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Cooperation in massively distributed information spaces

Olav W. Bertelsen & Susanne Bødker
Department of Computer Science, University of Aarhus, Denmark
olavb@daimi.au.dk, bodker@intermedia.au.dk

Abstract. Common information spaces are often, implicitly or explicitly, viewed as something that can be accessed *in toto* from one (of many) location. Our studies of wastewater treatment plants show how such massively distributed spaces challenge many of the ways that CSCW view common information spaces. The studies fundamentally challenge the idea that common information spaces are about access to everything, everywhere. Participation in optimisation is introduced as an important feature of work tied to the moving around in physical space. In the CSCW literature, peripheral awareness and at a glance overview are mostly connected with the coordination of activities within a control room or in similar co-located circumstances. It is concluded that this focus on shoulder to shoulder cooperation has to be supplemented with studies of cooperation through massively distributed information spaces.

Introduction

This paper discusses the massively distributed information space of a large industrial artefact, a wastewater plant. Common information spaces are often, implicitly or explicitly, viewed as something that can be accessed *in toto* from one (of many) location. Our studies of wastewater treatment plants show how such massively distributed spaces challenge many of the ways that CSCW view common information spaces. The studies fundamentally challenge the idea that common information spaces are about access to *everything, everywhere*. The paper looks at the distribution and geographical spreading of the information space, and the ways that workers organise their activity around this. As pointed out by Schmidt & Bannon (1992), providing a common information space is not a matter of providing overview and uniform access independent of physical location to a shared database. Nevertheless, many recent technical solutions are based on this assumption - e.g. that users want to access the same web pages from their mobile phone as they do from their office PC. This assumption is, however, contradicted by several authors, primarily from the perspective of technological diversity, arguing that it is better to utilise the particular capabilities of a particular device (screen size, etc. when accessing the information space from a particular device e.g. Nielsen & Søndergård, 2000).

Bannon & Bødker (1997) discuss some of the many problems of the general, idealised assumptions made about common information spaces. In the present study, we illustrate how workers actively construct the common information space that is necessary for them in order to run and not least to optimise the running of a wastewater plant. This active construction requires cooperation while moving about in the geographically dispersed plant, exploring and experimenting with optimisation of the plant, while being more or less peripheral to this experimentation process.

Re-placing the term space with the notion of place, is the key concern for Harrison & Dourish (1996). The argue that what we should be looking for are ".. sets of mutually-held and mutually available, cultural understandings about behaviour and action", their definition of place.

In the CSCW literature, peripheral awareness and at a glance overview are important concepts for understanding cooperation and transitions between cooperative work activities. However, these concepts are mostly connected with the coordination of activities within a control room or in similar co-located circumstances. In the wastewater plant we see a somewhat different version of peripheral awareness and at a glance overview; one that is connected to moving around and physically orienting oneself in the plant. The wastewater plant is not controlled and operated from one central control room and there is no single place where at a glance overview can be obtained. From this perspective the 'standard' CSCW concepts such as overview and peripheral awareness are given new meaning, contrasted with the situations of co-located cooperation. Furthermore, mobility is given a new meaning because workers move about in a well-known terrain where their information needs depend on their particular physical location. They zoom with their feet, not with their information appliance. Bellotti & Bly (1996) studied how designers have a high degree of local mobility in their design work so as to communicate with one another. They point out that these same designers, accordingly, do not cooperate from their desk. In a similar way, the wastewater workers are highly mobile and rarely placed in front of their computer. The difference between the two studies, however, is that the designer moves about to find people, whereas the wastewater workers primarily move about to control the plant.

The wastewater study

During the past year we have been engaged in a study of a wastewater treatment plant. We have conducted workplace studies, and we apply an interventionist approach through the construction of prototypes for new computer support for the running and optimisation of the wastewater plant. The project is part of an ongoing study of common information spaces. Furthermore, we use examples from one plant even though the research is part of a set of coordinated studies in three plants, carried out in cooperation with other research and industrial partners.

Our prototyping experiment has been focussing on how to get and maintain a local overview of parts of the plant while moving about, and on compiling and interpreting information that is massively distributed on meters and dials. For a more detailed description of the project and the study, see (Bertelsen & Nielsen 1999).

In the context of CSCW, a wastewater plant like the one we focus on is interesting because it challenges some of the central conceptions in CSCW.

