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# Manufacturing in the wild – viewing human-based assembly through the lens of distributed cognition

Jessica Lindblom<sup>a</sup>  and Peter Thorvald<sup>b</sup> 

<sup>a</sup>School of Informatics, University of Skövde, Skövde, Sweden; <sup>b</sup>School of Engineering Science, University of Skövde, Skövde, Sweden

## ABSTRACT

The interdisciplinary field of cognitive science has been and is becoming increasingly central within human factors and ergonomics (HF&E) and, since at the same time, there has long been a call for a more systems perspective in the area with a somewhat wider unit of analysis. This paper argues that the theoretical framework of distributed cognition would greatly benefit the application of HF&E to manufacturing and would offer a more holistic understanding of the interactions between different entities within a greater context, including the social, cultural and materialistic. We aim to characterize and analyse manufacturing as a complex socio-technical system from a distributed cognition perspective; focusing on the use, mediation and integration of different forms of representations, tools and artefacts in this domain. We present illustrative examples from authentic manual assembly, showing the cognitively distributed nature of the work, ranging from scaffolding strategies of the individual worker to the emergent properties of a whole assembly line. The paper further proposes and provides benefits of using a distributed cognition framework as a novel approach in the toolbox for the HF&E discipline, where it may have been found before, but the application to manufacturing has been absent.

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Distributed cognition; DCog; scaffolding; socio-technical systems; human-based assembly; manufacturing

## 1. Introduction

It has been widely acknowledged that an increasing number of researchers are calling for a more unified view of human cognition in the fields of Human Factors and Ergonomics (hereafter abbreviated HF&E) (Feyen, 2007; Karlton, Karlton, Berglund, & Eklund, 2017; Marras & Hancock, 2014; Thorvald, Högberg, & Case, 2012). However, many authors, while claiming to be champions for a more systems view of human cognition (e.g. Marras & Hancock, 2014), still use and refer to traditional information processing models of human cognition. Theories and models that view the human brain as central and the body as well as the social and material environment as mere problem spaces, or as best as external resources. This is opposed to studying the processes humans enact when interacting with

**CONTACT** Jessica Lindblom  [jessica.lindblom@his.se](mailto:jessica.lindblom@his.se)

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real material media when they cognize in the world, and how interconnected humans and their social and material environment are and strongly influence each other. Marras and Hancock's (2014) human-systems approach, for example, seems at a first glance to take a systems perspective, but when taking a closer look, we argue that this is merely putting an embodied icing on the traditional 'mental gymnastics' (Chemero, 2009) cake of traditional cognitive psychology, by only focusing on the individual cognizer.

For quite some time, the late prominent scholar Wilson (2000, 2014) has called for a more systems view of HF&E where humans and their actions should be understood within their contexts. Generally speaking, he questions several significant assumptions and perspectives in the HF&E community, and among many things, he specifically argues against the traditional dismissal of, primarily social, *context* within HF&E. He addresses the necessity to widen the unit of analysis, and the need for adding and complementing theoretical and methodological approaches within HF&E, in particular with contributions from the cognitive science field. He emphasizes that the (re)discovery of the importance of context also has parallels in the new advances within cognitive science that moves away from explaining and studying cognition as purely bounded 'within the skull' to being a science of mind that 'puts brain, body and world together again' (Clark, 1997). One of Wilson's (2000, 2014) main points is the change in the unit of analysis from the traditional cognitive psychologist's view where the individual is the focus of research whereas the topic of HF&E calls for a more systems approach. He argues that the unit of analysis should be expanded and should focus on the interactions between individuals, tools and contexts, i.e. having more in common with anthropology, where the unit of analysis is often at the level of interactions, than with traditional cognitive psychology. Consequently, he emphasizes that 'Within ergonomics, the unit of analysis should be the distributed cognition, the thinking which goes on amongst people and their computer systems distributed over space and time' (Wilson, 2000, p. 562). This without neglecting the necessity for circumstances where the unit of analysis should be the individual, given that much may be discovered from individual humans' behaviour and performance using scientific methods such as carefully controlled laboratory experiments. On the other hand, he puts forward that contrived experiments mostly hinder interactions as they unfold naturally in work practices that may result in reliable findings about a small feature of human behaviour, but which may have little significance in real-life settings as the vast amount of real world interactions that influence human performance are factored out. Wilson (2000) explains that the increased interest of ergonomists in ethnographical approaches, when the unit of analysis is 'interactions in the wild', strongly arguing that field research is fundamental 'for the core purpose of ergonomics, investigating and improving interactions between people and the world around them' (p. 563), which requires integration both within the HF&E discipline and with other disciplines.

However, Wilson (2000) stresses that there are some identified risks in taking a systems perspective in HF&E. Firstly, studying and investigating a systems level may mistakenly imply that researchers are dealing with a number of constituent parts rather than being holistic, thereby neglecting the emergent properties at the systems level. Emergence can be characterized as a process where larger patterns and regularities arise via interactions among smaller entities that themselves do not exhibit such properties. An emergent property of a socio-technical system, in the context of manufacturing, is one that is not a property of any entity of that system, but is still a feature of the system as a whole. This means that an emergent behaviour can occur when a number of smaller entities (e.g. humans and

artefacts) operate in an environment, thereby forming more a complex behaviour on a collective level (e.g. Clark, 1997). Secondly, if the level of analysis is too high and superficial, then researchers are running the risk that the outcome lacks significant value. Thirdly, the spectrum from ‘not seeing the trees for the wood’ to ‘not seeing the wood for the trees’ is an issue that pushes HF&E researchers and practitioners to decide proper levels of analysis initially. Fourthly, the contemporary view of any work activity should be considered as part of a network, paying attention to the *interactions* in the whole network where ‘there is a team of people, distributed over time, space and function, working with a multiplicity of display formats and signals to meet a number of different goals and targets’ (p. 563). In other words, the study of interactions within complex socio-technical systems is the fundamental and critical focus for ergonomics understanding and contributions.

It should be noted that many models of HF&E have highlighted the interactions between people, products and environments (e.g. Stanton, Salmon, Walker, Baber, & Jenkins, 2005), but their major focus on redesigning certain user interfaces, equipment or workspaces, have resulted in the production of many tools and frameworks in order to examine and measure interactions, with the intention of doing substantial improvements of the current work performance. Instead, HF&E practitioners should now study interactions not simply to design artefacts and workspaces, but also to understand the interactions themselves in order to grasp and clarify the more diffuse and complex socio-technical systems, which is the fact in many current work places (Wilson, 2000, 2014). During the years, various frameworks that present and define elements of complex socio-technical systems in HF&E, from a so-called *Cognitive Systems Engineering* (CSA) perspective, have been proposed. To mention two commonly used; *Cognitive Work Analysis* (CWA; Rasmussen, Pejtersen, & Goodstein, 1994; Sanderson, 2003; Vicente, 1999) as well as *Joint Cognitive Systems* (JCS; Hollnagel & Woods, 2005; Woods & Hollnagel, 2006) are made rather prominent. On the one hand, CWA is a broad framework that includes the design, development and analysis of complex socio-technical systems, assuming that these systems are dynamic with changing goals, work procedures and unanticipated events. CWA focuses on defining the boundary of the system rather than characterizing the trajectory of task procedures within the system. CWA views the system as adaptive, but closed-looped. In order to identify the boundary of the system, CWA provides five phases of analysis. The main purpose of the five phases of analysis is to decompose the socio-technical system in terms of its elements from different perspectives. The phases can be used individually or combined, depending on the type and scope of study. CWA is considered flexible to use, the various methods in the phases provide a toolkit to select from, and it has been appreciated in many studies that have used the framework. However, the flexibility of CWA can make it difficult to apply in practice, and it has also been criticized for being rather complex to apply as well as time consuming (Nilsson, 2010; Sanderson, 2003; Stanton et al., 2005). On the other hand, JCS focuses on the analysis, design and evaluation of complex socio-technical systems, and considers how external functions of the co-agency of human and machine can be described and comprehended (i.e. conditions for work, its constraints and resources). A major focus is on how JCS can be designed to effectively control and function in the intended work situation. The underlying principle in JCS, according to its founders, is that cognition is distributed through the operators’ coordination and cooperation with each other, since they are embedded in larger groups and organizations (Hollnagel & Woods, 2005). The major focus is on what JCS does (performance) and why, in order to improve

