# The role of space in socially distributed cognition: some issues for cognitive engineering

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**Abstract**

This paper explores and identifies cognitive issues that develop out of the use of representational media by collaborating groups of people involved in problem solving. We take the analytic perspective of distributed cognition to examine the role that these artifacts have on information processing activity in augmenting human action and in transforming the problem space. The analysis is further used in identifying issues for cognitive engineering in the design of spatial, augmentative resources to support collaborative problem solving.

## Introduction

A key paradigm within cognitive science is the notion that mental activity involves symbol manipulation in computations that allow us to traverse problem spaces. One of the things that humans can do is to externalize these symbols into the world to change the representation of the problem spaces and to make more effective use of the limited cognitive resources that we have available to us. This can both amplify our abilities, for example by increasing the size and reliability of our memories, through, for example a checklist, but it can also transform the nature of the problem (see Cole, 1990; Norman, 1991) to one that we are more easily allocate our mental resources to in its resolution (an isomorphic problem, but with a problem space that is organized differently). The design of computer-based tools to support and take advantage of this is known as cognitive engineering, and this is an important applied area of research for the discipline.

As well as being able to distribute problems over an individual and a (set of) tools, humans make use of another important resource – other people. Symbolic manipulations on group problems are carried out in much the same way as they are by individuals – the difference is that the way that the symbols are externalized and their manipulations are coordinated between the diverse participants involved in the problem solving activity. One of the most common representational forms that these symbols are encoded into is language – and in particular, speech. However, humans also make use of several other forms of physical symbolic structures in the world in their communications with one another. Common forms of these include paper documents or physical reminders or pointers to one another. Simple physical manipulations to these artifacts in the environment - by one or more people - result in a transformation to their informational status as a symbolic representation, and several successive changes to their representational state may result in goal resolution.

Space is an important organizing principle in the use of artifacts and the representational states that artifacts embody, yet it is a little understood, and under-researched area of interest, particularly given its applied importance in the design of computer systems that are intended to augment problem solving activity – both as individuals and working in groups. Whilst some research has been published on the role that space plays in supporting the activity of individuals, this is not the case (at least as an explicit aim) for supporting problem-solving activity by groups. In order to better understand how groups of people perform problem solving, this paper takes on the theoretical perspective of distributed cognition: this is briefly introduced in the following section.

## Socially distributed cognition

The form of distributed cognition advanced here (differentiated as "DCog" to distinguish it from other disciplines that have appropriated the term) has adapted the framework of individual cognition to explain how cognitive resources are organized within a context, drawing on multiple actors and other representational and non-representational elements in the environment to perform problem solving. Hutchins calls this 'socially distributed cognition' (1995a). Socially distributed cognition describes group activity in the way that individual cognition has traditionally been described - computation realized through the creation, transformation and propagation of representational states (Simon, 1981; Hutchins, 1995a). Central to this is the idea of work being distributed over a range of media and over a number of people. It is concerned with representational states and the informational flows around the media carrying these representations. The goal of a DCog analysis is to describe how distributed units are *coordinated* by analyzing the interactions between individuals, the representational media used, environment within which the activity takes place (the *functional system*). The DCog framework allows researchers to consider all of the factors relevant to the task, bringing together the people, the problem, and tools used into a single unit of analysis – although notably, DCog takes an explicitly cognitive stance on symbolic manipulation. This makes it suitable for developing an understanding of how representations act as intermediaries in the process of collaborative work. It is therefore an ideal method to use to discover the artifactual, social and cultural dimensions of work.

By performing simple manipulations on external resources, humans can logically process information without performing logic operations in their heads (c.f. Rumelhart *et al*, 1986). Preece, Sharpe and Rogers (2002) describe the process of 'external cognition' as people creating and using information in the world, rather than simply within their heads to do three key things. These involve externalizing information to *reduce memory load* (such as reminders), to *simplify cognitive* effort by 'computational offloading' onto an external media, and in allowing us to *trace changes*, for example over time and space, through annotation (such as crossing items off a list, or marking progress on a map) or in the creation of a new representational form to reflect this change. Whilst this description is a good characterization of how external cognition operates, at least for an individual, DCog attempts to place a stronger theoretical framework around this. The key to understanding the application of DCog is in its use to uncover how systems coordinate transformations on representations in *goal seeking* behavior. Bringing representations into co-ordination with one other involves a process of mapping a representation from one media onto another. This co-ordination may be at an individual level, as an individual creates or manipulates representations, with a focus on the co-ordination of how the representation is propagated between the representational media in pursuit of their goal, or at a group level, with a focus on the co-ordination of representations that are propagated between individuals through a variety of media.