While one might think that providing cleaned wastewater is the overall objective of wastewater cleaning, it turns out that clean water is but one of many parameters that have to do with optimisation of the running of the plant. The cost of running the plant can be reduced by producing as much electricity as possible, using gas turbines running on biogasses. Taxes are high on sludge, and can be reduced by proper fermentation and water extraction (pressing). The plant is built for a much smaller daily production of waste than what is processed today, and must handle a continuous overload of 25-50 pct. Accordingly, the plant is the scene of an ongoing experimental optimisation process.

At the plant, 8 people do their daily work in a large physical area. But for the water basins, well known from wastewater plants, most machinery and water processing take place in-doors in buildings that are spread out on the land so as to support the flow of water through the plant. The division of work is structured around this process, and hence, also geographically. One pair of workers is responsible for the inlet water and the initial filtering of this, one pair for the fermentation and gas production, and one pair for the removal of the sludge. Added to these three pairs are a foreman and a plant manager. The plant manager has his office in the main building where the remaining staff meets as well for breaks etc. It is characteristic of the plant, that there is no central control room from which it is operated, and where coordination of the activity takes place. There are two places in the plant where somewhat traditional control room overviews of the plant can be obtained through computers, networked with the central process automation and control system, but neither of these are places where people spend much time.

Fig 1: The fermentation towers.

We describe the work at the plant through four characters based on our studies at the plant:

Andy is the manager of the plant. Together with the leading biologist at the municipal wastewater office he develops and optimises the running of the plant by introduction of new machinery.

Bob is primarily working in the gas and electricity production area. Furthermore, he checks machinery in the plant in general, he does minor repair work etc. In contrast to his colleagues, Bob is sharing the managers overall motive of optimising the overall running of the plant.

Dan, together with his work-mate, is working with the sludge press. Their two main tasks are to monitor the press as sludge is filled in and pressed, and to scrape down the pressed sludge from between the slats of the press. In addition they move containers with pressed sludge, and they tidy the sludge press building. Dan is an old-timer at the plant, he knows how to run the sludge press so that it requires the least effort. The main objective for Dan is to maintain the smooth running of the press, i.e. to avoid too sticky sludge, and to avoid machine breakdowns.

Joe is responsible for testing inlet and outlet water and the water at different stages of the process. These tests are used for calculating taxes, and for monitoring the process in order to be able to optimise it. The tests are made with standardised test kits, with water from automatic test samplers. Joe uses mornings to collect the samples in the plant, check the samples, and make the tests. Joe and his work-mate are also responsible for the inlet area, mechanical filtering, and reception of trucks delivering wastewater.

The remainder of this paper is structured around themes introduced by means examples from our study of the wastewater plant.

Geography and participation

A basic tenet of our analysis of wastewater work is that geographical radius and action radius are closely related. Moving about is a basic feature of everyday problem solving. Participation in optimisation is related to how workers move in and through regions of the plant.

The first two examples are related to dis-colouring of water. Each of the situations shows how one worker observes the water and interprets it as a potential problem. Though the ways they deal with the situation are quite different, it is characteristic to both situations that *the workers are moving about to examine the problem and to deal with it*.

THE WATER IS BROWN

As part of his daily round, Bob checks the sludge tanks and notices that the surface water in the tanks is brownish. He immediately proceeds to where the water comes from to check a filter. This turns out to be in dire need of a rinse. This way of proceeding illustrates how he moves about in "his" part of the plant in non-routine ways so as to solve the problem. He explains that in normal circumstances he would have checked the filter anyway because it is part of his area of responsibility, but that he would not have done so until much later.

THE WATER IS GRAY

While Joe is out collecting the daily test samples, his work-mate calls him over to tell that the water in the inlet looks strange, "almost as gray as cement". They briefly discuss possible explanations, but decide that the best thing to do is to wait for the test results. Joe finishes his water sampling and goes back to the lab to make the analysis. After an hour and a half and a coffee break, the tests are ready, showing nothing out of the normal. Joe and his work-mate decide that there is no reason to take extraordinary action.

The two situations belong to the ordinary day to day routine and show how workers have to move about and orient themselves to various parts of the plant to deal with the everyday problem solving.