design. However, JCS has been criticized for not including the environment in the unit of analysis, given that the environment provides an understanding of the content and performance characteristics of the JCS. This way of working may result in a difficulty to portray why a certain joint function happens (Nilsson, 2010; Norros, 2014). It should be noted that although both CWA and JCS have the word ‘cognitive’ in their designations, they do not particularly stress either the role and relevance of cognition or the situated context of the socio-technical system. A promising step towards analysing cognition systems in context at nuclear power plants was taken by Mumaw, Roth, Vicente, and Burns (2000), although they are still not fully applying the DCog concepts in their analysis and are therefore not considered a full blown DCog study.

The manufacturing domain has primarily been researched from a work performance perspective by HF&E, rather than by human–computer interaction (HCI), cognitive science or related areas. Manufacturing can be considered a complex socio-technical domain where humans, technology and artefacts together form a holistic system. Information at the shop floor flows between different media, different roles (assembly workers, production leaders, technicians, maintenance, etc.), and separate locations at different time scales. In manufacturing, much information is shared, stored and retrieved and it is crucial that correct information reaches its target at the right time to the right person (Thorvald, 2011). Moreover, the domain is highly error sensitive, it is therefore critical for work processes to run satisfactory to avoid errors and other irregularities. It is a fact, whether known or unknown, that tools and artefacts mediate many of the actions and tasks that we, as HF&E specialists, investigate on a daily basis. Following the line of arguments put forward by Nardi (1993), for example, who argues that in reality there are no lonely users struggling in isolation, instead they make good use of other humans in their social environments to help them solve problems and compensate for gaps in their knowledge. Similarly, Rogers and Ellis (1994) argue that generally much work activity is cognitive, there is a major need to study cognitive and social activities of people that occur in workplaces as well as the material resources they use while performing their work practices.

This paper aims to characterize and illustrate manufacturing as a complex socio-technical system from a distributed cognition perspective; focusing on the use, mediation and integration of different forms of representations, tools and artefacts in this domain. The theoretical framework of distributed cognition presented by Hutchins (1995a, 1995b, 2010) suggests that cognition should be studied ‘in the wild’ as it naturally unfolds. Along with the views proposed by Halverson (2002), from here on we will use Hutchins’s theoretical framework of distributed cognition (Hutchins, 1995a, 1995b, 2010) abbreviated as DCog to refer to his theoretical framework, while written out it will refer to the general phenomena of cognition being distributed. The concepts and arguments put forth in this paper are true to Hutchins’s original work and omit approaches that deviate significantly from his original focus on the cognitive system. For example, the DIB method (Galliers, Wilson, & Fone, 2007) is too constraining to capture the different aspects of DCog because it involves creating a requirements list that may lose the holistic perspective of DCog. The translational cognition approach by Patel, Zhang, Yoskowitz, Green, and Sayan (2008) also lacks proper alignment with the core theoretical concepts of the DCog framework. It should be pointed out that the original DCog framework views cognition as a socio-cultural process, which is distributed in complex socio-technical environments. It also offers a shift from studying individual cognizers to studying the whole functional system, including the people, the tools

and artefacts that they use in order to perform their work and cognitive activities. In our opinion, DCog fits hand in glove with Wilson's request for a systems approach for studying complex socio-technical systems, offering the desired characteristics by providing a holistic and emergent perspective. It focuses on interactions between entities, widening the unit of analysis beyond the 'individual skull' combined with a major emphasis on the cognitive processes and the social context, and is conducted 'in the wild'. From this perspective, it is rather surprising that Wilson (2000, 2014) did not mention DCog when he promoted and favoured the new advances in the cognitive science field. The intended contribution of this paper is to offer another powerful cognitive framework in the HF&E toolbox for studying and explaining complex socio-technical systems from an emergent and holistic perspective. It should be noted that there are past studies applying distributed cognition approaches to HF&E (i.e. Blandford & Furniss, 2006; Furniss, Masci, Curzon, Mayer, & Blandford, 2014, 2015) but this is done in a medical context and proper application to manufacturing seems absent.

The remainder of the paper is structured as follows: The next section provides some historical and conceptual background that will be useful in motivating and framing the work presented in this paper. We stress the importance of offering a description of the underlying theoretical and philosophical assumption of the new theoretical advances in the cognitive science field. Furthermore, we present concrete illustrative examples from manufacturing, where several examples of how different forms of representations, tools and artefacts that are used in manual assembly are described and analysed from a DCog perspective. The final section then summarizes and discusses the work presented here, and also briefly addresses some future work.

## 2. Background

This chapter will first describe the theoretical advances in the cognitive science field in later years. Then the focus is on DCog and how the socio-technical systems perspective of cognition 'in the wild' allows for a wider unit of analysis, which in turn can provide insights and benefits to the applied study of manufacturing. To our current knowledge, application of the new advances in cognitive science to the manufacturing domain is scarce, not to say non-existing.

### 2.1. Situating cognition in context

How human thinking works is the major research issue addressed in the interdisciplinary field of cognitive science, which strives to provide explanations of how to characterize and study human cognitive abilities, e.g. memory, decision-making, reasoning and problem solving, as well as how these abilities are organized. Traditionally, cognition has been described as mental information processing that takes place inside the human brain, following the so-called *computer metaphor of mind* (Card, Newell, & Moran, 1983; Fodor, 1975; Neisser, 1967, 1976; Pylyshyn, 1984). In the computer metaphor of mind, cognition is considered to be symbol manipulation of internal mental representations, designed to produce an outcome on demand, viewing cognition as a kind of 'mental gymnastics', using Chemero's (2009) terms, where the body is reduced to an input and output device. As pointed out by Barrett (2015), the emphasis on the idea that the brain is a kind of computer (then claiming that



the ‘brain’ is synonymous with the ‘mind’), detaches the brain from both the body as well as the material and social environment. By this way of working, the intimate connections that exist between them is ignored and removed for the level of analysis, which is considered a theoretical failure of nerve from proponents of alternative explanations of cognition that do not follow the traditional dichotomy of mind vs. body. Barrett (2015) further emphasizes that we should be sceptical of relying too heavily on the computer metaphor of mind since it is not derived from a naturalistic view of cognition and behaviour.

