsible designer(s) was notified (by receiving a bug form). The Platform Master (a role that circulated among the involved designers) was notified when a bug had been fixed, and the Platform Master verified all corrections as part of the integration task.

To keep track of the progress of the testing work a copy of each bug report was kept in a central binder. The binder had one entry for each of the stages a bug correction could be in. The place of the bug report copy thereby indicated the stage of the correction.

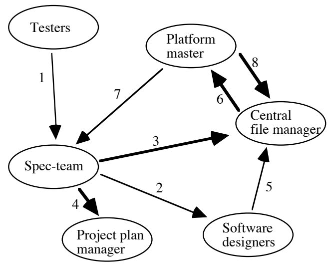

Figure 5. The process applied for handling the bug reports.

According to our observations and what the designers said more than 75% of all the problems were handled by means of the forms and the standard procedure without further interaction among the involved actors. In the rest of the cases the actors deviated from the prescriptions. For example, a person from Marketing used the same form for describing three very different problems. When the Spec-team received this they copied the information to three different forms and handled it as three problems. In another situation a tester from QA knew that designer Jensen was responsible for the pipette controller module. Hence, when he identified a problem with the pipette handling he called designer Jensen and asked if he was aware of the problem and whether he was able to solve it. To ensure correct handling Jensen then filled in a form and submitted it. Minor problems were corrected without the use of the form. Hence, such situations involved alternative means of coordination.

Towards standardization

The form and the procedure provided support for asynchronous coordination between distributed actors. They didn't have to meet to exchange coordination information.

The bug report form provided the actors with a standardized format for the information. It thereby functioned as a checklist for the actors by explicitly marking the elements in focus for the interaction with the following actor. Thus, much background information was explicated. By including a classification structure the form furthermore provided a "standardized language" for some of the central aspects of the interaction. The classification structure was far too simple and rigid to function as intended. Since it was a paper based medium including free text, the designers still had a flexible way of describing a problem or solution.

The form itself indicated the type of information. When any of the involved designers received a bug report form they immediately knew what they were supposed to do without further interaction with others. This was implicitly stipulated from their role, the form, and the procedure.

All forms were kept in a central binder that all designers had access to. This provided an explicit persistent representation of the state of affairs that could be consulted at any time.

As can be seen in Figure 4 the form has a number of references to the actual field of work (modules, applications, files, etc.) and to the organization of the work (responsible designer, platform period, etc.). The forms can be seen as external representations of states, but it does not include aspects on how the correction work should be conducted.

In case of uncertainty regarding the interpretation of a form the receiver typically contacted the sender and discussed it with him, i.e., the means for interaction (and coordination mode) was changed. This was also the situation when designers proposed suggestions for changing the form structure or the procedure for handling the forms.

Based on our studies we designed a prototype of a computer based form supporting distributed registration of bugs (including a more advanced classification structure) and automatic routing of bug reports. The prototype was developed for research purposes only and was not evaluated at Foss Electric. A few of the lessons learned from this will be included later in this paper. More detailed descriptions of the field study and the prototype can be found in [4].

Characteristics of artifact based coordination

The examples and discussion given in the above can be summarized into the following characteristics of artifact based coordination:

- In artifact based coordination information is made visible to the users, and the artifact functions as a checklist of information required: background information is to some extent made explicit.
- Coordination communication is persistent. It can be accessed by interested parties whenever wanted. An overview of the state of affairs in the field of work and the work arrangement is thereby provided.
- The artifact based coordination had no easy support for smooth changes between information in focus and in background. Uncertainties, mistakes, and other special cases have to be handled by other means of interaction.
- The protocol stipulating the flow of the process can be made explicit to the actors. When it is computer based the routing can be handled automatically. This supports the daily usage, but it might cause problems when special handling is required.

DIMENSIONS OF COORDINATION

In the above we have been interested in oral and artifact based coordination as modes of coordination each in their own right. In the following we will present a set of dimensions for characterizing basic similarities and differences between spoken and artifact based coordination.

Persistency

When comparing the examples of oral and artifact based coordination that have been presented in the above, we find that only the artifact is capable of preserving communicative contents over longer periods of time. Once information is inscribed on the bug report form it will remain, while spoken messages vanish after having been spoken. The difference is captured by the concepts of persistent and ephemeral coordination, where only persistent coordination will maintain its information over longer periods of time.

The practical implications of coordinating by ephemeral or persistent modes are significant.

Recall, that the bug report form was designed as an answer to severe coordination problems within the software testing work: The software designers had experienced increasing difficulties in maintaining an overview of the testing activities in general and the status of bugs in particular. In other words, the software designers needed an aid which would support them in assessing the here-and-now state of affairs within the field of work and the cooperative work arrangement, as well as an aid which gave the actor a historical view of the past processes involved in the testing work. The bug report form does both. But it is predominantly its historical record-keeping abilities which call for persistent representations.