In Joe's round he moves in his region of the inlet water. His primary activities are here, and he primarily co-operates with one work-mate who also has duties here. Their focus is on the filtering and initial preparation of the inlet water, the machines involved in this filtering and some of the sensors etc. connected to the water basins. On top of this, Joe does the lab work. The lab is centrally placed so that he can monitor various pieces of machinery and basins as he passes by, and so that he can utilise spare time between lab work for other kinds of supervision and maintenance, e.g. cleaning of primary filters. This leads him to take several rounds out into the open space of the water basins every day. Joe's rounds take him through much of the plant in order to pick up one of his samples. Our empirical material shows that these other regions do not belong to him: he passes ringing telephones that he does not answer, and on one particular day he had to use a computer in Bob's region. This was obviously not part of the daily routine to the extent that Joe had to ask Bob for permission to do so.

As exemplified above, all workers have a region of the plant as their main area. However, there are differences in how much they move about in the region, how large the region is, how it intersects with others, and how much they move out of the region. Furthermore, there are differences in how varied their ways of moving about are. At one end of the spectrum, Dan is mainly handling the sludge press and his main territory is the sludge press building. Joe, as described above, moves about more: his route takes him through a substantial part of the plant, including visits to two sites that are somebody else's main territory. However, his route is very much the same from one day to the next and variation is mainly a matter of what special monitoring is needed and how that may be fitted in between the lab work. Bob works in a different region of the plant, the part where most of the heavy machinery is placed. His daily rounds are more varied, he plans on varying the rounds, e.g. in order to maintain particular machinery, and suspends the routines entirely when he feels that this is needed. The manager, Andy, has no fixed rounds, he moves out from his office where computers provide overview of the running of the plant whenever he finds it necessary, and he has made a habit out of moving about the plant a lot.

In moving about the plant there is a large variety in how the workers are orientating towards others and cooperating. As described the overall coordination takes place in the coffee breaks where the workers and the foreman, Ed, meet in the lunch room. More detailed cooperation happens as illustrated by the following example.

ADDING POLYMER 1

Bob on one of his rounds passes a temporary polymer tank and observes that it is less than half full. Later he passes by a storeroom and sees that there is a couple of leftover sacks of polymer powder that could perhaps be used in the tank. He proceeds with his work, and much later he meets Andy. Bob asks if he should add the polymer. Andy acknowledges Bob's idea, but explains that for this specific optimisation experiment the polymer needs to be of another kind. They discuss this, and Bob proceeds with his work.

Workers collaborate in rather different ways beyond sheer coordination. In the one end, Dan and Joe primarily do their jobs as they have been told to and are expected to report back to management if there are problems that need to be dealt with. Andy is very dependent on Joe to report back if he finds problems with the water quality, because Joe is the first to know if a problem occurs. At the same time there is very little Joe can do on his own. Decisions to mend the problems have consequences to the entire water process and needs to be made with an overview of all of this. Dan and his work-mate in the sludge press building, however, deal with a variety of issues and problems that relates to the sludge. Bob solves some problems on his own and he engages in cooperative problem definition and solving with Andy and the foreman, Ed. Andy masterminds the optimisation process in an ongoing dialogue with Ed, Bob (as illustrated by the ADDING POLYMER 1 example) and the consulting biologist at the municipal water office. As described in Bertelsen & Nielsen (1999), he continuously modifies the purification and sludge processes with their help. They help him identify problems as well as they participate in finding and implementing the experimental solutions.

The mobility and flexibility of the movement of workers, along with their possibilities for action, contribute to their participation in the optimisation and to their orientation in the distributed information space that constitute the plant. They retrieve information as they move about, and their information needs depend on where they are, who they are, as well as on what they are doing. *They do not need access to the entire information space independent of location and purpose, on the contrary*. This is what we have called zooming with the feet.

Participation and learning

The perspective of the workers on the plant and their contribution to the optimisation is illustrated by the "position" from which they view, talk about and take responsibility for the plant. At one end of the spectrum, Dan is firmly located in the sludge press building and his perspective is anchored there. He is concerned mainly with optimisation from the perspective of what makes the sludge most suitable for pressing and for being removed from the press. Bob and Andy at the other extreme, are seeing things from the perspective of the plant *in toto.*

This difference can be illustrated by the basic difference between the way Joe and Bob act in the ‘water colour’ examples (THE WATER IS BROWN, THE WATER IS GRAY). Joe and his work-mate discuss the strange situation, but they take no immediate action. An important reason for not taking action in THE WATER IS GRAY is that there is no action to take at the inlet, if not related to the measurable parameters. In THE WATER IS BROWN, however, the strange colour is a result of malfunction of the machinery which can be corrected immediately. The two situations, however, point to a regular difference between the jobs of Bob and Joe. Joe is working primarily with standardised tests, monitoring the state of the plant for the purposes of both running the plant and reporting to the authorities. Bob is working with the later stages of the process, including the production of electricity, maintaining the equipment and optimising the process.

