Distributed cognition and organisational analysis

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Distributed cognition in the analysis of ‘open’ systems

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ABSTRACT
Distributed cognition provides a framework for examining collaborative systems with the aim of supporting systems design. The approach provides a theoretical basis for structuring the analysis of data from workplace studies within a problem-solving framework. Whilst the approach has been successfully applied in well constrained activity domains, well structured problems and highly organised infrastructures (‘closed’ systems), little is known about its application outside of these areas. In this paper, we explore how distributed cognition could be applied to less well-constrained (‘open’) settings, and where difficulties lie in its application. To demonstrate this, we present and critically reflect on data from a field study of a collaborative work system with relatively poorly constrained features. The findings suggest that the use of distributed cognition in an augmented form will be useful in the analysis of a wide range of activity systems in poorly constrained organisational settings.

KEYWORDS: organisational analysis, information processing, distributed cognition, data collection, human-computer interaction, computer-supported co-operative work.
1. INTRODUCTION

Human-Computer Interaction (HCI), and more recently Computer-Supported Cooperative work (CSCW), has long been concerned with the study of work activities. The theories and methods developed for, and applied to, different workplace settings have been a mainstay of HCI and CSCW research and have contributed to our understandings of technology-mediated work. The emergence of theories which have moved the focus away from the single user to a wider consideration of interaction have brought new dimensions to HCI/CSCW’s potential contribution. Such theories and associated methods of inquiry have provided new means of analysing and better understanding work practice, which can in turn inform the design of technologies to support and enhance work.

Distributed Cognition (DCog) is one such approach, having been used as a means of analysing work settings both in cognitive science (see, for example, Hutchins, 1995a,b) and in systems analysis and design (see, for example, Flor and Hutchins, 1992; Rogers, 1993; Fields, Wright, Marti and Palmonari, 1998). By attending to the informational content of activities, and examining them as information processing events, DCog can support user-centred design, applying a cognitive engineering approach to the development and implementation of technology to mediate work.

Proponents of DCog argue that the approach can be used to explore the performance of work by its participants and the co-ordination of that work through a variety of artefacts. It is unusual in that it seeks to study people, social interaction and artefact use within a common framework. DCog draws its theoretical and analytical foundation from cognitive science, which uses a mature vocabulary and set of exploratory techniques, augmenting these with techniques for primary data collection and ethnographic representation drawn from sociology and anthropology.

1 As discussed by Halverson (unpublished), there are problematic issues in the various ways that the term ‘distributed cognition’ has been used. We clearly distinguish the ‘flavour’ of distributed cognition drawn from cognitive science as DCog and developed by Hutchins, and differentiate it from other uses of the term. The term ‘distributed cognition’ is used in an analytically different way by writers such as Heath and Luff (1991), and in the book ‘Distributed cognitions’ (Salomon, 1993). Often, the term distributed cognition is used simply as a synonym for socially shared cognition (see Engestrom and Middleton, 1996, Resnick, 1991). Somewhat similarly, DCog is distinguished from theoretically related work, such as that by Zhang and Norman (1991) who discuss ‘external cognition’, but are interested in the location of representations, and not in their co-ordination.
The analysis of work settings using DCog focuses on representational transformations. These occur in systems as information is taken into them as an input and processed into an output that matches the system’s goal. In practice, information about the settings is captured using ethnographically informed observational and interview based methods in field studies of the workplace. This has been described as ‘cognitive ethnography’ (Hutchins, 1995a). Attention is concentrated on the actors/workers (who co-ordinate the representational transformations) and the media/artefacts in the environment (which encode the physical representations of work). The interaction between these elements is crucial in understanding how representational transformations are co-ordinated.

Whilst DCog has been hugely influential in HCI and CSCW, and has been successfully applied in understanding some working environments, its application has been limited to small, well-defined and tightly-constrained systems that use a specialised and limited tool set (for the purposes of this paper these will be known as ‘closed’ systems). Characteristics such as these are not shared in a vast range of work settings in other types of organisations (again, for the purposes of this paper these will be known as ‘open’ systems), such as design (e.g. Perry, 1997), accounting (Cole, 2002) or medical work (e.g. Strauss, Fagerhaugh, Suczek, and Weiner, 1985). It is interesting to note here that the existing DCog analyses focus on partial elements of wider work settings (e.g. in Navigation [Hutchins, 1995a], air-traffic control [Hutchins, 1995b; Halverson, 1995] and telephone call centres [Halverson, unpublished]) that are tightly constrained: by artificially setting the problem situation up as a ‘closed’ system, the analyst does not face the problems of extending their analysis outside of these limited settings. Other examples of this are numerous, including Rogers (1993), Rogers and Ellis (1994), Flor and Hutchins (1992), Hutchins & Klausen (1991), although the published literature has tended to revolve around a small number of researchers. Surprisingly, few more recent articles presenting DCog fieldwork have been published in the area, although there have been a limited number of recent theoretical articles on DCog (although see Halverson (unpublished); Ackerman and Halverson (1998); Ackerman and Halverson (1999); Ackerman and Halverson (2000) and Holder (1999) for a limited range of examples).
Whilst the analyses that existing studies have developed are extremely valuable, extending the domain of interest beyond the limited systems explored would provide an interest and valuable insight into the ways that these sub-systems were embedded into the larger work systems of the workplace. So, developing Hutchins’ (1995a) work on navigation for example, we might learn how navigational information is interpreted in the other functions of the ship, and how other aspects of activity on the ship might impact on back into the navigational sub-system. This type of analysis poses a different set of problems to those examined in these previous studies, but such analyses would nevertheless be interesting and useful, particularly in HCI and CSCW where we seek to understand wider systems of context activity than the simple task.

At this point, it is important to stress the distinction between the characteristics of work systems that have been studied using DCog and the nature of DCog as an analytical method. The focus of DCog research - up to now - has been on systems which are relatively simple, in terms of their structure, and that have a constrained set of problem solving activities, restricted resources and event durations (see, for example the studies by Hutchins, 1995a,b). However, in the systems typically seen in a number of other organisations these factors do not necessarily hold true: work may unfold over a period of time, the participants can co-opt a range of tools into their work and new people may be introduced into the system to assist in resolving problems, which may not be well-understood. Deriving an analysis of such workplace activity directly from the methods used in existing studies of DCog may therefore prove problematic as an appropriate means of understanding them. Whilst the theoretical framework of the approach may be congruent for these different problem domains, methodological issues and the application of theory to data may be different in these different domains.

In the following sections, the foundations and existing use of DCog will be discussed and examined to highlight the major concerns over its use in large and highly complex organisational settings. Briefly reviewing the theoretical and methodological underpinnings of the DCog framework will allow us to identify and discuss the areas of difference between the settings considered in existing studies and typical organisational systems. To demonstrate this, we draw on a field study, pulling out findings to highlight
the application of DCog in poorly constrained domains of work activity and to help us propose suggestions for the development of DCog and its evolution as an analytical method.

2. DISTRIBUTED COGNITION

2.1 DCog in user-centred design

The central concern of user-centred systems design lies in supporting work through appropriate technology, and goal centred descriptions of work can provide a means of achieving this. A DCog analysis shows how representations are acted upon and processed using social, technological and situated resources. By considering the information-processing element of work, components of the activity that relate to the goals and task alone can be highlighted. These focused descriptions of work have direct application to systems design, by showing technology developers how work is performed within its settings of action.