The fields and entries in the bug report form signify key events in the software testing procedure: a bug is found, tested, rated, corrected, etc. If all fields are filled in, and all steps in the prescribed workflow have been completed, then the bug has been tested and corrected. If only some of the fields have been filled, then the tasks remaining to be done will be indicated by the blank fields. This way, by providing a history of the activities, the form also assists an assessment of the present state of affairs—and this is further supported by the form's position within the binder.

Comparatively, a detailed history of events is not easily maintained by means of oral interaction. The problem is that cooperative work activities are distributed among several actors: In order for an actor to inquire into past activities or states he would first have to find out who performed the task that evoked the state in question, and he would then have to locate the actor who evoked the state and ask him in person as to the desired details. Then, possibly, on to another actor who performed a subsequent task, and so on. The needed recollection may no longer be available, and the quest for a historical overview is, in any case, labor intensive and cumbersome.

The periods of high-intensity cooperation and coordination in maritime operations last between two and five hours and occur during harbor approach and departure. Cooperation and coordination in the software design project was less intense but lasted several months. And this is probably the main reason why ephemeral coordination works relatively well in the former work domain but did not suffice in the latter.

Dedicated and non-exclusive coordination support

To demonstrate the difference between dedicated and non-exclusive modes of coordination we first need to clarify the concepts of work and coordination.

Coordination is an inescapable part of cooperative work, while the actor working in genuine solitude performs work only and has no need for coordination. The need for coordination in cooperative work is a product of the interdependencies between actors. When a set of linked tasks are performed by several actors these actors become interdependent due to the task interdependencies. Broadly speaking, coordination is concerned with the handling of actor interdependencies, while work encompass the activities concerned with the job itself, e.g., turning the rudder or writing code.

Some activities may exclusively serve work *or* coordination, while others serve both work *and* coordination at the same time. By dedicated coordination support, we understand means which are exclusively aimed on supporting coordination, while non-exclusive coordination means are work components used with a view to supporting coordination. An illustration:

When large vessels like the Sally Mærsk pass along coast lines they have to report their position, last and next port of call, cargo information, etc. to agencies ashore. Such conversations take place both when the vessel is sailed by a single person and when operations are performed cooperatively. The point in focus is that the conversation may take a slightly different form during cooperative operations. The basic contents of the conversation will remain unchanged but the actor on the bridge of the Sally Mærsk may choose to turn on the loudspeaker on the VHF radio for others on the bridge to listen in, or he may make the incoming information available to others by confirming the messages in a slightly louder voice as he would have done had he been alone on the bridge. Cooperation or no cooperation, the conversation with the agencies would take place in any event yet the form may change slightly. This is what we understand by non-exclusive coordination.

The bug report form on the other hand, illustrates a case of dedicated coordination support. All features of the bug report form mirror the fact that it has been designed to support coordination of the distributed yet interdependent work activities. The form would have little purpose if the software tests were performed by one single actor working in solitude. The form does not itself provide any significant support for the work activities: formal severity ratings of bugs and a standardized information structure are features which can be said to support the work activities. But they are first and foremost the vocabulary and structures needed in order to facilitate effective communication across a variety of roles, specialties, and interests, linked to a large number of interdependent actors. And they are, thus, primarily functioning in the service of coordination.

Degree of automation

By an automatic coordination means we understand a self-governing means which is capable of autonomously performing coordination, e.g., a computer based bug report form would, by virtue of the implemented workflow protocol, be such a device—while oral coordination and the paper based bug report form feature no automation.

Fully automatic coordination aids are rarely mentioned in the CSCW literature. Maybe because these means, strictly speaking, eliminate the need for coordination rather than support coordination. In process control, for example, at power plants and petrochemical plants, the cooperative control room personnel is greatly assisted by automatic controllers handling complex process interactions, e.g., the interaction between flow and temperature in the cooling system of a power plant. Without the automatic controllers the actors would be burdened with an even greater number of task interdependencies to handle, and the coordination workload and complexity would rise accordingly.

Stipulation

The fields for data entry on the bug report stipulate what type of information is desired and where it should be entered. Compare the bug report form to a blank sheet of paper and the stipulation becomes evident.

The computer based version of the bug report form implements a still higher degree of stipulation: no information can be entered outside the fields, and notes in the margin would no longer be possible. And the control of the routing would be either very restricted (e.g., as a multiple-choice menu) or completely absent (automated).

Oral coordination, e.g. one actor commanding or advising another what to do, is an extremely flexible form of stipulation compared to the stipulation implemented by the bug report form. And it is a completely different sort of stipulation too. The objectified artifact implies stipulation by means of physical constraints—while in our examples of oral coordination, the constraints are of an cultural or organizational nature: you perform as commanded due to the authority of the master or pilot.