Such differences can be further illustrated by the difference between ADDING POLYMER 1 and the following:

ADDING POLYMER 2

A typical situation in Dan's work is that the plant manager, Andy, calls on the phone and asks Dan to adjust the amount of polymer added to the sludge before it is pressed. The right amount of polymer gives an optimal reduction of water in the pressed sludge. For Andy, this is a matter of the costs of getting rid of the sludge. From Dan's point of view, adjusting the polymer may lead to more sticky sludge, and hence more work when removing the sludge. Accordingly, he perceives Andy's request as an annoying intervention in the smooth running of the press. As Dan maintains a somewhat peripheral role in the overall optimisation, his judgement call is more closely coupled to what is immediately more optimal to the work in his region.

The two situations of addition of polymer (ADDING POLYMER 1, ADDING POLYMER 2) illustrate the differences in optimisation and learning horizons between Dan and Bob. Bob's role in this situation is that of the apprentice where Andy's the master. In general, Bob does not take action independently, but he is aligned with the optimisation efforts and other concerns of the manager. Dan has more autonomy over the part of the plant that he deals with, but is far less involved in Andy's process of optimisation. Lave and Wenger (1991) use the notion of legitimate peripheral participation to describe how apprentices move from the periphery of a community of practice towards the centre, as they become more and more skilful participants. The central purpose of optimising the running of the plant is in itself an exploratory purpose, or we might say, a continuous learning process. If we look at the above patterns of looking at and moving about the plant from this perspective, we see that some people are indeed in the centre of the activity whereas others are more peripheral participants. They may be peripheral in several ways: either they are peripheral because they conduct a work where they don't have to orient as much to the central exploratory purpose, they can very much stay in their part and master that activity independently of the rest. Or because they move about, but do not take responsibility for the optimisation of the plant. All of these participants are indeed legitimate. What we find interesting in relation to Lave & Wenger's (ibid.) notion of legitimate peripheral participation is that in work at the wastewater plant some participants stay peripheral to optimisation, and may never fully move to the centre, even though all workers appreciate that optimisation is what it is all about. And even more interesting from the perspective of exploration is that the people who are concerned with optimisation move about a lot in the rather distributed space of the plant.

As a common information space the wastewater plant supports not one, but several kinds of learning and exploration. Learningwise people may end up at many different places in relation to the centre and periphery of the optimisation purpose of wastewater purification. At the same time they may thoroughly master their own more limited purpose and space.

Holding in common

Running the wastewater plant is a common endeavour taken on by the people working there. They are continuously recreating an overview enabling them to locate each other, and they are continuously rendering the status of the plant visible through the process of moving about.

Despite the varying degree of centrality in relation to optimising the running of the plant, all workers share a surprising sense of where to find each other when they need to talk to each other, as illustrated in the following.

> THE BROKEN WIRE
>
> One morning before dawn, Andy asks Bob to go and look at one of the secondary clarifier basins when he can see the details. The basin has been automatically shut down, probably because a wire pulling the sludge scraper is broken. Andy needs to know where the wire is broken to determine which preparations are needed before the blacksmith can do the repair. Bob goes about his normal routines and makes sure that he passes by the sludge scraper after daybreak. Later in the day, Andy has placed himself on Bobs "route" to hear his conclusions regarding the broken wire. Despite Bob's rather varied route, Andy has a clear idea about Bob's moving about, and he is able to locate himself so as to have the brief meeting.

The workers all contribute to rendering visible the status and history of the plant in the various distributed locations of the plant, as illustrated by the following examples from Bob's and from Joe's work (figures 2 and 3).

> READING THE GAS METERS
>
> The daily report for the gas generators is represented by a row in the monthly report table, one for each gas generator. This report is left in the room where the relevant meters are located. The report contains readings of e.g. oil temperature, oil pressure, errors and the power produced (in kW). When he has calculated the result, Bob furthermore brings them to the control room and confirms with computer readings. Only then are they entered into a paper protocol left on the table in this room.
>
> PRODUCING THE LAB REPORT
>
> In the lab, Joe enters all lab test results into a form that is stationary on the desk. While entering the numbers, he compares them with the results from the past month, and he is expected to let the manager know it there are any major discrepancies. The lab results are furthermore transported to the manager's office where Joe types them into the computer.