The results of a DCog analysis have the potential to provide system designers with valuable information on the problem solving processes that are enacted by the functional system. The approach focuses on the representations and processes of work, and demonstrating how these are used in transformational activity (i.e. situated problem solving). By making explicit the artefacts on which computational operations are performed and the social practices used to transform the representations, systems developers can build systems that are appropriate to the informational needs and requirements in performing their work itself. The importance of these studies to systems design and CSCW lies in the descriptive power that they have in making explicit the collaborative problem-solving element of work. By seeking to understand the transformational nature of work we can begin to design effective and appropriate technology for that work. Opening up the application of the DCog approach to a broader range of application areas is one way that we can help support this.
Two central components in DCog - representations and processes - are useful to studies of technology-mediated work and to systems design, because they can help identify the goal-directed aspects of the work activity (Perry, 1999a). Examining systems as having an initial state, goals, inputs, outputs, information-representations and information-transforming processes can be used as a common frame of reference between the analyst and technology developer for communicating design-relevant information. The focus of DCog on the representations and processes of work enables the analyst to describe the informational ecology of organisational work systems, in settings that are rich in organising structures. Good systems design is concerned with building computer systems that are not only functionally adequate, but are sensitive to the social, situated, organisational and cognitive aspects of the work. DCog, as applied in organisational settings of the kind described in this paper, is a highly promising means of informing designers about these aspects of work: it is more focussed on information and communication than a purely ethnographic study, yet has a wider perspective on an activity system than task analytic data.

2.2 DCog in Cognitive Science

The ideas behind, and terminology used in, DCog reflect its roots in cognitive science. Classical cognitive science provides a conceptual framework with which to examine intelligence and problem solving, exploring how information is represented in the cognitive system, and how these representations are transformed, combined and propagated through the system in goal-oriented behaviour (Simon, 1981). These cognitive processes and representations are considered to be internal to the individual and held mentally.

In DCog, a larger granularity of analysis is selected than that of the individual, to include the use of information artefacts in the cognitive process (see, *inter alia*, Hutchins and Klausen, 1991; Norman, 1993; Hutchins, 1995b). These systems include artefacts such as a pen and paper, which can be used as memory aids, as well as more complex artefacts that are integral to the computation, such as slide rules. As such, DCog provides a strong and coherent framework with which to structure the analysis of workplace systems in terms of their informational content and problem solving activities. As well as
incorporating artefacts in the cognitive analysis, DCog also differs from classical
cognitive science in its views of the cognitive process. DCog suggests that the cognitive
process can be described as being distributed over a number of people co-operating
through social mechanisms, often referred to as ‘socially distributed cognition’ (Hutchins,
1995a; Hollan et al., 1999).

The unit of analysis in DCog may consist of any number of representations, embodied in
people, computerised artefacts and non-technological artefacts (Rogers and Ellis, 1994).
As a framework, DCog provides a unique insight into how technology and the socially
generated media of communication act upon and transform representations, and in doing
so, perform computations, or information processing activity. The aim of DCog is
therefore to understand how intelligence is manifested at the systems level and not the
individual cognitive level (Hutchins, 1995a).

The mix of people and artefacts in a given situation contribute to the functional system of
activity, which includes all of the representation-carrying and representation-
transforming entities involved in the problem solving activity. A distributed cognitive
analysis examines the means by which the functional system is organised to perform
problem solving. From a computational perspective, the functional system takes in inputs
(representations), and transforms these representations by propagating them around the
units of the system. A distributed cognitive analysis involves deriving the external
symbol system (Newell and Simon, 1972) by capturing the elements of processing
(representations and processes) that transform system inputs into outputs for particular
tasks. In most cases, these distributed representations and processes are brought together
by agents - people - and co-ordinated through social mechanisms.

2.3 Socially distributed cognition and the division of labour

Socially distributed cognition allows the analyst to describe group activity as a
computation realised through the creation, transformation and propagation of
representational states (Simon, 1981; Hutchins, 1995a). By bringing representations in
the system into co-ordination with each other, information can be propagated through the
larger cognitive system, being continually modified and processed by a number of
individuals and artefacts, until the desired result is reached. However, whilst processing of the information available to the group is analogous to an individual’s cognitive capabilities, the architecture of this activity differs significantly. How these socially embodied activities are organised with respect to one another is known as the ‘division of labour’. Understanding how this division of labour operates within the functional system provides a means of understanding its internal organisation and working practices – in effect it determines a large component of the computational architecture of the distributed cognitive system. Of course, there are many ways that work can be done, and this division of labour is malleable and subject to change as the actors within the functional system learn, change roles or introduce new technologies into their work.

Distributing work across a group of agents must involve the organisation of that group to co-ordinate activity – they need to develop a working division of labour, an architecture for computationally acting on the problem representation(s) so as to effect a solution. To solve a problem collaboratively, this division of labour must operate so that work is broken into parts but managed so that these (partially resolved) components can be re-incorporated together. Internal cognitive (i.e. mental) factors that are effectively invisible to the group (and to the analyst) need to be trained on the problem by individuals to bring their expertise to bear on these sub-tasks before they are able to re-incorporate their sub-task with the global task. This means that within the distributed cognitive system, problem-solving expertise lies not only in the knowledge and skills within individuals, but in the organisation of those individuals. This larger unit of knowledge organisation may be determined explicitly in predetermined protocols and procedures, or more informally through the context of their work environment being made visible or through the configuration of the artefacts used in the environment. How such strategies arise is a subject of intense interest in CSCW (Heath and Luff, 1991; Lave, 1988; Rogers, 1993; Suchman, 1987). DCog presents a powerful method of describing and analysing how this operates using the computational metaphor from cognitive science, but applying this to the functional system as a whole, rather than to a single individual.

The extent to which the division of labour is clear-cut and explicit (i.e. visible to the analyst) in the work activity will determine the extent to which analysts can develop a
precise description of the activity of the distributed cognitive system. Where the activities, actors and information artefacts in a workplace system are constrained and work roles are clearly specified in known protocols, the application of DCog to analyse the functional system should be relatively straightforward. This is likely to be particularly the case if the problem representation is explicit and can be tracked through its transformations in the system. Unfortunately, as any experienced ethnographer will recount, this is rarely the case, even if work with systems appears to be well defined at first impression. In many cases, the only way to find systems that are even remotely well defined is to pick out (relatively) simple sub-activities from workplaces and to examine these – and this had been the case for the majority of DCog studies to date.

2.4 DCog: application in data collection and analysis

A central feature of a distributed cognitive analysis is that it examines representational states, information flows, and the co-ordination and breakdowns that compose work, leading to a better understanding of the ways in which collaboration is co-ordinated and work undertaken. Whatever data collection methods are applied, these need to identify information-representation transitions (Flor and Hutchins, 1992) within the functional system that result in co-ordination and problem solving activities.

Data collection within the analytic framework of DCog must allow the identification of the representations and processes in the goal directed behaviour. The analyst needs to show how these elements are used as resources in information processing by demonstrating how this is mediated through action. Emphasis is placed on the role of the artefacts carrying information representations and on collaboration around these artefacts. Analysis therefore centres on the artefacts that are used or created, how they are used, who they are used by, how changes are made to them, and how the organisation structures access to these artefacts.

Whilst the framework of DCog is non-prescriptive in its application to data collection, one method – ethnography\(^2\) – has come to be pre-eminent. It allows the analyst to

\(^2\) Ethnography has its own traditions within sociology and anthropology and has long been used as a technique for gathering naturalistic data about activity within workplace and other settings. However, at its core, ethnographic
physically ‘enter’ the functional system and to build up a picture of work from the member perspectives, but which encompasses a higher-level perspective than the individual, showing interdependencies within the division of labour. These may be invisible to the participants themselves.

DCog can be used as an analytic framework to structure the ethnographic data, allowing the analyst to focus on the salient points relating to the cognitive (i.e. information processing) characteristics of the functional system. In order to do this, data about the task, the tools used, and the organisational context of their activity needs to be tracked, following the information input and output pathways of the functional system. The analysis of the data involves mapping out the information flows through the organisational structure, identifying the sources and sinks of this information, the tools used to manipulate and transmit it, and the ‘chains of command’ initiating activities.