Direct and indirect referencing

The concepts of direct and indirect referencing signify the difference between (directly) telling somebody what to do, or providing him with information which will allow him to (indirectly) assess what to do—a direct and indirect mode of coordination. Consider the following example.

At the end of a berthing maneuver the master may announce over the walkie-talkie that 'we are in position' or he may say 'tie her up'. For all practical purposes both utterances will lead his men to perform the same set of tasks, namely finalizing the mooring procedure. The first statement signifies a state of affairs within the field of work, while the second statement is a direct specification of the task to be performed.

The observed oral coordination utilizes both modes of coordination: sometimes the masters issues direct commands while at other times he may chose to provide his crew with the information necessary to trigger certain activities on their part. Overall, however, oral coordination by direct referencing is by far the most frequently used mode in complex maritime work situations.

The bug report form primarily coordinates via indirect referencing. Actors are provided with information about the software complex. They are, so to speak, presented with problems to be solved but are given no directions regarding the path to resolution.

The bug report form and oral coordination in maritime operations seem to suggest a relationship between the coordination modality—direct or indirect—and the working division of labor: Direct referencing demands that the coordinating agent has detailed knowledge about the tasks being coordinated, and this is not necessarily the case with indirect coordination.

Specialization, within the navigating crew, is hierarchical and accumulative. You start out as a second officer, then you advance to first officer, chief officer, and eventually you may be promoted to captain. In terms of specialization this means that the master knows the work of the officers in great detail because he himself was an officer. This, combined with the fact that all information runs through him during critical operations, allows the master to perform direct coordination, i.e., coordinate the work of the cooperative work arrangement via direct orders stating the exact nature of the desired task.

This may not always be the case in software engineering: individual actors work on specific modules of the software complex, and no single actor has a highly detailed overall picture of the state of affairs within the complex as a whole. This may in some cases—in the collaboration between certain actors—render direct coordination impossible. Notice, however, that we are not implying that it would be neither feasible or nor desirable to establish the conditions necessary for direct coordination in this particular setting.

Dynamic and static

In this and the next section we will discuss the causal relationship between the coordination means and the world around it. First we will consider the coordination means' ability to *reflect* state changes in the field of work and the work arrangement; and in the following section (coupling and detachment) we will consider the coordination means as an *agent of state changes* in the field of work and the work arrangement.

A dynamic coordination means automatically reflects changes within the work arrangement or the surrounding world. Static means do not. The state of a dynamic coordination means will change if (specific) state changes outside the means itself occur.

A ship’s radar is an example of a (persistent, non-exclusive, indirect) *dynamic* coordination means. The radar provides the navigating crew with a specific view on the objects (land, traffic, buoys, etc.) surrounding the vessel. If a state change within an object is detected (change of course, speed, etc.) the radar will update the representation of the object in accordance.

A bug report form does not automatically reflect changes in its surroundings—neither when bugs are found nor when they are corrected. In this respect, the bug report form must be considered static means.

Oral coordination, as performed by the master and the pilot, is dynamic. The state of affairs within the field of work and the work arrangement is observed and interpreted and coordination information is adapted accordingly. If a turn is needed, then a rudder or course command will be issued; if an actor violates the protocol he will be notified as illustrated in Fragment 4, etc.

Coupling and detachment

The above mentioned concepts of static and dynamic viewed coordination means as an object of change—while coupling and detachment deal with the coordination means as an agent of change. That is, if the coordination means is coupled to the field of work or the work arrangement, then certain state changes within the coordination means will result in a state change outside the coordination means.

Oral and artifact based coordination, in the examples so far, are both detached from the field of work and the cooperative work arrangement. There is no mechanical causality dictating that a state changes within the bug report form leads to a state change outside the form, i.e., the correction of a bug will not actualize just because an actor writes 'bug corrected' on the form.

Schmidt and Simone discuss the causal relation between the coordination artifact and the field of work. The conclusion is that the artifact should be "distinct from the field of work in the sense that changes to the state of the field of work are not automatically reflected in the state of the artifact and, conversely, changes to the state of the artifact are not automatically reflected in the state of the field of work" [19, p.178].

In the terminology of this paper the above means that a (dedicated) coordination artifact should be neither dynamic nor coupled to the field of work. However, Grinter [6] examined the use of a workflow—like configuration management system used in software development and found that *dynamic* features of the system were helpful to the software developers:

> "The main view that the developer sees when she launches the tool [configuration management system] is the one corresponding to a directory of components she is currently working on, but it is very unlikely that she will be working there alone. Other developers will be changing other files–or possibly the same file–in that directory, and that information is available to her through the shared feedback mechanism within the tool" [6, p.200].