In recent years, the cognitive science field has introduced more elaborate views on cognition, which Marsh (2006) refers to as DEEDS (Dynamical, Embodied, Extended, Distributed, and Situated) theories of cognition that have entered the scene. In a similar vein, Barrett (2015) refers to 4E-cognition (Embodied, Embedded, Enactive, and Extended), arguing that although they differ from each other in a number of significant ways, all DEEDS and 4E-approaches share and have in common the idea that cognitive processes emerge from the unique manner in which an agent’s (either human or robot) morphological structure and its sensory and motor capacities enable it to engage successfully with its social and material environment in order to bring forth adaptive and flexible actions. According to Hutchins, ‘enaction is the idea that organisms create their own experience through their actions. Organisms are not passive receivers of input from the environment, but are actors in the environment such that what they experience is shaped by how they act’ (Hutchins, 2010, p. 428). Taken together, these theories of cognition are all approaches to understanding and studying the human mind that challenge the traditional view of human information processing, following the computer metaphor of mind. Accordingly, two underlying assumptions for the DEEDS and 4E approaches of cognition are: (1) the agent’s embodied interactions matter for intelligence and (2) the need of broadening the focus and scope of the agent’s cognitive system.

This way of thinking was illustrated by Polyani (1966) with the classical example of a blind man using a stick: What are the bounds of the blind man’s system – does it or does it not include the stick? In more recent years, the use of strategies such as taking advantage of external structures to coordinate perception and action for cognitive activity might be considered another and complementary way of explaining intelligent behaviour, commonly referred to as external cognition (Rogers, 2012). These external structures function as a kind of supportive framework or *scaffolding*, i.e. external resources to support and simplify cognitive activity for an individual agent (e.g. Clark, 1997). As pointed out by Rogers (2012), successful scaffolds are no longer considered merely cognitive amplifiers or aids, since they have become an integral part of humans’ activities through the multiple ways we interact with the environment and other humans (there is neurological evidence for the inclusion of external tools into the body schema in favour for this argument, see Iriki, Anaka, & Iwamura, 1996). In a broad sense, the human brain and body plus these external factors result in the ‘mind’, the boundary of which extends further into the world than cognitive science initially assumed (Clark, 1997). Hence, Clark (1999) claims the environment can be viewed as a ‘source of cognition’, since it complements biological computation and processing, which he states as follows:

The external environment, actively structured by us, becomes a source of cognition – enhancing ‘wideware’ – external items (devices, media, notations) that scaffold and *complement* (but usually do not replicate) biological modes of computation and processing, creating extended cognitive systems whose computational profiles are quite different from those of the isolated brain (Clark, 1999, p. 349 original emphasis).

Proponents of DEEDS and 4E-cognition (e.g. Barrett, 2015; Chemero, 2009; Chiel & Beer, 1997; Clancey, 1997; Clark, 1997, 1999; Clark & Chalmers, 1998; Dreyfus, 1992; Hutchins, 1995a, 1995b; Lindblom, 2015a; Norman, 1993; Rogers, 2012; Suchman, 2007; Wilson & Golonka, 2013) argue that one of the biggest misconceptions of human cognition is that humans function as computers, i.e. as machines, where cognition happens in the brain alone. While in certain circumstances, there may be similarities between how humans and computers (machines) function, but recent research provides compelling evidence that human cognition is the result of humans' bodily interactions with a social and material environment. The central idea is that the cognitive system would offer a broader unit of analysis stretching from the individual, across people, material and technical artefacts to culture, as much of everyday cognition is embedded and situated in working life practices. Accordingly, the focus on *interactions* between the cognitive agents and the social and material environment is also strongly emphasized in the DEEDS and 4E approaches to cognition. However, it should be noted that there are several different opinions to what extent these theories differ significantly from the computer metaphor of mind, ranging from the traditional foundation of cognitive science (i.e. information-processing and computationalism) being preserved, and thus the embodied nature of cognition is merely considered a constraint of the 'inner' organization and processing, to a more radical view that goes much further and sees a fundamental shift in the explanation of cognition that is 'profoundly altering the subject matter and theoretical framework of cognitive science' (Clark, 1999, p. 348). Due to space limitations, we are unable to fully compare and contrast the similarities and differences of the DEEDS and 4E approaches to cognition, since this is beyond the scope of this paper (for an extensive review of embodiment, see Lindblom, 2015a).

For the aim of this paper, we follow Rogers and Ellis (1994) suggestion that the theoretical framework of DCog is a viable approach in order to study cognition and information flow in complex socio-technical domains. Furthermore, DCog stays rather close to the computer metaphor of mind, which may make it easier for HF&E specialists trained in that tradition to grasp the ideas and concepts of DCog than more radical DEEDS and 4E approaches to cognition, and subsequently offering another powerful cognitive framework in their toolbox for studying and explaining complex socio-technical systems.

### **2.3. The theoretical framework of distributed cognition (DCog)**

The theoretical framework of DCog, originally presented by Hutchins (1995a, 1995b), proposes that cognition should be studied 'in the wild' as it naturally unfolds. DCog offers a shift from studying individual cognizers to studying the whole functional system, including the people, the tools and artefacts that they use in order to perform their work and cognitive activities. It has been noted that personnel in different domains routinely extend and distribute their cognition into the environment to perform their given tasks efficiently and to contentment. The nature of this distribution of cognition differs very slightly from different domains and tasks where the factory worker might be using external memory aids to remember the size of the current production batch or, which is not uncommon, to compensate for poor information interfaces (Thorvald, 2011); the office worker uses post-it notes to offload memory systems and communicate with colleagues (Kirsh, 2001); and the ship captain and navigator heavily rely on their crew to fulfil their part in the very complex task of running a ship (Hutchins, 1995a). These examples are all cases where the cognizers

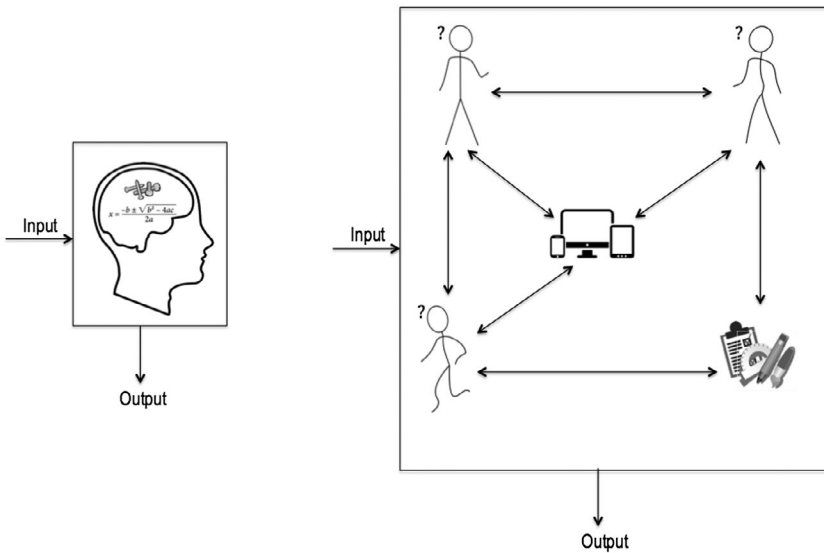


use external tools or peers to extend and mediate their cognition into the environment with the purpose of (1) offloading cognitive load and freeing up cognitive capacity for other tasks and (2) collaborating with peers and tools to allow for more effective cognitive processing, with the whole functional system as the unit of analysis.