Whilst DCog has a number of highly useful features in representing the information processing component of collaborative work, as with any focussed description of activity, potentially valuable information can be lost. This can have benefits, when information not relevant to problem solving is filtered out, but it also means that important information about the setting may be lost. One example of this is motivation - DCog analyses cannot provide a means of examining motivational factors in work relevant to its performance. The problem solving systems described in DCog are ‘impersonal’ (i.e. systems are described in terms of their external resources), and whether or not the work is tedious or poorly rewarded, for example, is not considered. It is interesting that Hutchins discusses these factors in his seminal book on DCog (1995a), but describing negotiations of the distribution of labour in taking beam bearings, and how some activities outinely deviate from stated procedures, but that he does not attempt to phrase these in computational terms, rather he phrases them descriptively, in ethnographic terms. In a DCog analysis, computation is at the core of the process and the personal concerns of actors are seen as irrelevant – actors are computational agents, acting on and transforming representations. A DCog analyst is engaged in an (and not the definitive) examination of

analysis provides a means of exploring how work is organised (Hughes et al., 1992; see also Anderson, 1994; Hammersley and Atkinson, 1995 for overviews).
work, as performed (i.e., it investigates enacted, or situated knowledge (c.f. Lave, 1988) rather than an individual’s knowledge structures), to give a better understanding of real-world (and not idealised) activities. If this is not the form of detail required in an analysis, then DCog is unlikely to be an appropriate method of investigation.

In principle, the analytical framework offered by DCog is clearly of value in its analysis of highly complex open organisational work systems, through demonstrating the mechanisms of co-ordination and collaboration in problem solving. It can be applied to develop an improved understanding of the system in itself, and in the re-design of work systems through supporting the development of new representation-bearing technologies and organisational processes to facilitate an appropriate division of labour. Its focus on the ‘social’ aspects of technological and organisational information processing identifies it clearly as different from almost all other forms of analysis as it uses the same ‘language’ to describe all of the system components and their operation. However, the nature of many workplace activities is such that the functional system within which they are situated is not always fully specifiable or easily captured by a cognitive ethnographer using a standard DCog approach. This appears to have so far limited the potential for applying DCog as an analytical method in such contexts.

3. A COMPARISON OF STUDY SETTINGS

In assessing the analytic value of DCog applied to open systems, it will be helpful to provide a comparison of their key constituent dimensions against settings in previously published studies of DCog (see table 1 for a summary). We will refer specifically to the ‘navigation’ systems considered by Hutchins (1995a) as they are representative of the systems to which DCog has been ‘applied’. It is important to recognise that this comparison is illustrative, and it is not suggested that all contexts of one kind or another will share all of these characteristics. Rather, these dimensions are intended to highlight areas where there are likely to be contextual differences which impact on our ability to employ DCog effectively. Please note that these dimensions are not completely distinct and there are interdependencies between them.
<table>
<thead>
<tr>
<th>Key Dimensions</th>
<th>Navigation (‘closed’) systems</th>
<th>Organisational (‘open’) Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to resources</td>
<td>Actors and representational artefacts are restricted to a predetermined set.</td>
<td>Actors and representational artefacts are unrestricted to a predetermined set and may change over time.</td>
</tr>
<tr>
<td>Problem structure</td>
<td>Well-structured, identifiable and expected problems that are recurrent.</td>
<td>A tendency toward ill-structured problems that have a high degree of uniqueness.</td>
</tr>
<tr>
<td>Organisational structure and</td>
<td>Organisation has pre-specified modes of operation, characteristic of tightly constrained and managed organisations with rigid modes of operation. Division of labour is well understood and ‘standard operating procedures’ underpin much of normal work. Problem dynamics are relatively stable over time.</td>
<td>Organisation’s operation is only partially pre-determined; established work processes operate at an abstract level and are augmented by ad-hoc approaches in interpreting these high-level operational directives. Divisions of labour are informally defined and enforced. Problem dynamics are unstable and dynamic over time.</td>
</tr>
<tr>
<td>problem dynamics</td>
<td>Relatively short cycle for problem solving, coupled tightly to the task.</td>
<td>Problem-solving cycle tends to be variable, with different classes of problem in the same workplace system taking place over widely different time scales.</td>
</tr>
</tbody>
</table>

Table 1: A comparison of key dimensions in workplace settings

**Access to resources**

The main difference between navigational and systems within open organisational systems can be most clearly seen in terms of the distinction between their access to resources. In navigation, the system is closed: the process has a fixed and restricted set of resources and external agents are not able to involve themselves in the system. In such open organisations, participants can call on a larger set of resources, which may not be initially specified or known to be available at the beginning of the activity.

**Problem structure**
The problems that the two types of system have to solve are also structured in different ways. In navigation the problem is ‘well-structured’ prior to its solution; the task is repetitive and actors are well practised in performing the task. In open organisational systems, the problem is more usually ‘ill-structured’ and only becomes well-structured in performance: the participants learn about the problem during problem solving.

Organisational structure and problem solving dynamics

The methods that are used to organise the co-ordination of activity differ between navigational practice and open organisational systems. In navigation, the communication pathways are (necessarily) well-specified and constrained to a number of pre-defined modes of operation. These are enforced by (naval) regulations, which prescribe the division of labour on particular tasks. However, in open organisational systems, not all of the communication pathways are well-specified prior to problem solving, and their organisation are likely to be only partially constrained by pre-determined modes of operation. Whilst we recognise that navigational work is not always routine, this is far more exaggerated in open organisational systems. There may be few absolute organisational structures, and the artefacts, communication pathways and participants available are likely to change over time. Some processes may be formally specified, but many are generated in an ad hoc fashion. Formal specifications may be stipulated at a high level, but the mechanics of implementing these are frequently left to the interpretation of participants, subject to professional and legislative constraints. In open organisations, it is common for procedures to be defined at an abstract level, and it may be left to the interpretation of individuals to decide on what actions to take as circumstances change.

The changing nature of the problems faced by the navigators and by actors in open organisational systems differs substantially, and this has implications for the way that problem solving strategies develop and enter the culture of the workplace. Navigation by triangulation is an unchanging process, developed over centuries of practice3. The

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3 The work of positional location described by Hutchins (1995a) has radically changed with the introduction of the Global Positioning System (GPS). Here, the problem has itself been transformed: satellite information rather than
procedures can remain unchanged over multiple fix cycles, and although each cycle may be of short duration in itself, they are highly repetitive. In open organisational systems, the duration of the activities that they perform is likely to be far longer — for example, contract negotiations, design development, or product testing are lengthy activities, and over time, and even within the activity, procedures are likely to develop and adapt. This is unlikely to occur within the fix cycle, although Hutchins shows how the development of practice and of the practitioners (1995a, p.372) does change over time — but over multiple cycles.

Cycle duration

The duration of the activity cycle differs substantially between open and closed systems. For example, in navigation, the ‘fix cycle’ is of short duration (a matter of minutes or seconds). These fix cycles are ‘snapshots’ in time, and each involves taking a bearing of the vessel’s present location. However, in open organisational systems, work processes can occur over much longer time-spans. In one sense, this reflects the difference in the work being done, where the tasks in the navigational system are more self-contained and time-critical.

These brief descriptions suggest that work performed by closed and open systems has the potential to be very different, in terms of goals, technical resources and contexts of use. However, both may be seen as information processing systems with a similar high level (cognitive) structure and it is at this level that a common approach like DCog can be applied. Nevertheless, because these systems differ in significant ways, it is likely that the methods used to examine them will also have to differ. This suggests that we cannot draw directly from previous studies of DCog and apply them directly to the analysis of other workplaces.

Rather, we need to consider the differences more closely, undertaking and

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visual information is used, and the configuration of the functional system in navigation is therefore also likely to change.