The aim of DCog is therefore to understand how intelligence is manifested *at the systems level* and not the individual cognitive level (Hutchins, 1995a). Analysts require a means of describing the components within this system to explain the mechanisms that co-ordinate groups of collaborators. In cognitive science, these properties are described in terms of the representations and computational processes of individual thought. This cognitive framework can theoretically be expanded to examine larger units, to include individuals interacting with external representations, and the interactions of multiple individuals in a work setting. DCog analyses have been used to examine the cognitive properties of airline cockpits (Hutchins, 1995b), navigation systems of naval vessels (Hutchins, 1995a), air traffic control (Halverson, 1995), shared CAD systems (Rogers & Ellis, 1994) and collaboration between programmers (Flor and Hutchins, 1992) amongst others.

One of the most important features in the analysis of socially distributed cognition are the objects that support co-ordination (also known as common artifacts, coordinating representations or boundary objects in different academic disciplines). These artifacts are involved in making information publicly available and help create a 'shared awareness' between the actors in a distributed cognitive system. These artifacts allow problem solvers to co-ordinate their behaviors and bring their individual work contributions together, to interact with one another *through* the object itself, as collaborating participants' activities are mediated and rendered visible through them. Yet the objects of coordination do not simply exist socially – they exist within real spaces, and these spaces carry meaning and provide particular constraints that support (or in a broad sense, 'afford') particular forms of use and suggest particular interpretations as to their meaning. It is this these spatial qualities that are imbued in the use of artifacts that we examine in the next sections.

## Environmental setting: a cognitive resource

Little attention has been paid explicitly to the role of space within socially distributed cognition although it has been indirectly acknowledged as an important factor in a number of DCog analyses using the broader reference of 'context'. The reason for this appears to be the core focus of DCog on the internal structure of external representations, and the transformational role that these representations play in problem solving. This is not to say that internal structure of cognitive artifacts is unimportant, but the spatial context within which these cognitive artifacts are used has an importance that has, so far, only been acknowledged in passing.

One of the main papers that space has been addressed in supporting cognitive action is Kirsh's (1995) seminal work on the topic – however, even here, the cognitive role of space is applied solely in reference to its support of *individual* cognition. Whilst several of the factors noted by Kirsh about the role that space has in supporting the individual can be extrapolated from to show how they would support the activity of a functional system composed of several individuals, the domain is theoretically rather barren. In order to better understand the role that space plays in organizing human action at the level of an individual, the next section discusses Kirsh's work on the 'intelligent use of space'. At the core of Kirsh's argument is the role that space plays in supporting cognitive behavior, and the notion that our externalized structuring actions reduce the descriptive complexity of our environments and simplify the cognitive complexity of the world. The three main elements that Kirsh describes that are of relevance to this paper are discussed in the following sections.

### Using space to simplify choice

Humans use cues and constraints from their environments to support their cognitive activities. Decision problems are made combinatorially less complex by information 'read' from the environment, and Kirsh describes three ways that this can occur:

a) Reducing the number of perceived possible actions at decision points. This can be achieved through making use of the affordances of objects, either by 'hiding' affordances (constraining what is feasible, otherwise known as a *forcing function*–Norman, 1985), and 'highlighting' affordances (cueing attention to one approach).

b) Simplifying perceived possible actions, thereby reducing the need for previously necessary decisions. This is achieved by substituting choice with compliance in the design of the representational artifacts and the constraints of the space within which they are used.

c) Creating arrangements that act as heuristics to indicate the desirability of an action. An example of this is the use of linear space to encode the temporal order of actions (with the result of offloading memory into the environment).