DCog (Hutchins, 1995a, 1995b) is grounded in the theoretical roots of traditional cognitive science, staying mostly true to the classic assumption of cognition as computation but slightly modified, and extends the notion of cognition *beyond* the boundary of the *individual* organism's skull. According to Perry (2003), DCog merely extends the traditional notion and theoretical framework of cognition as computationalism, since it still uses the notions of representations and representational transformations for describing human cognitive activity in larger units of study. Perry (2003, p. 194) points out that 'researchers trained in cognitive science do not have to abandon their theoretical knowledge and conceptual apparatus to understand distributed cognition'. The main difference from computationalism 'is in its theoretical stance that cognition is not just in the head, but in the world (Norman, 1993) and in the methods that it applies in order to examine cognition "in the wild"' (Perry, 2003, p. 194). Accordingly, Hutchins (1995a, 1995b, 2006) argues that cognitive science made an error when it mistook the properties of a person in interaction with the social and material world for the cognitive properties that reside inside the person. Instead, cognition is viewed as *creation*, *transformation*, and *propagation* of *representational states* within a socio-technical system (Hutchins, 1995a). The underlying principles from a DCog perspective are that human cognition is fundamentally distributed in the socio-technical environment that we inhabit. DCog takes a system's perspective, and discards the idea that human mind and environment can be separated and cognition should instead be considered a process, rather than as something that is contained inside the mind of the individual. Accordingly, cognition is an emergent phenomenon resulting from the *interactions* between different entities in the brain, the body, and the social and material environment. In other words, the whole is more than the sum of the individual parts. Arguably, DCog can be considered as a reaction to the traditional view, given that its primary focus is to characterize the general *flow*, *propagation* and *transformation* of various kinds of representations (internal and external) in the distributed system, thus providing a systems view of human cognition (Figure 1).

The DCog framework differs from other cognitive approaches by its commitment to two theoretical principles (Hollan, Hutchins, & Kirsh, 2000). The first principle concerns the boundaries of the unit of analysis for cognition, which is defined by the *functional relationship* between the different entities of the cognitive system. The second principle concerns the range of processes that is considered to be cognitive in nature. From a DCog perspective, cognitive processes are seen as interaction between internal processes, as well as manipulation of external objects and the propagation of representations across the system's entities. When these principles are applied to the observation of human activity *in situ*, three kinds of distributed cognitive processes become observable (Hollan et al., 2000, p. 176).

- Cognitive processes may be distributed across the members of a social group.
- Cognitive processes may involve coordination between internal (e.g. decision-making, memory, attention) and external structures (e.g. material artefacts, computer systems and social environment).
- Processes may be distributed through time in such a way that the products of earlier events can transform the nature of later events.



**Figure 1.** From a traditional cognitive science perspective (left) the unit of analysis is narrowed to the inside of the individual's head, while from a DCog perspective (right) the unit of analysis is expanded to be distributed across people and artefacts where cognitive processes are the result of the functional relationships of the entities of the cognitive system.

The DCog approach has since its inception in the mid-1990s gained increased interest and been used as an analytic tool for capturing the interactions between humans and technology in various settings and contexts (Rogers, 2012). Major reasons for this development are DCog's focus on artefacts and the manner in which information (in form of different kinds of representations) is propagated and transformed within the cognitive system, its emphasis to provide detailed analyses of particular tools and artefacts, as coordination between *external* and *internal* structures are highly stressed. In other words, to study material structures like tools and tool use reveal properties about cognitive structures that become visible 'beyond the skull'. Another important aspect of tools is that they may serve as *mediators* in social interaction. Thus, it is important to recognize how information is transformed when mediated through tools and artefacts as well as how they function as *scaffolds* (Clark, 1997; Hutchins, 1995a). In a broad sense, the human brain and body plus these external factors result in the 'mind', of which the boundary extends further into the world than cognitive science initially assumed.

Given that DCog treats the work practice as the unit of analysis, it makes human work performance explicit while portraying how humans handle tasks in action, based on the spatial, structural, social and temporal distribution, through the use of various *coordinating mechanisms* (e.g. rules and legislation, prescribed work procedures and local work practices, tools and artefacts (for further information regarding the distinction between tools and artefacts see Susi, 2006)) in order to grasp, access and share information (Clark, 1997; Hutchins, 1995a, 1995b). This portrayal facilitates identification of workarounds and breakdowns, and therefore highlights different kinds of interruptions in the cognitive system. Various forms of external tools and cognitive artefacts are considered essential *coordinating mechanisms*, given that they carry a portion of the system's cognitive workload (Hutchins,

1995a, 1995b; Norman, 1991). Norman (1991, p. 17) defines cognitive artefacts to encompass 'any artificial device designed to maintain, display, or operate upon information in order to serve a representational function.'

An example used by Hutchins (1995a) is the practical usage of the navigational chart. The chart is used for offloading cognitive effort to the environment and to present knowledge that has been accumulated over time. Furthermore, he describes the navigational chart as an analogue computer where all the problems solved on charts can be represented as equations and solved by symbol-processing techniques. The chart is also used for representing additional data that are not present in the represented phenomena itself, and introduces a bird's eye perspective of local space, position and motion that is almost never achieved by any person on the deck of a ship, factors which complicate computation. Hutchins (1995a) illustrates how multiple embodied biological brains combined with tools (sextants, alidades, etc.), and artefacts (maps, charts, etc.), interact and collaborate during human performance. These external resources allow the human users 'to do the tasks that need to be done while doing the kinds of things people are good at: recognizing patterns, modeling simple dynamics of the world, and manipulating objects in the environment' (Hutchins, 1995a, p. 155). An important insight here is the relationship between the *external* structure (the chart as a representation) and the *internal* structure (the computation). In other words, the study of external, material and social structures reveals properties about an individual's internal, mental structures without going inside the skull. Hence, by studying cognition with this larger scope in mind, it is clear that the system has cognitive properties that cannot be limited to the cognitive abilities of individuals. Consequently, taking the whole system as the unit of analysis makes it possible to observe the different kinds of representations, visible (external) or invisible (internal), which are fundamental parts in the socio-technical system. As Halverson (2002) points out, DCog uses the same theoretical concepts for both humans as well as artefacts and tools, which have led to criticism of DCog (e.g. Nardi, 1996), assuming that humans are equated with non-biological entities (tools and artefacts), which in some way denies our human nature. It should be pointed out that this is not the case, but rather a misunderstanding. Arguably, the various kinds of cognitive artefacts that we use in our work practices, should be considered scaffolds and coordinating mechanisms in managing intelligent behaviour, they complement human abilities, aid those activities for which we are poorly suited cognitively, and enhance and help to develop those cognitive skills which we are biologically predisposed to process easily (Norman, 1993).

Substantial work has been done to apply the DCog lens in different settings and domains. This includes, among others, *ship navigation* (Hutchins, 1995a), *aviation* (Hutchins, 1995b), *Human-Computer Interaction* (e.g. Hollan et al., 2000; Perry, 2003; Rogers & Ellis, 1994), *heart surgery teams* (Hazlehurst, McMullen, & Gorman, 2007), *medical informatics* (Hazlehurst, Gorman, & McMullen, 2008), *information visualization* (Liu, Nersessian, & Stasko, 2008), *technostress in the office* (Sellberg & Susi, 2014), and *interruptions in manufacturing* (Andreasson, Lindblom, & Thorvald, 2016).