4 The nearest that DCog analyses have come to this in their application to highly complex settings are Hazelhurst’s (1994) and Holder’s (1999) PhD theses, although these do not examine the methodological extensions that have
drawing on new studies of organisational work to help us evolve an effective analytic method for distributed cognition into these contexts.

4. DISTRIBUTED COGNITION IN ORGANISATIONAL ANALYSIS

This section suggests how DCog can be applied to the study of ‘open’ systems. Through examples it demonstrates:

i. the differences between the traditional domain of study for DCog and the less constrained, open organisational settings discussed in section 3; and

ii. an approach to gathering data that allows us to undertake an analysis of aspects of work within these settings.

The rest of this section introduces a field study from which several examples are drawn, and provides a basis from which we argue for the extension of DCog as an analytic approach. Please note that these examples are intended to illustrate the two points above, rather than making a particular claim about the engineering design process from which the data was taken.

4.1 Background to the Study Setting

The field study involved an examination of design and construction on a large road building project (see Perry, 1997 for more detail). Fieldwork covered the participation of several spatially distributed group working for a construction company. To build the permanent road structures (the ‘permanent works’), the construction company had to design supporting structures known as ‘temporary works’. The temporary works comprised of non-permanent items, such as scaffolding, concrete moulds, supply roads, and so on. These temporary works were derived from the designs of the permanent

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been made to extend the approach. Moreover, the problems described within the settings have been carefully ‘bounded’ so as to create a simplified problem space that does not account for the larger setting.

5 Readers are referenced to Suchman (2000) for similar analysis of engineering on a bridge building project, which focuses on the use of design representations, and although this is not a DCog analysis, it is interesting in the similarity of the approaches used.
works, but their designers had to take into account the site conditions (slope, weather, soil condition, and existing structures) and the available resources (money, time, materials, equipment and labour) that were not accounted for in the permanent works designs.

A large number of people were involved in the functional system developing the temporary works design, including a construction team, made up of a team leader, seven engineers (one senior, three site, and three graduate engineers), two foremen (work supervisors), two gangers (junior work supervisors), and general labour (fluctuating at around 40). The team operated on the site, but were supported off-site in specifying the design of the temporary works by a design co-ordinator who worked at another location on the building site. The design co-ordinator worked closely with a design engineer (located several miles away from the site) to develop the team’s requirements into a temporary works design solution. Several other individuals and groups external to the organisation were closely involved in the process; including a ‘resident engineer’, who checked that the road was designed and built according to contractual standards, a railway operating organisation, over whose tracks a road bridge was being built, and an environmental agency, responsible for pollution monitoring.

The high level aim of this functional system was to design and construct the road, according to the previously generated permanent works designs and contractual details (quality and time), with commercial constraints (on cost) and without disrupting railway services or causing watercourse pollution.

A huge number of informational artefacts within the functional system were identified. Physical media included drawings, paper and pencil sketches, letters, post-it™ notes, schedules, method statements, risk analyses, works records (a diary of site instructions, records and requests for information), and other paper-based forms that had to be completed in the course of work. All of these artefacts bore representations that could be communicated between the collaborating actors involved.

The temporary works design processes were partially prescribed in the handbooks and manuals that determined relationships between people, and in the organisational structures they inhabited. These specified where the responsibilities for tasks lay and
determined the roles that the individual people had to fulfil. Whilst these were generally followed, particularly the safety-related rules, they were used more as organising principles, followed when appropriate, but worked around when other methods might be more appropriate in the circumstances.\(^6\) The context of the interactions during such activity played a major role in the interpretation of these materials, as we shall see in later sections.

Structures in the environment at the site and office also played a role in determining the processes that would be applied to particular problems. These determined the configurations of representations and processes that could be applied to the design problem. For example, the physical size of the site made locating people on it difficult, and communications were complicated accordingly. However, when in the construction team’s on-site office, the engineers and foremen shared a physical space and had a rich and wide range of media with which to communicate.

According to DCog, the transformational activity in temporary works design to be performed by the functional system would involve taking inputs into the functional system, transforming them into representations and re-representing them until they match the desired goals. Problem solving would therefore involve the co-ordination of the representations by matching them to the appropriate processes. However, the different resources available in particular circumstances, and the different ways in which individuals could resolve the problem-solving situation, meant that problem resolution could be achieved in a variety of ways. Hutchins (1995a) also describes this, showing how ‘local functional systems’ are built up around - and exploit - the particularities of individual problem situations.

4.2 Illustrative Examples from Fieldwork

Having established the broad stetting of the field study, we can now look at it in relation to parts i. and ii., exploring the differences between traditional studies of DCog and the construction setting, as well as the approaches used to gather data in undertaking an

\(^6\) Clearly, this can be compared to the work of Suchman (1987) which shows how rules are used as resources for action, but not deterministically as generators of those actions. **KEEP THIS? – is it too obvious?**
analysis of aspects of construction work within the DCog framework. These examples from the fieldwork illustrate the five key dimensions described earlier (see table 1). What we attempt to do here is to use examples that demonstrate the differences between what we have called open and closed functional systems.

**Access to resources**

The key resources in design and construction are rarely pre-determined before the problem solving activity is initiated. The fieldwork illustrates how the problem solving activity changed as additional actors and artefacts become available. When new designs or requests for information arrived at the site, there were a variety of different follow-on activities that might result from this, although it was by no means ‘programmatic’ what these might be. Hutchins (1995a) recognises this ‘availability of data’ as a key controlling factor in how a functional unit can organise its computational and social structure: additional information can lead to new social arrangements, which in turn lead to new computational structures (Hutchins, 1995a, p.342). Where Hutchins’ analysis diverges from the concerns relevant to this particular fieldwork (and ‘open’ systems in general), is in terms of how often the navigational fix cycle data becomes available and who in the group is available for action, in contrast to the arrival of a different form of (relevant) information and/or new actors with entirely new roles and responsibilities into the system. This is a fundamental difference with wide reaching consequences: it is not simply the configuration of the functional system that will change, but its very constitution.

The construction team’s office was an important resource in their work. It had an ‘open plan’ layout, and the engineers and quantity surveyors were able to see who else was present. It allowed them to speak to each other without moving from their desks, to overhear other people on the telephone or when speaking to each other, and to see the information laid out on each others desks. Whilst doing the fieldwork, there was a relaxed atmosphere to interactions, and when members of the team were not doing any work, the room layout facilitated the team members in engaging in social conversations, or in
joining conversations if something interested them. These conversations almost always turned to work.

Whilst the construction team were centred in this office, individuals spent a large amount of their time on-site, and the distributed nature of the construction site made contacting these individuals difficult. When people were not present to talk to directly, other media were used to communicate, either synchronously through the use of the radio link, or asynchronously, through placing written notes, sketches, method statements or risk assessments on people’s desks, or jotting notes onto a whiteboard. Messages were also left with people who were in the office for when that person came back. A photograph of the office space, its contents and layout is shown in figure 1.

Figure 1. Photograph of construction team office.

As can be observed, the workplace was informationally very rich. Paper covered almost every surface, often several layers deep, even pinned onto the walls. When information was required from a person who was not physically present, this ‘desk litter’ could provide clues to their location, in the forms of the drawings and other representations on the desk, indicating the task that they were currently engaged in, and providing a guide to
their current location. Other artefacts also provided information about the whereabouts of people: if a person’s Wellington boots and hard hat were missing, they were probably out on site; if someone had a pair of muddy boots under their desk, it meant that they had been on the site and could be asked about the current work situation. Depending on the weather, it was even possible to see how long ago a person had been out on the site, for example from the wet or dried mud on boots, which could be useful if one of the team was trying to locate another individual out on the site. Equipment such as the geodometer was also useful in this way - if it was missing from the office, then a graduate engineer would be out on site and could be asked to run a favour by the more senior engineers over the radio. Even the window was used to see whether a person’s vehicle was in the car park outside the office: if this was the case, then that person was highly likely to be somewhere on the site.