### Spatial arrangements that simplify perception

This involves reorganizing arrangements of objects within space to facilitate perception. Again, Kirsh suggests several approaches used to achieve this:

a) Clustering to categorize, highlighting the similarities between entities, allowing groups of things can be categorized by factors such as similarity or purpose. This works because it is harder to 'lose' big things than small ones (especially in a visual search), or to forget the function of the larger group of things,.

b) Symbolic marking allows us to draw attention to, or provoke recall of things; we can monitor the informational state of an item in a task, or signal its importance through symbolic marking - although we *cannot* display what that marking means (for example, placing one of a series of posit-notes on its side to mark it as being particularly important).

c) Finally, clustering is used to support perceptual recognition: similar things tend to look alike (within certain contexts). To discriminate between items, they can be grouped into categories by similarity, and then searched within those categories so that the differences between the grouped items are easier to pick out.

### Saving internal computation

This last factor involves the computational exploitation of the physical form of objects within an environment involving a "visual cue that serves to make the property of the physically displayed entity in question explicit.

a) Problem solving computations can be offloaded onto physical manipulations on objects. For example, moving an artifact is cognitively simpler (quicker and less error prone) than mentally 'rotating' it.

b) By externalizing representations, we can perform 'perspective flipping' (i.e. trying out conjectures). This allows us to open up ideas to computations that are far more complex when mentally conducted.

## Group artifacts in space

The role that space plays in social interaction is hugely complex and beyond the scope of this paper. It has been addressed by a number of disciplines with different focal perspectives, ranging from social psychology and ethnomethodology to human geography. For the purposes of this paper, we examine the role of space in the use of artifacts through its influence on the creation, interpretation and transformation of those artifacts, and the cognitive impact of this on problem solving within the group.

There are a number of ways that space can itself be used as an organizing resource in support of group function – forming an important part of the *architecture* of the distributed cognitive system. One of the more obvious distinctions is that between items located within preconfigured (designed) spatial arrangements (e.g. item placement within vertical or horizontal visual displays) and arrangements of items within previously non-configured spaces (e.g. ongoing arrangement and categorization of written ideas into separate piles of paper). Kirsh (1995) respectively refers to these 'pre-structuring' and 'jigging' – and this has clear links to ill-structured and well-structured problem solving (cf. Simon, 1973).

The internal constraints (or affordances) of the artifacts used and the constraints understood to be common to by the actors within distributed cognitive system (or their 'cultural affordances') provide opportunities for appropriation of those artifacts for behavioral functions, and in the case that we are interested in, in the organization of action within a socially distributed cognitive system.

## Supporting research framework

As a means of identifying the role that space plays in the use of artifacts, we have turned to real world data collected in a series of ethnographic field studies. However, we do not present the full data set given the extended and discursive nature of ethnographic observation and its representation These studies were conducted in office-based environments looking at artifact use in the design process within meeting rooms and group areas. Whilst this domain (design) and the particular locations examined are not necessarily representative of the totality of collaborative artifact-based problem solving, this data provides a useful perspective onto, and grounded findings for the area. Ethnography has developed within the disciplines of sociology and anthropology as a technique for gathering naturalistic data. At its core, the ethnographic analysis provides a means of exploring *how* work is organized (see Hammersley and Atkinson, 1995 for an overview).

A huge range of artifacts and resources were used in the coordination of the groups observed and in the performance of their work tasks. To list a few, these included paper (as printouts, drawings, sketches, photocopies, notebooks, post-it notes and loose leaves), whiteboards and foam-boards (for sticking and pinning materials onto). In some respects, it might appear that the meeting room seems to be something of a desert in respect of tools for social interaction, but even the simplest of these resources provide support for the manipulation of cognitive resources within the environment.

The majority of group-working tools used by the observed participants within these settings were non-computational (in the sense of digital technology), although email and (to a lesser extent) web pages were used. This was particularly evident in face-to-face working, which was largely supported with paper-based (A4 paper, post-its, etc.) and paper-like materials (e.g. black/whiteboard), and other simple resources available in offices (tables, chairs, wall-space, etc.). This was not to say that all of the collaborative activity that was observed was verbal with the available informational resources being used as simple memory aids. The participants' behavior was far more subtle and complex than this, making effective use of artifacts to coordinate and drive collaborative action.