There are several ways of doing DCog investigations within work settings and common to all of them is collecting ethnographic data through naturalistic enquiry which are then analysed and interpreted in terms of work practices, routines and procedures followed (Rogers, 2012). The primary focus of DCog is on the general flow, propagation and transformation of information in the distributed cognitive system, but less discussed aspects are what happens when the information flow breaks down or when alternative ways of handling

the information flow emerge in the system. Rogers (2012) points out that through properly conducted DCog analyses, problems can be identified and described in terms of information flows and communication pathways that are being interrupted or hindered due to inefficient information propagation. Accordingly, different workarounds (i.e. the discrepancy between the prescribed work practice and the current work practice) that humans develop when dealing with various demands during work performance become salient through a proper DCog analysis (Rogers, 2012).

However, DCog and its application power as an analytic tool has been criticized; two posed forms of criticism regard the DCog view of the very nature of cognitive phenomena and its utility as an analytic tool (Rogers, 2012). Nardi (1996), for example, criticizes the need for extensive fieldwork to reach a proper analysis and subsequent results in a given setting and also the lack of interlinked concepts that can easily be used to identify specific aspects out of the collected data. In a similar vein, Halverson (2002) argues that few theoretical constructs are explicitly named in DCog, which is a drawback. As pointed out by Rogers (2012), a skilled DCog analyst has to be able to move between the different levels of analysis. Indeed, a well-executed study of a work setting that results in detailed analyses can be useful for design, identifying why problems occur, and offering a design of how to solve the situation (Rogers, 2012). Such detailed and abstract analyses can provide several suggestions how to change the design to improve user performance and, in the long run, the work practice (Rogers, 2012). Hence, DCog is not a ‘quick and dirty’ approach but consequently, the DCog approach has been used as a base for the construction of methods in areas such as the *Resources model* (Wright, Fields, & Harrison, 2000), *DIB method* (Galliers et al., 2007), *CASADEMA* (Nilsson, 2010; Nilsson, Laere, Susi, & Ziemke, 2012) and *DiCoT* (Blandford & Furniss, 2006). Although these methods have their foundation in DCog, to varying extent, they oversimplify and sometimes omit several central aspects of importance for a detailed DCog analysis (Sellberg & Lindblom, 2014). However, DiCoT has been proven to facilitate the learning of applying the DCog framework (Berndt, Furniss, & Blandford, 2014), and recently, a lot of work has been performed in health care using the DiCoT methodology (Furniss et al., 2014, 2015; Rajkomar & Blandford, 2012). While DiCoT has been successfully applied in health care, there are still issues regarding the lack of proper notation for changes between representational formats. These changes often occur between humans and cognitive artefacts and are especially relevant in DCog. Some initial attempts to overcome this gap are developed in Lindblom and Gündert (2016) in a manufacturing domain.

### 3. Illustrative examples from manufacturing

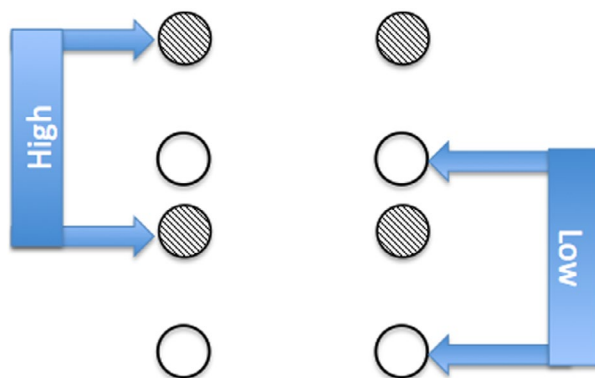
Looking at manufacturing, and perhaps more specifically, manual assembly, a significant amount of examples of workers externalizing their cognition using different kinds of scaffolds are evident. The following illustrative examples are gathered through several years of work and observation in the field as well as from conversations with assembly workers, mostly collected by the second author, who has both first-hand experiences of manual assembly in practice as well as a researcher studying assembly work. Please note that these anecdotal examples are meant as a basis for illustration and discussion rather than as empirical evidence.

### 3.1. Example 1 – high or low

At an assembly factory where assembly instructions (i.e. cognitive artefacts) came in the form of a bunch of clipped together papers, the assembly time for the worker on a specific product was around 1–1.5 h and the worker usually investigated the instructions first, took mental note of it, i.e. internalized the symbolic representation (written assembly instruction), and then commenced work on the product, usually without consulting the instructions again. This way of working was possible due to limited component variation that resulted in the workers being able to remember most of the relevant information. Still, strategies for coping with an increased cognitive load were developed and one of these strategies dealt with the mounting of a bearing using four bolts. Neither the bearing nor the bolts ever differed between products but the assembly position did differ. There was an option between placing the bearing ‘high’ or ‘low’, referring to two different hole patterns and the assembly instructions clearly stated what position the bearing should be mounted in. The bearing had four holes where the accompanying bolts were placed and the main product that the bearing should be fitted to have eight threaded holes (Figure 2).

In this case, it would have been optimal to mount the bearing immediately as the instructions had been read but this was impossible since other assemblies had to be done first. To avoid having to explicitly remember the position of the bearing solely ‘in the head’ and to avoid having to consult the assembly instructions again, many workers used a felt pen to mark the high or low position on the product in advance. This way, when it came time to mount the bearing, it was a simple matter of identifying the hole pattern with the markings on it.

This is an illustrative example of the offloading of cognitive load onto the environment, i.e. scaffolding, and shows how cognitive processes may involve coordination between internal (e.g. memory, attention) and external structures (e.g. markings). More specifically, it is the cognitive process of externalizing memory into the cognitive system with the ultimate purpose of the cognizer to free up allocated and limited biological memory processes to be used elsewhere. With the worker not having to explicitly remember what position the bearing should have, memory and attention capacity is freed and available for other operations. By doing so, workers offload their internal memory and move parts of the internal



**Figure 2.** Illustration of the hole patterns where the grey dots indicate the high hole pattern and the white dots indicate low. Assembly of the bearing in the high position would make use of holes 1, 2, 5 and 6 (counting top left to right and down), whereas the low position would make use of holes 3, 4, 7 and 8.

memory process onto another, more observable medium outside the ‘skull’, i.e. the marking of the felt pen, which makes it possible to select certain actions over time. An important insight here is the coordination of cognitive processes between the *external* structure (the marking as representations) and the *internal* structure (the memory process), in which the knowledge of how to mount the bearing emerges. Moreover, the markings with the pen have no similarities with the actual assembly instruction since the representation of the information (where to mount the bearings) is transformed (from the written text in the instruction to the marking with the pen). It is also propagated (from instruction to the actual object) in the information flow of the coordination process of that particular assembly task that was distributed through time in such a way that the products of earlier events (reading the instruction and doing the marking with the pen) transforms the nature of the later events (the actual mounting of the bearings).

### 3.2. Example 2 – keeping track

At an assembly production line for specialized combustion engine assembly, the overhead task was to finish 23 products/day. However, there was no easy global way of keeping track of finished products, which led to workers developing their own strategies. This desire to use external memory aids (scaffolds) to keep track of produced engines manifested itself in several ways, two of which are described here.

At one of the workstations, one of the assemblies was the mounting of a so-called ground washer, a single bolt and a washer with the purpose of providing an electrical ground point. Many workers, when working at that station therefore started their day by placing 23 washers on 23 bolts and thus keeping track of products finished by just looking at how many bolts and washers were still on the working table. Hence, the workers visually and concretely externalized the amount of products to mount ‘out in the open’, releasing cognitive capacity for performing the ‘real’ assembly task while simultaneously keeping track of the overall work process status by the creation of external representational states that were transformed within the functional system.