Fig 2: Bob's Gas protocol

Fig 3: Joe's Lab report

In these studies we see a variety of ways of cooperating, from sheer coordination of separate activities over coffee and coordination caused by changes in the state of the plant, to systematic, continued discussions of the optimisation process between Andy and Bob. Within the various regions there is much everyday coordination and cooperative solving of a variety of problems such as in THE WATER IS GRAY example. However, very much of what takes place is to render visible the status and history of the plant for future problem solving and for optimising.

We have observed that wastewater workers create an overview of the wastewater process and the status of the plant by walking around in the physically distributed plant. Joe samples water for lab testing in the various corners of the plant, similarly Bob routinely checks up on machinery at locations around the plant. While performing these tasks they walk by the water basins, inspect the wastewater by looking, Joe looks at the incoming water and sludge when cleaning the filters, etc. The smell, together with the look at the water and sludge sampled along the way, allow the workers to form an overview of relevant parts of the plant and the waste processing. This overview is supported as well by meters, alarms (on components and in the central automation control system), and other kinds of support technology distributed in the plant.

The overview created by the wastewater workers cannot be retrieved from any central position in the plant; neither can it be separated from being physically present in particular parts of the plant. The information necessary for the creation of overview is irreducible; it cannot be obtained from pure measurements alone. The wastewater workers need to see and smell the actual water and they need to touch and look at the actual components to create the overview. Otherwise they would risk letting totally strange water pass by, or risk not replacing worn down components in time. In many ways the distributed sampling and looking as one passes by serve as distributed windows into the purification process. What is seen through each of these windows are often not very important in isolation. It is through the physical and geographical location of the "windows" and through the juxtaposition of the information created by the workers when walking about, that the overview is created. The need for information cannot be separated from specific action, which in turn is tied to specific places. This is what zooming with the feet is about: the purposeful "reading of information" placed according to physical arrangement, systematic context, routines, responsibility and action. Thus, enhanced information in the wastewater treatment plant is not a matter of providing universal access to huge amounts of data — "everything, everywhere, for everybody".

How information reception and handling was dependent on action, location and responsibility was evaluated in a series of experimental prototypes, where we explored the possibilities of walking about without e.g. reading and recording values, or of not walking about at all. The experiments pointed to the importance, in the work we have studied, of creating overview through acts such as rewriting numbers in columns with the numbers from previous days, in the various dispersed locations. However, it also became clear through the studies that rewriting alone does not guarantee that the numbers are digested. Actual responsibility and possibility to act on the state reflected by the numbers seemed to be a better guarantee for thorough digestion. In the case of the wastewater plants we have studied, overview is about the state and history (optimisation) of the plant/process. It varies very much how much of such overview each person has, what the person has an overview of, and what this overview is used for. In our examples we have seen that the kind of overview needed by Dan is very different from that needed by Andy or Bob, and similarly that the work they do to maintain the overview differs.

Common artefacts

To further explore the matter of artifacts that are held in common by several cooperating uses, we turn to Robinson's (1993) notion of common artefact. According to Robinson (ibid.), *overview* is one important dimension of a common artefact. The common artefact is an elaboration of the dimensions of communication that takes place through and is supported by a computer application/an artefact. Any specific artefact with the requisite dimensionality is considered a common artefact. A common artefact is an effective tool for getting a job done. It helps people see at a glance what others are doing. It enables actions and changes made by others to be understandable, and appropriate changes to be made. It provides a focus for discussion of difficulties and negotiation of compromises; it offers an overview over the work process that would not otherwise be available. As such we make the hypothesis that *if common artifacts exist, the wastewater plant is one*.