## Use of space to orient problem solvers to a common perspective

Perhaps the most obvious aspect of using spatially organized artifacts is that they are available to all of the actors within line of sight. They can be referred to in speech and pointed at (deixis), adding contextuality to speech. At a basic level, this is used as a mechanism as actors try to maintain a single perspective with which to interpret inputs into and representations within the cognitive system. We identify three characteristics of this factor that focus the orientation of problem solvers onto a common perspective:

- *Visibility to all*: factors that are taken to be critical to a discussion (both of its content and structure) can be made explicit and represented (semi-)permanently within space. Depending on the shared areas' spatial configuration, information can be oriented to show to only those people within visual range as a filtering device; this can be used to cut down the complexity of the problem in the division of cognitive labor across the larger group. This element integrates with the mobility of people as they physically move within a space. In terms of DCog, this simple reorganization of information and individuals in space to re-orient themselves to information involves a change to the functional architecture of the cognitive system.
- *Visibility of the perspective of other actors*: the visibility of artifacts (see previous point) and the visible orientation of other problem solvers to those artifacts provides actors with cues to interpreting the division of labor (i.e. the computational structure) in the distributed cognitive system. This allows them to organize and optimize their problem solving activities so that there is less likelihood of unnecessary redundancy of effort, and to initiate communication pathways directly to those people that their individual or collective work processes are likely to butt against. This can be observed at a number of levels, as people orient themselves towards general areas of interest, or towards particular areas of informational content within an artifact or set of artifacts.
- *Externalized collective 'memory'* – the generation and display of artifacts provides a focus for those present that is retained over time, and which can be referred to, reorganized, brought into focus, transformed and placed back into the background again. It is also possible to restructure displayed content so that associations can be created for searching within that content. The residual visual artifacts left behind in the process of working on external representations also provides a 'view' back into the problem solving process to see how decision had been made, and allowing the problem solvers to discuss their decisions and collectively step back through the process to renegotiate issues. The spatial aspect of material on display allows a 'zooming' effect to be applied in which items can be *physically* moved into the foreground or background. This can be loosely compared to human working memory and long-term memory in terms of its utility in information processing, with similar (but *physically* constrained) limits on the number of (literally) 'chunks' of material displayed in close proximity for detailed examination.

## Using space to structure social organization

Aside from the role of visibility in providing a focus for social organization, actors within a distributed cognitive system can use space as a resource in structuring the division of their cognitive labor. Three important elements regarding this are addressed below:

- *Organizing the parallelism of collaborative work processes* - physically present artifacts can be used as cognitive resources in different concurrent activities. Conversely, this means that they can accidentally be used concurrently, and whilst this redundancy is often useful, this duplication of effort can also add to the workload of the problem solvers. By manipulating the proximity and access to artifacts and people within a space, this physical access to resources can effectively structure the computational architecture of the cognitive system. The time and effort costs of this can be lower than doing this organization explicitly through negotiated agreements. It also allows for a greater degree of flexibility and contingency because spatial arrangements can be more easily and simply changed than explicitly and verbally renegotiating task responsibilities, lines of communication and individual workloads.
- *Physical distribution of work* – The ability of artifacts to be moved within space allows them to be removed from a common space to a private one (or even to 'create' a private space without changing the physical display through behavioral cues and body posture around it). This public-private transition provides a physical instantiation of the division of cognitive labor in the distributed cognitive system – representation-bearing artifacts cannot be worked on easily if they are not accessible. Moreover, the fact that artifacts may be visibly not present (for example, leaving a gap in a display space) or currently being used within a public space provides a clue to other problem solvers that this task is being worked on independently, and that they should organize their own work activities around this. As an example of this, we have seen displayed materials (foam boards) physically assigned to people with the delegation of work complete when all of the materials have left the display space to be worked on individually.