At another workstation, the task was the assembly of fuel lines for the engine. The connecting ends of the fuel lines came with plastic cap covers to ensure the cleanliness of the fuel line. The plastic caps were removed manually just as the fuel line was fastened to the engine, thereby minimizing the time that the critical parts of the fuel line were exposed to dirt and dust particles in the air. To keep track of finished products, many workers employed a routine to keep one of the plastic caps from each engine as opposed to throwing it into the plastic recycling bin as was done with the rest. The amount of saved plastic caps would then serve as an external reminder of how many products had been produced during the shift. Through employing this strategy, the workers did not have to be remember ‘in the head’ (internal representation) the current state of production. Hence, the workers generate cheap and efficient tricks to handle the situation, in order to avoid a decreased cognitive performance and a high cognitive load.

These illustrations are two sides of the same example, i.e. strategies for counting down versus counting up the overhead task. The example shows cognitive processes developed to help meet the desire of the workers to keep track of the day’s work in an easily accessible way involving coordination between internal (e.g. visual perception, memory, attention) and external structures (e.g. pairs of washer and bolts as well as plastic caps). Just as in the

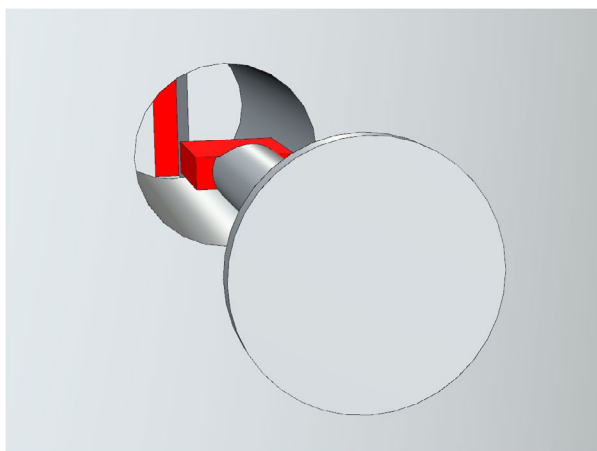


first example, it deals with scaffolding and offloading of cognitive load onto the environment although the reason for it may differ slightly. In both examples though, the workers use their limited biological cognitive capabilities (memory, attention) more effectively and could potentially perform other tasks better, faster or more accurate. These are partly the humans' internal cognitive abilities, but other important external resources are material artefacts and articles used in the assembly examples described above. The two short examples obviously show that the information flow and the propagation of information are flowing back and forth between the assembly workers' internal representations, and the ways the workers have altered the environment to structure their work practices, where the cognitive processes are distributed through time.

### 3.3. Example 3 – minding the body's action-perception couplings

An example of using the tactile–kinaesthetic representations of the body and its interactions with the physical environment for making adequate action–perception couplings (e.g. Dreyfus, 1992; Lindblom, 2015a; Wilson & Golonka, 2013) can be found in a case of mounting fuel pumps on heavy diesel truck engines. The pump had a long, cylindrical rod with a flat end that should fit into a slit on the inner parts of the engine. This slit was not visible at the viewing angle of the standing worker but one had to bend down and look through a hole on the engine block to see the position of the slit which could vary over 180° (Figure 3).

Instead of bending down and looking into the hole, a majority of the workers carefully inserted the rod into the hole, rotating it slowly when reaching the bottom of the hole until it fell correctly into the slit. The workers favoured the use of the bodily tactile–kinaesthetic representation of information and the superior work posture it entails over bending down and trusting vision (another representational format) to give clues to the angle of the slit. In so doing, the workers, to various degrees, experienced a wide range of tactile sensations of the body and its interactions with the physical environment. Considered from this perspective, the *bodily experience* in the course of making *action–perception couplings* with the



**Figure 3.** Illustration of the rod being inserted to fit into the hidden slit. The rod which can be seen closest in the picture was rotated as it was inserted and the worker used tactile–kinaesthetic representations of the body to judge when the flat end lined up with the slit, both marked in red.

environment can be described as an example of ‘embodied representations’ that are sometimes hard to verbalize, i.e. we might lack proper concepts for our embodied knowledge (e.g. Dreyfus, 1992; Lindblom, 2015a)

The rod provides the worker with additional tactile–kinaesthetic information to decide whether or not it has been inserted properly in the visibly hidden slit, represented in an embodied, felt tactile experience. This is similar to the classical example of a blind man using a stick (as presented earlier). When using the rod to fit into the slit, it ceased to be an object and instead became part of the body for the accustomed worker. As a result, the bounds of the actual body can be extended beyond the skin, being regarded as part of the functional system. Accordingly, the assembly activities and the embodied practices described in this episode clearly show the transformation, propagation, distribution and interpretation of different representational formats (visual, tactical) in the information flow. This emphasizes the great importance of tactile–kinaesthetic and sensory-motor coordinations in time-locked activities such as inserting the rod into the hidden slit.

### **3.4. Example 4 – socially distributed assembly and competence**

So far, the earlier examples have focused on single agent–environment interactions as the unit of analysis, but this last example includes several interacting peers, all distributed over time and space, widening the unit of analysis. The example takes place at a major automotive industry facility, although the example is gathered from one of the minor lines, feeding a larger one, the minor line being the chosen socio-technical system at this level of analysis. This line had eight workstations and assembled some of the outer parts of the engine, such as the air intake, oil cooler and oil pan among other things. The *cognitive processes* are *distributed across time, space* and the *members of the group* during the coordination of their individual, but cooperative work activities. In order to achieve this joint result, different coordination mechanisms at the line are needed that have the capacity to handle the propagation of representational states through the system.

At this time, the current generation of engines being assembled was called the C engine. Earlier generations of the same engine were consequently called the A and B engines. The B engines had been quite short lived and were no longer in production but on occasion, the odd A engine was still being produced and, being a much earlier generation than the present C engine, its assembly was much more complex and required a much higher degree of expertise for assembly on around 50% of the workstations of the line. Since the A engine was quite rare and really only occurred perhaps once every two or three weeks, it was not deemed cost efficient to train all workers on all workstations for this specialized assembly. Instead, once an A engine was to be produced, the workers quickly communicated (utterances as external representations) what was coming between each other and subsequently reorganized themselves into positions (workstations) where they had training for the old A engine. This means that the A engine functioned as a *coordination mechanism* for this reorganization of the workers at the critical workstations. This usually meant that experienced personnel who had worked at the facility for a long time took up position at one of the workstations that included complex assembly for the A engine. Newly hired personnel or personnel without specialized training for the A engine, took up position at one of the ‘simpler’ workstations where assembly for A and C engines was the same or very similar. The workers then remained at this workstation until the A engine had passed through the entire

line (usually less than 30 min from start to end), being the central bearer of information and functioning as the coordination mechanism for the emerging distributed work process (both in time and between humans) at that line, and then the workers proceeded to move back to the workstation that they had occupied before the move. This example shows socially distributed cognition over time and space and how the whole cognitive system, which in this case would include the entire line and the personnel and tools in it, is capable of much more than the individual worker itself, given that the functional system as a whole could rearrange and handle different types of engines and assembly operations.