Spoken communication was conducted from the desks, allowing all of the participants in the room to be aware of developments, or allowing them to contribute to the discussion. When the senior or site engineers wanted to speak to the graduate engineers, they would stand up and chat over the tops of the partitions, providing a visual and auditory focus of attention in the room. This allowed people to work whilst keeping an ear to the conversation and keeping abreast of developments, to ask questions, but also allowing them to enter the conversation and add to the discussion. An example of this type of office conversation is noted in box 1:

| Senior engineer: <goes over to graduate engineer at his desk> ‘Have you got the delivery tickets for fifty two fifty six?’ [the term relates to a particular set of substructure pile reference numbers]. |
| Graduate Engineer: <mumbles. Begins to search through a file on his desk>. |
| Quantity surveyor: <sitting on desk opposite graduate engineer, and overhears conversation> ‘I’ve got copies. I think I’ve got the ones you’re looking for’. |

Box 1: peripheral awareness in the site office.

In addition to these ‘open’ co-present conversations, telephone conversations were carried out in loud voices; this was partly because the level of ambient noise in the room could be fairly high, but also because it allowed the others in the room to overhear (one
side of) the conversation. One of the site engineers in particular would deliberately raise his voice whenever he was speaking about topics that he perceived to be particularly pertinent to the others. Occasionally he even stood up and waved his arms around to gain attention, or pointed to artefacts that were relevant to the discussion so that the others in the room might better understand the topic of conversation.

Within the literature of workplace studies and CSCW, such observations are relatively commonplace (Heath and Luff, 1991; Heath et al., 1993; Murray, 1993). However, within the DCog framework, the analyst must draw from their observations how particular representations are propagated and transformed. Here, in the example above, the range of representations to select from is enormous, and they can be used in a variety of ways to achieve the same goal. In the event of a similar situation arising, it is unlikely that the same resources would be available in the same configurations as before, and used in the same way. This differs significantly from the examples of DCog documented in aircraft and navigational settings, where stable behavioural patterns (Hutchins calls these ‘computational sequences’) tend to be recurrent.

The consequences of this resource-flexibility is that it is harder to build generalisations or models about activity. In these situations, ethnographic descriptions of work are likely to represent ‘one-off’ solutions, generated by members who generate and maintain a computational structure that utilises only a subset of the potential resources available. Such descriptions will therefore be useful to illustrate how and which resources are used, but they cannot be seen as anything more than exemplars, or instances of problem solving. This is informative in understanding the activity in general, but not so much the predictive performance of an activity. So, for example, it may be useful in understanding the formalisms within engineering drawings that allow people to communicate using them, but not in how a particular problem might be resolved in which engineering drawings were a component part.

**Problem structure**

The examples below demonstrate the nature of the problem structure faced in the construction setting. The design/problem space is poorly understood prior to the initiation
of the problem solving activity (i.e. they are ill-structured (Simon, 1973)), and a component of this activity is to understand exactly what the problem is as well as how to resolve it. This differs significantly from previous studies of DCog in navigation and cockpit activity, in which relatively regularised and well-structured problems are encountered: thus there is the fix cycle in navigation and the landing sequence in an aircraft cockpit. Deviations can and do occur, but these are relatively highly constrained and delineated within a well understood set of criteria – the goal is clear, and the set of operations that the participants have to operate on is limited and practiced. The examples given below demonstrate the structure of the problem faced by the designers at the construction site. The section begins with a description of the global design situation and shows how that within this, ongoing problems were identified and transformed from ill-structured problems to well-structured problems.

In order to begin the steel work, concrete pours and other general work that made up construction, resources had to be put to work, in terms of labour, plant and materials. Much of the physical component of construction work was demand-led, and work could only occur when the site had been prepared: materials or other resources might have to be ordered or cancelled at the last minute because the site was prepared for the work earlier or later than expected. The use of different construction methods or materials (which might be used because of product non-availability, or particularities of the situation) in the permanent structures could change the project’s specifications, and such changes would need to be checked with the resident engineer (RE) to ensure their suitability. Changes to the materials used in temporary works structures also meant that these designs had to be checked by the senior team engineer or off-site by the temporary works designer, again, to ensure that they were safe, cost effective and would not conflict with future work.

Information relating to the state of the site was collected from the different groups of workers on the site, each using their different skills and experience to determine discrepancies with the original designs. Small problems relating to the construction materials would usually be noticed by the tradesmen, who would pass this information to the gangers, where it would precipitate upwards through the team hierarchy to the
graduate engineers. These in turn would either record the problem in the ‘works record’ which functioned as the official record of activities on the site, or they would mention the problem to a site engineer who could determine an appropriate course of action. Structural problems on-site would be investigated by the engineers on their patrols around the site (known as ‘site visits’) where they would check how the activities that they had been assigned to manage (by the senior engineer) were progressing. These site visits were an opportunity for the engineers to engage in ad hoc encounters with the workers on the site, which provided a source of information on developing problems. In one site visit observed, a site engineer was taking a crane hire representative around the site to discover what sort of crane they would need to hire to place several beams onto the underside of a bridge - an awkward situation to reach. Standing under the bridge, the site engineer and the crane representative were joined by a foreman, and they deliberated over possible methods of access to the bridge and scaffolding and other features that would have to be removed or reached over by the crane. Whilst involved in this discussion, the assistant section resident engineer (RE) (the RE’s representative on site) saw them and came over. They became embroiled in an amicable argument over the method used in a concrete pour on a section of the bridge adjacent to the area that they were standing on. It appeared that the Project Engineer (the creator of the designs that the RE was administrating) had not specified in the drawings how the concrete was to be poured, and the construction team’s engineers had decided on a method that was not approved by the RE. A consequence of this mistake was that the RE could not legally enforce this due to the oversight. No conclusion was reached, but they agreed to continue the discussion at a more convenient time.

The example above clearly demonstrates how little was fixed in the detailed design process until much of the design and construction was already underway, first in accessing the bridge, and then determining a means of pouring the concrete. Contrast this with Hutchins’ descriptions of the pelorus operators who knew what landmarks to look out for, and how to communicate this to the next link in the chain until it was marked onto a navigational chart. This is a very different kind of work. In a second example
below (box 2), we show how physical representations were used to structure the design space and to help resolve the problem.

In official project procedures, the team’s senior engineer should formally present the initial ‘design brief’ (a temporary works design specification) to the design co-ordinator before a temporary works design could be generated. In practice, this design brief was often little more than a few ideas sketched or jotted onto a scrap sheet of paper. This occurred because the senior engineer had too little time to perform the task, and often had very little understanding of what information the design engineer might require in the problem specification. Through discussions with the design co-ordinator, a detailed specification would be generated, containing information about the site conditions, the materials, labour and other resources available to construct the temporary works structure. The construction team’s senior engineer and the design co-ordinator would then sit down together and pore over the permanent works drawings, the initial temporary works design brief and several sheets of blank paper. As they discussed the problem, both tended to make sketches, and they often elaborated on old sketches. This can be seen in the next example in box 2:

| Senior engineer (SE): ‘If you look here, there’s a barrel run there’ (points at sketch generated in the meeting of a section view through a design structure) |
| Design co-ordinator: ‘Yes I see’. |
| SE: ‘So if we dig here...’ (he holds one hand to the sketch and runs a finger on the other hand along a permanent works drawing (plan view) beside the sketch, indicating a line of reference) |
| Design co-ordinator: ‘No you can’t do that because of drainage problems...’ (pauses) ‘...No, no, I see now’. |
| SE: ‘So if we cap these piles here...’ (indicates several points on the sketch) |
| Design co-ordinator: ‘Yeah. OK. Let’s do that’. |

Box 2: use of multiple media in collaborative problem framing.