In contrast to the bug report form, the system studied by Grinter is dynamic in relation to both the field of work and the work arrangement. That is, state changes in the field of work and the work arrangement are reflected in the state of the artifact. The dynamic relations are provided by the shared feedback mechanism conveying state changes in the field of work (the software complex) and state changes in the work arrangement (who is working on what code module) to the artifact.

Some artifacts function as work tools and coordination means at the same time, and it is among these that we find the *coupled* coordination means. Within the maritime domain artifacts like the engine telegraph, rudder dials, thruster handles, etc. are examples of coupled coordination means. These are non-exclusive coordination means which have not been fitted primarily to support coordination but to support work. Yet the fact is that they—intentionally or not—support coordination in important ways by providing information about the state of the field of work. The setting of the engine telegraph, for example, is indicated by the physical position of the rather large handle itself and by a small hand connected to the handle which points to a scale (slow ahead, half ahead, etc.). The handle and the hand makes the setting of the engine telegraph publicly available within the cooperative work arrangement and allows the actors to adapt their work to the speed of the vessel. Thus, when changing the position of the hand and handle one changes the state of the field of work (acceleration or deceleration) as well as the state of the coordination artifact (the spatial and numerical representation of the setting provided by the handle and the hand pointing to the scale).

Flexibility and reduction of coordination workload

In many cases a significant reduction of the coordination workload remains a theoretical possibility unless the coordination means is flexible. Much complex work requires room for deviations from the standard. Yet coordination support also calls for structures which stipulate the course of coordination.

The CSCW literature bares plenty of evidence that the optimal balance between stipulation and flexibility is not easily achieved. As noted by Schmidt and Simone [19] the first generation of actual computer based coordination support systems failed because the underlying protocol was either to rigid (e.g. The Coordinator, [23]), or because the facilities for modifying the protocol were too poor (e.g., DOMINO, cf. [14]). The second generation features systems like OVAL [17] and WorLDS [5].

Our own study of the bug report form, like the power plant study mentioned in the introduction, has illustrated that the actors will, if possibility is provided, resort to oral coordination when the need for coordination transcend the functionality of the coordination artifact itself. In these cases oral coordination caters for the required flexibility and the study of maritime coordination hinted to the nature of the flexibility.

Oral coordination and the bug report forms run by protocols constituted by agreed-to conventions and procedures regarding who should do what, where, and when, etc. In the computerized bug report form, conventions have been given persistent physical form in the protocol—they have been objectified and implemented, and they have as a result lost certain aspects of their otherwise highly plastic nature. They have, so to speak, gone from being conventions to actual physical barriers.

As the examples of maritime operations showed coordination did not break down because the protocol was violated. Coordination just moved to up one level in the protocol to second-order coordination or the level that keeps first-order coordination in place. It is important to note that the oral sanctions are optionally asynchronous. In Fragment 4, the master did not address the helmsman the moment he violated the protocol but waited until the following course command was issued. Violations are noted instantly but sanctioned when the overall situation allows for it.

Once more consider a computerized bug report: This would instantly put up a barrier if the protocol is violated. Then, given that the needed tools for changing the protocol are available, the actor may modify the conventions so as to avoid similar barriers in the future. He must do so before the coordination task can be completed—or he must find a way to work around the barrier.

Oral and artifact based coordination utilize different techniques in order to achieve a reduction of the coordination workload. Oral coordination makes extended use of backgrounding, while the bug report form relies primarily on stipulation and—in the case of the computerized bug report—automation. The computerized bug report form implements automation of selected steps in the workflow procedure.

In oral coordination the intended receiver of spoken information is sometimes stated explicitly but most often it is the nature of the information in itself that determines the de facto receiver. In the latter cases the sender-receiver relation is mediated by the highly structured division of labor at play in the maritime domain. In contrast to the software design project, the maritime workplace features a relatively static allocation of responsibilities to certain actors. One actor may assume several roles but two actors hardly ever interchange roles. This stable division of labor, and the strong sense of personal role supports the elaborate use of backgrounding which is oral coordination's most prominent way of reducing the coordination workload.

CONCLUSION

Oral and artifact based coordination are distinct and dissimilar modes of coordination. Yet in the design of computer based coordination support systems the change from oral to artifact based coordination is frequent. The paper set out to characterize and compare these two modes of coordination in order to better understand some of the pitfalls and problems that often go along with radical changes in mode of coordination.

We have pointed to a limited number of dimensions along which the modes of oral and artifact based coordination can be characterized and compared. We believe that the dimensions indicate the design related value of characterizing modes of coordination. The present provides neither detailed characterizations of the individual modes of coordination nor a full comparison between them—but we hope to have indicated that work in the direction of 'sharper' dimensions of comparison and a more detailed understanding of similarities and differences between different modes of coordination could be highly instrumental to CSCW design.

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