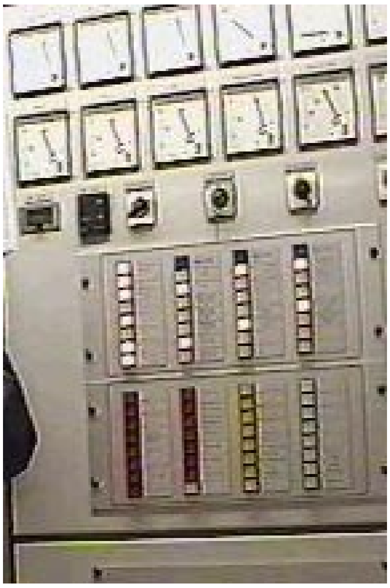

Fig 4: The meter panels

Robinson mentions *predictability* as an important dimension of common artifacts. Predictability is covering issues like dependability, functionality (including consistency of, compatibility of), and appropriate interface (including comprehensibility) as an important dimension. All our experiments and studies point out that predictability is a very local thing in the wastewater plant. Bob handles a large number of dials and meters (see fig 4) every time he calculates the amount of produced electricity: All the instruments/meters that need to be read are visible (i.e. not behind panels or doors). The meters are read differently: some of the meters are just counters/numbers where others have a needle pointing at a scale or are lightbulb-buttons. Some values are read instantly while others need to be focused on for several seconds before the values are written down. For the calculation of the electricity produced in a day Bob uses 4 protocol pages, which he has piled up on the table, a pocket calculator, an A5-pad and a pen. He reads numbers from the protocol page, makes calculations on the pocket calculator, transfers the result to the pad where he makes the final calculation when all 4 numbers needed have been calculated. This pad already has other columns with similar calculations. When the result has been calculated, Bob transfers the numbers to a small personal notepad he always carries. These numbers are carried to the control room and confirmed with the computer before they are entered into a paper protocol. This illustrates how the wastewater workers are able to handle a wide variety of different interfaces, functionality etc., depending on where they are and what kind of purpose they are facing. In the wastewater treatment plant, predictability is bound to location and purpose so much that consistence and coherence seem to be unimportant aspects of the big artefact.

Peripheral awareness is conceived as local and immediate ("at a glance"). We have on several occasions observed how the workers are very able to identify the location of each other in the plant. This is despite the fact that they cannot see and hear each other in the manners most often discussed in studies of peripheral awareness (e.g. Robinson 1993). This is illustrated by the following example:

LOCATING JOE

After completing the daily tests Joe finds his work-mate in a small room used for hanging around during shorter breaks. A couple of minutes later, Dan comes to talk to Joe and his work-mate about some possible later problems resulting from repair work of the sludge press. Dan knows when it is time to find Joe in a more or less idle state.

A general example of peripheral awareness at the plant is that we have called on the phone many times to arrange meetings, field trips, etc. Very often the person we needed to talk to has not been available. However, the person answering the phone (one of the 8 persons working on the plant) has always been able to tell where the person we tried to reach was.

Peripheral awareness in the wastewater plant is a product of the way people are moving about in physical space. It is not the side by side positioning, but rather the passing by and talking occasionally and during breaks that is the basis for being peripherally aware; the shared rhythm of work, the shared objective of optimal running, the shared domain.

The dimension of *double level language* includes conventionalised implicit communication through the artefact ("shared material") and the role of artefact as "indexical focus" for dialogue. In the wastewater plant a very particular double level language is unfolding, that of the "optimisation debate". From our studies we find that a prerequisite for keeping this exploratory discussion going is that the workers each know when they need to report problems to Andy. This means that they carefully digest the numbers that they read off meters and off measuring equipment and write these into the reports. The experimentation also benefits from the master-apprentice relation between Andy and Bob. Bob knows what optimisation is about and has ideas about how to optimise. He is, however, not able to undertake the overall optimisation himself. In this he is clearly the helper of Andy.

If common artifacts exist, the wastewater plant is one. Indeed, Robinson's definition (ibid.) has helped shed light on important features of the wastewater plant as a common artefact. Two aspects stand out as interesting, the first being that the notion of a common artefact is indeed seen as something that is tied to a place. Whereas the wastewater plant is also located in one place, our research shows that it is exactly the moving about and the purposeful action in a variety of places that makes possible the juxtaposition of information, and hence the running and optimisation of the plant. Overview, predictability and peripheral awareness are all related to how people move about in the plant, and not to a particular location. Whereas many examples of common artifacts and coordination mechanisms (Schmidt & Simone, 1996) that we have come across are separate artifacts that serve the purpose of cooperation and coordination, the wastewater plant as such serves this purpose, and the additional artifacts used cannot be separated from this.