This second example, involving the transformation and combination of information on two representations, again shows how little was understood by the actors about the
problem structure before they commenced the design process. The problem itself (generating an effective way to provide structural support) arises out of the comparison of artefacts (sketch and drawing). Having recognised the problem, the two later went on to generate a solution. This is very different to the structured ways that the chart was used in Hutchins’ description of navigation. The structure of the problem in the work of construction is not fully specified, and the problem solvers must endeavour to clarify what they need to do to achieve their goal (in the case of the last example, to provide an appropriate form of structural support). Typical cockpit and navigational examples in the DCog literature do not involve this form of behaviour: the problem solvers already have a known problem and a well-practised set of procedures with which to generate a solution. The importance of this difference in problem solving for DCog in such settings is that the problem space is constantly changing over the time period - and repetition of activities is consequently infrequent.

Where part of the problem solving behaviour involves the functional system in self-organising itself, much of what is observed is not directly problem-centred but involves re-organising the functional systems’ internal processes around the dynamics of the problem situation. In many ways, this is itself a problem solving activity, but it is very different in nature to a functional system that is already self-organised to solve a well-understood problem (such as navigation). Whilst self-organisation is recognised and discussed by Hutchins as a feature of activity within functional systems in navigation, we have observed far more ongoing self-organisation in our research into highly complex settings. A crucial component of self-organisation is the awareness of the participants about the state of the local functional system, so they are able act appropriately to the situation. The analysis therefore needs to clearly show how the participants in the functional system manage to achieve situation awareness. Situation awareness is not normally assumed to be a part of problem solving in DCog (because it is not associated with representation transforming activity) and as such has been relatively ignored. We argue here, that in DCog studies of complex settings, situation awareness must be considered as a core feature of activity, even when it is not directly associated with a particular problem-solving event.
Organisational structure and problem solving dynamics

In this section we show examples of how the components of the functional system were organised in the construction project. In the terms used by Hutchins (1995a), there were a number of documents that determined a ‘standard operating procedure’ (or SOP) including manuals and handbooks. However, their application was not as rigidly enforced as those of navigational or aircraft cockpit systems, for a range of reasons (in navigational SOPs, these may control time criticality, safety, number of participants, and personal accountability). The organisational structure inherent in the SOP provides a basic structure for construction work, but it allows flexible interpretation by the actors involved. The example in box 3 shows an instance of how materials were ordered by the construction team and the resourceful way in which they managed to accomplish this (from fieldwork). To set the scene, a site engineer was discussing a concrete pour with a remote person over the telephone (note: only this part of the telephone conversation could be monitored by the fieldworker):

Site engineer: (stands up and speaks loudly into telephone) ‘So, what I’m asking is: should we put concrete into the tower?’ (raises his head and looks at the senior engineer with raised eyebrows)

Senior engineer: ‘Yes’.

(Site engineer, completes the telephone call, then lifts a radio to speak to a foreman to give the go ahead. A graduate engineer overhears this:)

Graduate engineer: (orients towards senior engineer) ‘Do you have any spare...(pause)...can I have three cubic metres?’


(Site engineer overhears this and radios through to the foreman to arrange it).

Box 3: an opportunity for the flexible accomplishment of work.

In this observation, the open-plan office space allowed the overhearing of telephone conversations, and was used by the site engineer as a means of asking the senior engineer if he could go ahead with construction. This was not pre-planned, but arose from a request for information arising from a distant third party. A graduate engineer, in turn,
overheard this, and made a request for materials, which was arranged by the site engineer. This saved money (and effort) by ordering one and not two concrete deliveries, yet none of this was planned in advance. Tasks were fluidly discussed and finalised as the participants were made aware of on-going activities around them, which they used to initiate and direct their own work.

This situation was able to take place because of the open-plan structure of the office space, but also because the participants knew that they did not have to order their materials through the specified SOP by ordering each load of concrete through a formal order. In this case, a separate order of concrete would have had to be made, tying up resources and losing the economies of scale that come with a large order. However, it was possible to avoid duplication of a materials order (and the accompanying bureaucracy and wasted time) by taking advantage of the ongoing activities around them.

A second example shows how the organisational structure acted as a resource for problem solving, whilst the mechanisms used in resolving the problem were socially mediated and negotiated between people:

In the construction project, tasks were allocated to people through a number of mechanisms, dependant on hierarchical structures of seniority and the contextually dependent features of the setting. Whilst allowing a degree of autonomous freedom in behaviour, the participants understood their responsibilities and the roles that they were expected to perform. The example below illustrates how knowledge distribution occurred through a variety of actors and media. There, a graduate engineer was asked to check on the particular characteristics of a concrete mould (known as ‘shuttering’) by the clerk of works (who was employed by the RE). According to company regulations, queries raised by the resident engineer or their staff should involve recording the problem, finding the answer, and filling out a ‘works record’, which would be sent to the site office, placed on file, and a copy sent on to the RE. Accordingly, the graduate engineer filled out a works record form with the problem request and sketched a diagram of the concrete shuttering and the setting it was placed in. He telephoned [someone] off-site, and discovered that the information he needed about using the shuttering was in an advertising/promotional
leaflet sent out by the shuttering company, and which had just been sent on to be held on file in the team’s office. Almost immediately, he noticed that this leaflet was lying on one of the foremen’s desks, as he had been looking through it with an eye to ordering more materials. The engineer read off the technical details from a table on the leaflet and added this information to the form. He then posted the works record to the site office for circulation. As the works record was an official form, no accompanying contextual information was required because the nature of this structured document meant that it would always be processed in the same way. Due to the slow speed of the internal postal service, the engineer later went back on site, located the clerk of works and reported his findings personally.

The example demonstrates how the members of the local functional system (in this case, the graduate engineer, unknown telephone informer, foreman, clerk of works, and resident engineer) created and used representation-bearing artefacts ‘on the fly’ (the work record, the teams’ file, sketch, and leaflet). This involved the use of different channels of communication (spoken, postal, and telephoned), each with different qualities for the transmission of the information. This process was not specified in the operating procedures laid out by the construction company and was generated and interpreted creatively by the participants. In this way, the formal organisational structurefunctioned as an (incomplete) organising resource rather than a set of instructions, and it was loosely applied in the performance of work. It did not determine the physical actions required, which were selected according to a range of social, material and spatial factors. In this respect, it was creatively interpreted, rather than followed.

What is noticeable about the example is the way that the task involves both formal (i.e. established) work practices, some of which are given in the SOP, and an *ad hoc* approach to collaboration. Showing that work involves formal, or explicit, and informal, or tacit, features is not itself a novel finding in workplace studies (Grudin, 1994). Nonetheless, this activity differs significantly from the practices noted in previous DCog analyses of work, in which the formal characteristics of work are exaggerated because of the particularities of the situations examined. Recognising the unpredictability of work and the participants’ use of *ad hoc* work practices to deal with this is a critical feature of
examining work in the analysis of open organisational systems. This interrelationship between the formal and *ad hoc* work practices is important in understanding work. Whilst Hutchins (1995a,b) and to an even greater extent Fields *et al.* (1998) place emphasis on the formal or proceduralised aspects of work, they do not ignore the informal aspect of collaboration entirely. However, within open systems (as described in this paper), the participants’ ongoing orientation to the constantly shifting problem situation is central to their performance. The participants’ access to a wide range of resources and the flexibility in the management of their own work organisation means that the actors within the functional system may exhibit many unique, situation-specific solutions to the problems they face. Use of the DCog approach in these settings must reflect this lack of precedents in the workplace and the actors’ artful use of the resources at hand.