Taken a broader unit of analysis, while this example is described at a more organizational level, there is potential to combine this level of analysis with the lower level for each and every assembly worker on the particular line, as in the previously presented illustrative examples, in order to obtain more detailed levels of analysis of the information flow of the whole line. In other words, and as briefly mentioned in Section 2.2, one of the main benefits with DCog is the possibility to vary the level of granularity and thus move continuously between the different levels of analysis. Hence, the boundary of, what we analyse as, the system can be anything from the individual level in the first examples to the organizational one described here, and beyond. From the combined effort of the individual workers, each not sufficient for achieving the task goals alone, an emergent phenomenon arises from the combined effort, allowing the system to be self organizing and thus reach task goals that the sum of the individual efforts would not have achieved.

Finally, the coordination of different representations (external and internal) is an emergent property of the system as a whole, not easily reduced to an evident property of a certain entity (human or cognitive artefact). This holistic and emergent view is the central foundations of the DCog approach; the total sum is more than the sum of the individual parts since the socio-technical system has emergent properties. Thus, cognition is viewed as *creation*, *transformation*, and *propagation* of *representational states* within a socio-technical system (Hutchins, 1995a, 1995b).

#### 4. Discussion and conclusions

This mostly conceptual paper has attempted to both motivate and show concrete examples of how and why a systems perspective must be applied within manufacturing, and in the long run to be more prominent in HF&E. The inclusion of DCog may be a promising step in that direction given the absence of relevant cognitive frameworks that provides a systems perspective in theory and practice in HF&E applications to manufacturing. In an effort to stay true to Hutchins's original concept of distributed cognition (DCog), we have had no intention of investigating all the different adaptations that have been derived from Hutchins's work in the past 20 years. We believe that we have chosen some of the most prominent advocates for Hutchins's original thoughts, which are Hutchins himself along with his colleagues Hollan and Kirsh, and also Rogers, who has successfully applied DCog in HCI, thereby narrowing the gap towards the HF&E application of manufacturing. The reason for addressing JCS and CWA specifically was that they are commonly used in HF&E and thus in manufacturing and we wanted to point to the differences from DCog and the shortcomings of the two from a cognitive science perspective.

Applying a systems perspective would allow us to recognize that the HF&E discipline '... only makes sense in the full richness of the social setting in which people work' (Moray,

1994, p. 529). In line with this remark, Hollnagel and Woods (2005), for example, report that since there has traditionally been a distinction between technology (i.e. external resources) and humans, not conceptually questioned in HF&E, the theories and practices of the discipline focus on the internal processes of the brain, occasionally including the external resources and the connections there between but not from a systems perspective. Therefore, the HF&E discipline has some problems to consider the ‘bigger picture’, i.e. the wider web of connections that the more traditionally ‘narrow perspective’ of human–machine interaction is *situated* within, in the sense that the environment affects, but does not determine the organization of interactions under the present constraints. They conclude that because traditional HF&E did not doubt the validity of the distinction between human and machine, the discipline has encountered some difficulties in reaching a systems perspective. More recently, Hollnagel (2012) emphasizes that the role of humans in systems is not only to be a part of the system, but also to *shape* the system, and therefore it is relevant to portray the systems by studying and analysing their behaviours and activities. Accordingly, the set of mutually dependent functions existing within a system is characterized with what it *does* rather than what it is (Hollnagel, 2012).

In a similar vein, Norros (2014) points out that the discipline of HF&E needs to focus on principles of *interaction* and *co-functioning* between elements of a *whole* system. Moreover, she advocates HF&E researchers to deal with *technology-in-use* in its scientific discourse in order to comprehend the various roles of technology that people take advantage of in their various activities, particularly in *work practices* (Engeström & Middleton, 1998; Kuutti & Bannon, 2014; Miettinen, Samra-Fredericks, & Yanow, 2009). Norros mentions, for example, the seminal work conducted by Orlikowski (2000), who provides good insights in her analysis of the ways that technology shapes the routines and resources of social organizations. Indeed, Norros points out that she has been inspired in her own work by theories of human–environment relationships, including activity theory (AT) (Leont'ev, 1978) and habits (Peirce, 1958) as different ways to consider and study *technology-in-use*. Norros (2014) concludes that there is a need for a more holistic view of the historical, cultural and developmental roots of the generic patterns of work practices involved in technology-in-use, rather than merely offering tentative explanations for a particular course of action from a more narrow ‘snap-shot’ view. In other words, we agree with the necessity of providing a linkage between what happens ‘now’ to asking ‘why does this happen now in this way’ from a prolonged perspective. We suggest studying the whole web of patterns rather than just pulling on a single thread, in order to reveal the underlying reasons that can explain the identified pattern of work practice. That is, instead of blaming a particular person for some performed ‘human error’, a systems perspective could explain how and why this particular error occurred in the system as a whole, by examining how past and current work practices may have been altered given the inclusion/exclusion of new/old tools, which may have resulted in the emergence of new pattern of work practices. This is a shift from merely examining particular situations to proceed to studying and using relevant theoretical frameworks in order to reveal generic explanations of the observed work practices, providing a deeper and coherent understanding of humans’ *situated* actions.

Norros (2014) further argues that given the difficulties in tackling problems emerging from the complex socio-technical systems of today’s modern workplaces, the HF&E society faces a pressure for a paradigm change. Some identified reasons for this change are not only characterized by the earlier revealed challenges addressed above, but also the need

for additional analytical and theoretical approaches, which are capable of articulating new and more relevant problems to reach a so-called 'high-quality HF&E (Norros, 2014). She further emphasizes that a common denominator to these new approaches in high-quality HF&E is to conceive human–technology–environment as a *unity*, and adopts this as the new object of analysis, arguing that these approaches offer articulated concepts to what a systems HF&E should be. We suggest that DCog could provide a relevant complement to the aforementioned approaches of human–environment relationships (AT and habits) that provides a support for a systems perspective, thus adding DCog to the toolbox for conducting high-quality HF&E (for a more theoretical comparison of cognitive ergonomics, AT, and DCog, see for example Decortis, Noirfalise, & Saudelli, 2000; Halverson, 2002; Nardi, 1996; Rogers, 2012).

It should be emphasized that although we do not go as far as to claiming the urge for an instant paradigm change in HF&E, we highly stress the need to consider the epistemological and ontological challenges that occur when incorporating new theoretical constructs and analytic lenses from one discipline to another. Different theories provide different concepts, perspectives and historical roots when conducting research, and there is a necessity to 'filter and focus' the rich stimuli of real world settings from a theoretical perspective (Nardi, 1997). Similarly, Decortis et al. (2000) describe the role and relevance of the theoretical perspective as a 'theoretical filter' through which the practitioners investigate and analyse the phenomena of interest, where the selected 'theoretical filter' puts forward some aspects of the observed situation and puts other aspects in the background. Thus, either lacking a 'theoretical filter' or not understanding it, may result in the practitioners not knowing how to properly handle the observed situation and interpret the collected data into distinct concepts of meaning. We therefore emphasize that it is wrong to claim that one theoretical framework is significantly better than another one, given that different frameworks enable the researcher to perceive and portray different possible viewpoints regarding work practices in complex cognitive socio-technical systems.