### Using space to structure collaborative computations

Spatial arrangements can be used to configure collective computational action within the distributed cognitive system. Three characteristics that support this are described below:

- *A unique physical reality* – physical space allows only one current solution of arrangements, unless material is duplicated. This is particularly important in work involving categorization in which material can be ordered in multiple ways.[1] Whilst different problem solvers involved in the activity may *interpret* the layout of the artifacts in space, this interpretation is an order of magnitude of complexity lower than there being no unique visible representation of its structure.
- *Spatial placement constrains the order of action* – materials can be physically ordered and re-ordered into structures embodied within the physical environment. Stacking, or ordering, artifacts presents the viewers of an information-rich space with a linear structure of the items in it for discussion and working on. Pre-structuring the environment places constraints on the use and interpretation of the representational artifacts that are intertwined in these embodied networks. For example, a post-it note stuck on a document requires its examination and removal before the material underneath it can be read - this may affect the interpretation of that material. Space is also dynamic reconfigurable allowing the re-structuring of materials within it in an ongoing manner, thus supporting *sequential* rearrangements of the problem space. An example of this was seen in the fieldwork, in the way that the foam boards were arranged around a team room. Each foam board contained all of the paper-based artifacts related to a single design concept. This ordering of the foam boards around the room embodied the ordering that was used to create a narrative for a client presentation.
- *Structural arrangements map conceptual arrangements* – spatial organization allows cultural or socially determined symbolic meanings to be made explicit. Humans have developed conventions for interpreting and making use of these, for example in western culture, linear developments often follow the convention of written text – starting on the left, moving to the right, and moving progressively from the top to the bottom of a visual space. These need not always be culturally determined – for example, a local agreement could be made that the left and right side of a space carry a common symbolic meaning. In a simple example from our fieldwork, one design team used different locations in their project space to categorize ideas, placing ideas on pieces of paper that were categorized as being weak in a distant corner.

## Engineering artifacts and spaces to support cognition

Whilst this work is clearly interesting in and of itself in understanding the role of space in structuring the computational architecture of socially distributed cognitive systems, this understanding clearly has an applied dimension to it. As designers of our own spaces, both physical (in terms of architecture and managerially in providing physical resources to problem solvers) and virtual (in terms of the computer-based technologies that we can design in support of people working in real and virtual spaces) we can use this knowledge to augment socially distributed problem solving that is mediated through spatial arrangements. If we take the three key factors raised in the paper, each

[1] This can be a drawback: visualizing material simultaneously in multiple ways can also be useful in searching for multiple solution pathways, and this can be supported by a variety of computer tools.

of these has important design-related consequences in building spatial environments and technologies:

1. *Visible presence*: space has an important role in providing an orientation to the available artifacts and other individuals and their role within the problem-solving situation. However, it is not only making the artifacts and other people visible, but making visible the historical and social context of problem solving. Moreover, physical manipulations to artifacts within space do not require an abstract knowledge of information within the artifact, and physical effects such as 'zooming' have simple yet powerful consequences in focusing group attention.

2. *Organizing effort:* the location and movement of artifacts within space has important consequence for the division of labor within problem solving groups. Spatial cues and constraints are used as mechanisms for the allocation of tasks and shared knowledge about the computational structure of the group. We need to support this simple approach to spatial organizational in collaborative problem solving through the design of appropriate spaces and technologies.

3. *Spatial structure:* space is used in the ordering and categorization of information within it, forming a physical informational 'state' of the cognitive system. Simple methods of allowing visible structuring, restructuring and association are clearly of relevance.

## Conclusions

The paper presents a critique of the current understanding of the use of space in cognitive science, discussing three cognitive functions that space supports: the use of space to orient problem solvers to a common perspective, in structuring social organization and in structuring collaborative computations. This develops and extends previous work by Kirsh; however, when we reexamine Kirsh's work, several aspects apply equally to patterns of activity in a socially distributed cognitive system (the use of space to simplify choice, spatial arrangements that simplify perception and in saving internal computations). Interestingly there is a difference in the way that these are applied in socially distributed cognition, in that these patterns of activity are typically mediated through social and cultural norms, and explicitly agreed up protocols generated in the course of the artifact's use, and are not applied in the same way as might be the case for an individual, although functionally of a similar equivalence.

The research presented in this paper is not intended to be an exhaustive discussion of the role that space plays in structuring and forming cognitive processes within socially distributed problem solving groups, but it is intended to highlight what we have seen as important issues arising from our data collection, and to challenge researchers about their assumptions within, and their use of cognitive theory in this domain. The role of space clearly requires a great deal more consideration than it has so far received in terms of its impact on collaborative problem solving behavior.

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