The example above was by no means an isolated incident; many of the activities observed on the construction project were arranged ‘on the fly’, emphasising the contingent nature of collaborative planning and the *ad hoc* methods used to achieve this co-ordination. In most cases, the standard operating procedures were used as a resource which the participants oriented their behaviour towards, but were not obliged to do so. Suchman (1987) addresses issues of rule use in detail; however this rule orienting behaviour is less apparent in the sorts of DCog analyses describing ‘closed’ systems where actors within the functional system have an obligation to follow rules, even though they have a degree of interpretation about which rules to apply and which of the limited available set of resources to bring to bear on the problem.

The cognitive ethnographer needs to be aware of the SOPs, but also needs to understand how these are socially mediated within the context. Whilst Hutchins is aware of this, social mediation is of far greater importance to collaborative action in wider settings than that described in earlier studies of DCog, which focus exclusively on transformations to physical artefacts and visible and audible co-ordination mechanisms. However, for the analyst, there is a greater degree of uncertainty in investigating how people use representations mentally because these are not open to direct inspection. Resolving this problem can only be achieved by an increased interpretive ethnographic element in analysis (*ref*, *ref*, *ref*). This may be supported by interviews with participants in the
functional system – retrospectively asking participants what they were doing or thinking. This interpretive investigation of social mediation is necessarily less ‘precise’ in showing how work is achieved than the direct observation of a visible representation, but is no less interesting as a cognitive phenomenon, or less useful to system designers. Indeed, the method of enquiry – ethnography – is not well suited to positivistic representations of human activity, and an analysis of ethnographic data that attempts to provide strictly ‘objective’ data is bound to provide, at best, only a limited and partial explanation of activity.

*Cycle duration*

The cycle duration on the construction and design of the temporary works was highly variable - in terms of the project as a whole, the work was expected to take three years; far longer than the cycles of navigational fix taking. However, within this project, a number of smaller problem solving systems could be identified, each of which could be examined as a functional system in its own right. These different classes of problem ranged from specific temporary works designs (such as scaffolding towers), permanent works designs (ranging from pile placement to whole bridge designs), individual concrete pours, and so on, taking place over widely differing time-scales.

Similar tasks could also take place over radically differing time-scales. These were dependent on the availability of information about the problem, the intellectual problem solving resources, and the physical resources available to the functional system. Examples of this are impossible to demonstrate with snippets of observational data, and it is perhaps unnecessary to attempt to do so. The three year example of the project is itself an ample demonstration of cycle duration in a design and construction project; work took place over an extended period of time, punctuated by periods of inactivity and intensive action.

For the cognitive ethnographer, the long duration of a project presents something of an obstacle: the complete design and construction project took far longer than the time available to study it. A three year long project is by no means unusual in the construction industry, and similarly long project durations are relatively common in industry in
general. It is therefore unlikely that a study could be made of the process as a whole within even a medium term research project. This must be contrasted with the observations and analysis of navigational fix cycle or cockpit behaviour, which could be measured in seconds or minutes. Whilst similarities exist in the abstract nature of problem solving itself, the practicalities of this difference between the two kinds of problems and settings could not be more different.

The implications of this for DCog are that the cognitive ethnography cannot be a complete study of the work process, but only a part of it. Data will have to be collected from before the period of study, and the analyst will have to envisage how it will be continued following the field study, by projecting their findings forward. In comparison to the previous studies of DCog, there will be little chance of looking at another problem cycle to see how differences occur. However, it is possible to compare the management of activities between two or more organisations - something that was done in the construction study, although not described here (see instead Perry, 1997).

4.2 Summary

The examples presented in this study clearly demonstrate some of its differences compared to ship navigation, aircraft cockpits and the other more limited situations in which we have seen problem solving examined through the use of DCog. Most noticeably, the work is heavily contingent, and the participants make extensive use of the wide range of representational resources that they find around them. The nature of this work of the functional system was that these were highly context-dependent and unpredictable. Whilst the engineers made plans, and organised labour and materials in an attempt to control the situation (the ‘planned’ component of activity), they were also constrained by the context within which the activity occurred. This involved adjusting their ongoing behaviours to the evolving circumstances on the site and making use of the resources available. This is not to say that previous studies of DCog did not account for this contingency, but that it is more exaggerated in open organisational systems and requires a greater degree of attention.
5. REFLECTIONS ON USE OF THE TECHNIQUE

The fieldwork vignettes presented above demonstrate how the computational architecture of the functional system arose through the relationships between the actors, where the transformation of problem situation into design solution involved a variety of computations. This was implemented within a distributed cognitive architecture that incorporated a number of actors with different skills and roles, in combination with a range of other representational media, and operating in an environment rich in resources that structured these transformations. The social and organisational co-ordinating mechanisms that brought representations together worked in concert with the physical resources and constraints of the setting to determine the outcomes of these computations.

The descriptions of action in the earlier sections focus on the informational transformations that take place, as representations are re-represented in various media. In most respects this is identical to the traditional form of DCog analysis. However, in this study, snapshots of activity were collected and presented from across a very large and distributed functional system, and through time. It is not the theoretical framework of DCog that differs in this then – the analysis is still of representations and processes, transformations and co-ordinations that allow aspects of the information processing structure of the functional system to be made explicit - but it does differ significantly in its practical application (limited by a small and incomplete data set) and theoretical interpretation (relying on a hermeneutic, interpretive research stance). In this sense, the description is less like a task analysis, in which a single episode is examined in detail (as with traditional DCog), and is more descriptive in the traditional sense of an ethnography, where the analyst selects representative aspects of the situation. However, what is being described is how representational transformations operate within these representative samples and extend into computations across the larger functional system.

In a study of a large and complex organisational system, such as the example given in this paper, data collection and its analysis will need to encompass the whole range of

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7 In the terms of ethnography, this is also confusingly known as its *representation*. Use of the word ‘representation’ is distinct in meaning to its use in DC, where it is applied to the symbol processing activities conducted in the functional system, and not by the analyst.
information processing activity that the functional system is capable of performing. As researchers examining these systems, we cannot fully specify the structure of the functional system. In the terms of cognitive science, the external symbol system derived will be incompletely specified and it cannot give us the granularity that Hutchins (1995a,b) provides us with in a formal, functional structure of the activity. In practice, the wide scope of the organisational systems analysis means that the ‘density’ of the data collected and the coverage of the analytic methods and approach is far lower than the standard DCog approach can provide us with. In a large organisation, we have no means of examining all transformational actions in the functional system. What it demonstrates is how, in the situations observed, the resources were applied to perform representational transformations achieving the system goal (or possibly failing to do so). Necessarily, some (possibly important) situations will not be observed (or be otherwise accessible) that are relevant. Moreover, the interpretative nature of ethnography does not lend itself to this worldview (Perry, 1999b). A realistic approach is therefore to do one of three things:

(i) We can reduce the activity examined to a subset of the complete activity. This is the kind of approach used successfully by DCog researchers to date. However, such an approach means that we cannot see how the activity within the organisation as a whole is performed.

(ii) We can accept that the level of granularity in the analysis will be lower, and that the descriptions of the actions performed will be less detailed. The analysis will explore the higher-level, organisational features of work rather than its practice. However, this approach means that we cannot look at the actual use of the representations and processes in detail. In many instances, this is what management and organisational analysts do, and in so doing, miss out the valuable roles that local practice and artefacts play in the performance of work.

(iii) We can focus on the significant actions that the participants and the ethnographer deem to be of particular importance to the performance of the functional system as a whole – whether it is particularly difficult, important to their co-ordination,
where they have particular problems, or have to perform repair functions (i.e. resolve breakdowns) in particular situations.