Our purpose is to contribute to the understanding of the theoretical and analytical properties of the DCog framework, in order to support HF&E specialists to do explicit and appropriate choices for the particular aim of study. Furthermore, it should be mentioned that the same terms used may have different semantic meanings in different frameworks, for example, the semantic meaning of the concept of 'activity' differs between cognitive ergonomics and AT (Decortis et al., 2000). Although DCog has roots in the prevailing computer metaphor of mind, it still offers some conceptual challenges with its systems perspective, its anthropological roots, and the changed *situated* view of how to consider and study the interaction between human and technology 'in the wild'. It should be noted that the simplicity and low detail in the four illustrative examples only goes to demonstrate how HF&E specialists might be missing quite a bit of relevant distributed cognitive processing by having a scope and unit of analysis which is based merely on the human, or even worse, on the human brain. The systems perspective, in this case DCog, allows us to expand the unit of analysis to also include other actors and tools as making up the emergence of the socio-technical cognitive system. We also argue that our understanding of the intricacies of cognitive processes will be inadequate if we fail to consider the human cognizer as a part of a larger system, as proposed in the new DEEDS and 4E approaches in the advancing cognitive science field. It should be noted that these new approaches did not originate from an *a priori* perspective as in the computer metaphor of mind, rather they are being based on

observed results that comes from empirical evidence and cognitive modelling (robotics) in artificial intelligence (AI) (Dreyfus, 1992; Lakoff & Johnson, 1999). In extension, the human cognizer should be seen as a live agent with their own incentives and urges, and not as a mere machine acting on input and generating output, ‘as a factor, a passive element that can (...) be trained to perform whatever operations [are] required’ (Bannon, 1991, p. 28). Instead, we favour the ideas put forward by the DEEDS and 4E approaches to cognition, and as Dix (2002, p. 2) puts it; it is about finding equality between the human and the world and ‘... not just act **on** the world, but act **with** the world’ (our bolds).

Successfully employing DCOg in the HF&E discipline, especially in the manufacturing domain, can easily be argued to shed light on understanding and grasping the role that the various forms of representations play in the coordination of work practices in complex socio-technical systems where the individual human is considered a component among others (peers and cognitive artefacts) in the system. This was previously unobservable due to a limited perspective of the distributed coordination of human–technology interaction as well as the unit and scope of analysis. Among other things, DCOg with its own theoretical ‘focus and filter’ on the system’s goal can help in:

- Mapping out the trajectory/journey of the information flow and the propagation of information over time and space in the distributed socio-technical system.
- Identifying various *kinds* of representation formats (graphical, numerical, written, embodied) used in the information flow as well as recognizing the different *shifts* between representation formats during the propagation of information in the distributed socio-technical system.
- Including ‘embodied representations’ (e.g. the embodied interactions and experiences with our senses) that put significant attention on the tacit knowledge present in the craftsmanship associated with being a skilled worker in manufacturing, which becomes visible through coordination of different kinds of internal and external representations in the information flow and propagation of information in the distributed socio-technical system.
- Identifying workarounds and subsequently prevent breakdowns from a systems perspective. It is widely acknowledged that with obtained experience, workers become increasingly skilled at their work and one part of this is finding workarounds that allow for faster, more efficient work, through the use of smart coordination mechanisms in order to reduce cognitive load (i.e. handling shortcomings in different cognitive artefacts) with the ultimate individual goal arguably being to ease their own work situation, i.e. identifying skilled workers’ developed ‘best practices’ and ‘lessons learned’ in the distributed socio-technical system.
- Changing the level of analysis to enable moving between the more general system’s level to the more detailed level that specify concrete details of actual use of available cognitive artefacts by studying the assembly processing at the shop floor, i.e. in the wild in the distributed socio-technical system.
- Enabling a coherent systems analysis of work practices with the added value of grasping the workers’ actions related to the various used tools and cognitive artefacts (from current but also historical perspectives), including the emergent situations where workers benefit from functionalities not intentionally designed for or when they invent new usages and routines of available tools.



- Providing implications for design and redesign of new and/or existing cognitive artefacts as well as the organization of various levels on a production line in the socio-technical system where the distributed and socially shared representations among workers are taken into consideration. Observing and analysing how assembly workers do work in the wild can enable engineers to produce realistic requirements which then can be properly implemented in the design of new products (e.g. tools and cognitive artefacts), while not being a design method as such.

Considering these identified insights, which can mainly be accomplished through a systems perspective would allow for the spreading of knowledge to others in the same domain. Identifying workarounds, for example, that are efficient and quality conscious or previously unobservable tacit knowledge can prove beneficial and can be used in training of new employees among other things. As exemplified by Albihn (2015), a skilled assembly worker, not following the prescribed standard operating procedures (SOP) during quality inspection, cuts the required time from about 45 to 15 min by changing the order and procedure of the operations. More detailed examples of this are also visible in Andreasson et al. (2016) who has conducted a thorough DCog analysis of manual assembly. Viewing it this way, it becomes easily arguable that companies, through their skilled workforce, possess knowledge and competences that they did not know they had. We emphasize the importance of HF&E specialists to challenge incorrect or sometimes insulting assumptions of the workers' competence, skills and performance, given that they want to do their best to accomplish the goals with the available tools and cognitive artefacts and prescribed work processes in the socio-technical system as a whole. We strongly suggest that studying and analysing work practices 'in the wild' from a DCog perspective are aligned with the 'mission' of the HF&E discipline, i.e. making more effective, efficient, safe and desirable products. All of these benefits will come to HF&E specialists by just applying a perspective that *makes work practices in manual assembly visible*.

This paper has focused on trying to apply a DCog perspective to HF&E society and to consolidate this cognitive framework to a high-quality HF&E discipline. However, despite the emphasis on interactions between agents and their social surroundings, the DCog framework offers little on the embodied nature of human cognition, and is currently peculiarly 'disembodied' (Hutchins, 2006; Lindblom, 2015b), and there are theories within the DEEDS and 4E approaches that are complementary to DCog (e.g. Lindblom, 2015b). Furthermore, investigating the role of the body in manual assembly from an embodied cognition perspective has been done by Kolbeinsson and Lindblom (2015) who applied an embodied interpretation to interruption management.

To summarize; the main objectives of this paper have been to expand the unit of analysis in systems ergonomics to include not only the human, but the entire social and material context as contributing entities in the cognitive system. We have attempted to show how DCog can be successfully applied to study the manufacturing domain within HF&E and we have supplied real world illustrative examples of the distributed nature of human cognition in manufacturing. Future work will also include more of the embodied nature of human cognition and other more 'radical' DEEDS and 4E approaches with the ultimate goal of consolidating and expanding upon the areas of cognitive and physical ergonomics to become a high quality HF&E discipline.

Our final remark is that we are convinced that the HF&E discipline has great potential in shaping the future workspaces at the shop floors in manufacturing, and that this requires a willingness for cross- and trans-disciplinary work, although encountering some epistemological and ontological challenges which we think the discipline can overcome given its multidisciplinary past. We believe that the DEEDS and 4E advances in the cognitive science field is a prerequisite for the next step in the development of a systems perspective, going beyond the view of the assembly worker as a factor or actor, and consider the assembly worker as an *enactor*. Both perspectives, the new advances in cognitive science and the HF&E discipline address the need for reducing the common friction between human and technology, since much of current technology is designed to bend our embodied human being into an unnatural shape of interaction. Instead, we should emphasize how this interaction is *enacted* through bodily actions and real world experience, designing for mutual relationships between human and technology from a systems point of view.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## ORCID

Jessica Lindblom  <http://orcid.org/0000-0003-0946-7531>

Peter Thorvald  <http://orcid.org/0000-0002-8369-5471>

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