Common information places

Our findings regarding the constitution of information in the wastewater treatment plant, emphasise that information is always located according to what Harrison & Dourish (1996) refer to as place; not necessarily geographically fixed but well defined according to some social orderliness. Unfortunately, in most of the CSCW literature place is taken to be geographically fixed. The constitution of shared workspaces has been the focus of Suchman and colleagues, with inspiration from the studies of Lynch and others of scientific practices and cooperation. Suchman (1993, 1996) brings their view on space out of the science lab and into such distributed work settings as an airline operations room (and surroundings). She states that the operations room "is not so much a locale as a complex but habitual field of equipment and action, involving intimate relations of technology and practice, body and person, place and activity" (Suchman 1996 p. 36). This description fits well with the wastewater plant as well. Suchman goes on to analyse a number of cooperative situations that all, in ways similar to those of Heath & Luff (1992), deal with situations where people, while dealing with their own activities, can perform surreptitious monitoring of the activities of others by (primarily) overhearing what is happening. The wastewater plant is different in this respect. As we have pointed out it is possible for the workers to maintain a peripheral awareness of others in the large geographical area, even when they cannot see and hear each other. And more noteworthy, perhaps, this peripheral awareness does not involve the creation of what Suchman calls centres of coordination, geographic places that people set up to assure that they can meet other people in distributed settings. It could be argued that the place where Andy meets Bob in the BROKEN WIRE example is a centre of co-ordination, but that would be to accept very ephemeral and transient phenomena as being centres.

Our conclusion is that the wastewater plant, in contrast to many cases described in the CSCW literature, and in contrast to such ideal cooperation devises as common artifacts, reveals a continuum of places of which many are geographically fluent. With reference to Harrison & Dourish (op. cit.), we might call such continuums "spaces of understood reality". Spaces that are dealt with through movement, and movement as a precondition for learning, participation and experimentation.

The way in which peripheral awareness is a product of movement rather than location may not be specific for wastewater treatment. We suspect that the focus on co-locatedness in the literature comes from the methodical convenience of being able to capture the object of study within one scene.

Our study of wastewater treatment work feeds into the design of (and for) common information spaces by pointing to the intertwining of physical and virtual space in a sort of wired wilderness. Constitution, ordering, juxtaposition and interpretation of information are mixed with and depending on the continuous rearrangement and reinterpretation of the technical installation. Interestingly in the case of the wastewater plant, action radius in the information space is correlated with action radius in physical space. Computer applications aiming at supporting overview, awareness, etc. should not do so by providing uniform access to information across geography and purpose, but rather by supplement the implicit information space already present through the technical arrangement of basins, pipes, pumps, etc. Furthermore, we have seen strong indications that overview is not isolated from purposeful action. There is no technical solution that can yield overview to anybody beyond his horizon of action.

We have, however, also seen that very experienced and competent workers may have a very local horizon of optimisation and exploration, thus staying in the periphery (of the general optimisation of the plant) forever, in a perfectly legitimate way. The very different activities in the wastewater treatment plant,with their varying optimisation horizons are over-layered and mutually dependent. These activities "take place" as they are all supported in the common information space, but not all actors are on the way to become part of the total optimisation activity. Common information spaces, as well as wastewater plants, have centres and peripheries, and they are composed of overlapping regions. With this perspective, learning takes place in parallel with the ongoing juxtaposition of information in the intertwined physical and virtual common information space.

Conclusion

Our studies of wastewater treatment plants show how such massively distributed spaces challenge many of the ways that CSCW view common information spaces. Furthermore, the studies support the idea that common information spaces is not merely about access to everything, everywhere. Participation in optimisation is introduced as an important feature of work tied to the moving around in physical space. In the CSCW literature, peripheral awareness and at a glance overview are mostly connected with the co-ordination of activities within a control room or in similar co-located circumstances. Whereas the wastewater plant is also located in one place, our research shows that it is exactly the moving about and the purposeful action in a variety of places that make possible the juxtaposition of information, and hence the running and optimisation of the plant. Overview, predictability and peripheral awareness are all related to how people move about in the plant and not to a particular location. The wastewater plant reveals a true focus on common spaces, rather than common places. Spaces are dealt with through movement, and movement as a precondition for learning, participation and experimentation. Common information spaces have several centres and peripheries, and are composed of overlapping regions. Learning takes place in relation to the ongoing movement and juxtaposition of information in the massively distributed common information space.

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