This third option is the one that we would advise, and have used ourselves in the fieldwork described in this paper. This allows a degree of scope for the analyst to select aspects of the functional system that are particularly significant to the participants, and to do a deep analysis of the representational structures involved. However, this will not provide a complete description of actions in the functional system, and may be prone to a degree of subjective bias in the actions selected for detailed analysis. It relies to a greater extent on the importance attributed to situations by the ethnographer and participants than the standard DCog approach, but this is generally an accepted component of interpretive research (c.f. van Maanen, 1988; Hammersley and Atkinson, 1995) and is not, by itself, a failing. The method of data collection – ethnography - and the analytic framework suggested provides a means of examining aspects of information processing in organisational systems. It cannot be treated as a total description of work, but is a means of getting a deeper understanding about the activity within its context.

The application of this third approach is influenced strongly by the key dimensions of difference highlighted earlier. We suggest several features in the analysis of open systems that differ from the traditional approach used by Hutchins and other DCog theorists:

1. The DCog analysis is useful in illustrating how and which resources are used, but field data can only be understood as an instance of problem solving activity - at another time, work may be performed very differently because the functional system has access to a wide range of resources. It should not be presented as a complete and systematic computational description of an activity in the way that Hutchins describes navigation or cockpit activity, because of the one-off uniqueness of the activity sequences observed.

2. Piecing together the component parts of the analysis is not a simple matter. Because of the size and complexity of the organisation being studied, the analyst will have to link a large number of interacting local functional systems (for example, the generation of the design brief or a materials order) together to form a picture of
higher-level problem solving (in the case of this paper, temporary works design). When doing the analysis, the cognitive ethnographer will need to identify which local functional systems form the ‘trajectory of work’ (Strauss, 1985), and to investigate these with an aim to linking them together in the final analysis of the functional system.

3 The cognitive ethnography cannot be a complete study of the work process, but only a part of it (over time, space and task) that is extrapolated to cover the whole problem solving cycle (a related point to 1 and 2 above). The analyst is unlikely to be able to examine another problem cycle to see how differences occur. However, it may be possible to study another organisation to compare activities. This should not be an attempt to validate the data through triangulation, but present a cross-cultural dataset: analysts should not attempt to produce absolute answers to questions about the organisation of work, but to provide a better understanding about the practices and organisation of work in context.

4 The nature of the problem in the situation studied will be ill-structured and, as a consequence, the participants will strive to understand the nature of this problem and their co-workers’ orientation to the problem and each other. The focus of the study is therefore as much on understanding ongoing system’s self-organisation as it is with directly looking at problem solving on the task. The analyst will need to pay increased attention to how actors in the functional system are made aware of ongoing, but problem-unrelated, situation monitoring so that they can self organise. This is related to the actor’s situation awareness which, we argue, must be considered as a core feature of activity in the functional system, even when it is not directly associated with a specific problem-solving event. Hutchins does discuss situation awareness (1995a), but only in relation to known environmental events: for example, when landmarks come into view, when observations are shouted down the intercom, when marks are made onto tables and charts or when actors within the functional system leave or join. He does not account for situational awareness in unexpected situations, because all of the situations he (and other DCog theorists) describes can be resolved using the existing methods of maintaining situational awareness.
There is a need to pay particular attention to how standard operating procedures are used as *resources* (c.f. Suchman, 1987), and not as behavioural *rules*. Indeed, Hutchins does not suggest that this should be the case: “the written procedures are not used by the members of the navigation team as structuring resources during the performance of the task, nor do they describe the actual tasks performed. Furthermore, if a system was actually constructed to perform as specified in the procedures as written, it would not work” (Hutchins, 1995a:178); however, in his *computational* descriptions of human activity, it is precisely this rule-following that is analysed – deviations from, and MMM, being discussed in purely ethnographic terms (i.e. not in the ‘pure’ sense of a computational account using DCog). In particular, the analyst needs to address how social interaction and negotiation are used to mediate action, and how *ad hoc*, or informal, approaches to dynamic problem situations take place. This places an increased importance on interpretive analysis – in the hermeneutic sense - where the ethnographer makes observations based on the experience of their immersion within the setting, rather than on direct observation and quoted examples. This is the stuff of a classical anthropological ethnography (e.g. Douglas, 1975), where the ethnography is not used positivistically as an objective means of showing what happened, but as the ethnographer’s interpretation of what took place - based on the available evidence. Interviews with participants, asking people what they often did or thought about their work systems are one means of doing this. However, we need to recognise that ethnography can be used successfully in situations where objective measures of the validity and reliability of the dataset are not possible. In ethnography, the instrument of calibration *is* the ethnographer, and as long as the data is not represented as the ‘definitive account’ of an activity, but an account of an activity, this should not present its users with a problem. What we propose then, is to promote the acceptability of a more ethnographic account of distributed cognition, recognising it for its limitations, but valuing its contribution to understanding problem solving activity in open systems.
7. CONCLUSION

DCog can be used as an analytic technique to structure and delimit the scope of the fieldwork. The framework of DCog allows the analyst to examine the computational nature of work, and the problem solving activity that occurs over a distributed group of individuals and artefacts. The analysis lies not in the abstract processes of work, or in a description of the communications that made work possible, but on how the work and its co-ordination are inter-linked through task performance. In this, we do not seek to radically alter the foundations of the DCog approach: DCog is a broad church and does not advocate adherence to a particular method or approach to gathering data about the functional system (Hutchins, 1995a; Hollan et al., 1999). However, as yet there are no well thought out methods to extend the approach beyond the areas that it has already looked into. This paper makes a contribution in this area and gives suggestions as to how this may be achieved.

The role played by DCog in the past has not allowed researchers to examine organisational systems outside tightly specified systems of activity. The possibilities that DCog offers as a framework cover a far greater range of applications than this because many organisational activities can be characterised as involved in information processing. We have therefore re-examined the methods used by Hutchins and questioned their appropriateness in these new domains. We challenge the methods that have so far been developed and apply the technique in these new contexts and application areas. It is important to recognise that this is not critical of the approach used in traditional DCog; rather it is an attempt to show how DCog can be applied to situations to which the traditional DCog approach (exemplified by Hutchins, 1995a) would not be possible to be used in.

A core difference between the sorts of distributed cognitive analysis performed in this study and the sort of study performed in closed systems is that we do not attempt to describe a complete computational structure for the functional system. Rather, we look to the framework of DCog as a means of exposing the most relevant information processing aspects of work (as judged by the fieldworker or workplace analyst). This is in contrast to
Hutchins, who has attempted to produce well-defined accounts of functional systems that capture most, if not all, of the information processing characteristics inherent in them. However, because of the characteristics of open systems, this is not a feasible option in these settings. The examples documented can only be particular instances out of a potentially infinite set of work practices. What the kind of examples presented in this paper as vignettes do, however, is to give an insight into collaborative problem solving behaviour and the use of artefacts in the performance of work.

Whilst the form of analysis advocated here for open systems cannot be as precise as that produced by an analyst working with what we have loosely called ‘closed’ systems, the approach is clearly of relevance to HCI, CSCW and organisational studies. Rather, it changes the remit of the analyst from providing a near complete specification of a problem solving activity into one that demonstrates how to focus the analysis of ethnographic data onto the informational component of work practice. This focus on information processing to show how representations and processes can be appropriated for use in performing and co-ordinating distributed problem solving activity has direct implications for systems design. This contribution builds a deep understanding of the role of information in work because it unites the social, organisational, psychological, situational, and artefactual aspects that contribute to problem solving. The value of this is that technology and organisational designers are able to see the interconnectedness of these factors in the work, and to envisage how interventions might have an impact on the information processing characteristics of the function system - either beneficially or harmfully.

The importance of these studies to systems design and CSCW lies in the descriptive power that they have in making explicit the collaborative problem-solving element of work. By seeking to understand the transformational nature of work, we can begin to design effective and appropriate technology for that work. Opening up the application of the DCog approach to a broader range of application areas is one way that we can help support this.
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