

Theoretical Frameworks for Human Computer Interaction

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Abstract: This paper is concerned about the state of theory in HCI and discusses the adequacy of current theoretical frameworks that have been proposed for HCI. These findings are based on our study of these frameworks and their application on various systems under study. Approaches such as activity theory, cognitive ergonomics and distributed cognition are three theoretical frameworks explaining co-operative work. Each of them is applied on multiple case studies describing different work settings. But those work settings usually refer to different work realities, so it is difficult to properly compare those viewpoints. So we analyzed the same work setting, with the three different frameworks mentioned above. The report does not pretend to give detailed case studies but aims to underline how approaches which explain co-operative work can be used to analyse a same work situation. This will allow us to compare the relevant questions each theory is asking and should answer when studying a co-operative work situation.

Index terms: Activity Theory, Artefacts, Cognition, Cognitive Ergonomics, Context, Distributed Cognition, Human Computer Interaction(HCI)

1. INTRODUCTION

Human-computer interaction (HCI) lies at the intersection between the social and behavioral sciences on the one hand, and computer and information technology on the other. It is concerned with understanding how people make use of devices and systems that incorporate or embed computation, and how such devices and systems can be more useful and more usable.

It is not possible to fully understand how people learn or work if the unit of study is the unaided individual with no access to other people or to artifacts for accomplishing the task at hand. Thus we are motivated to study context to understand relations among individuals, artifacts, and social groups.

HCI specialists will be most valuable to designers when we can provide

- (1) a broad background of comparative understanding over many domains,
- (2) high-level analyses useful for evaluating the impact of major design decisions, and
- (3) information that suggests actual designs rather than simply general design guidelines or metrics for evaluation. To be able to provide such expertise, we must develop an appropriate analytical abstraction that discards irrelevant details while isolating and emphasizing those properties of artifacts and situations that are most significant for design.

We look at the unit of analysis proposed by each approach, the categories offered to support a description of context, the extent to which each treats action as structured prior to or during activity, and the stance

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toward the conceptual equivalence of people and things.

Activity theory, cognition ergonomics, and distributed cognition are evolving frameworks and will change and grow as each is exercised with empirical study.

2. ACTIVITY THEORY

Activity theory is a theoretical framework for the study of different forms of human practices as development progresses, with both individual & social levels linked at the same time.

This framework uses 'activity' as the basic unit for studying human practices.

The activity triangle model incorporates the Subjects, Object, and Community components; also mediators of human activity, namely: Tools, Rules and the Division of Labour.

The 'Object' component reflects the motivational or purposeful nature of human activity that allows humans to control their own behaviour.

The 'Subjects' component of the model portrays both the individual and social nature of human activity as reflected through collaborations and consultations in order to satisfy a shared objective.

The 'Tools' component of the model reflects the mediating aspects of human activity through the use of both physical and conceptual tools.

Physical tools are used to handle or manipulate objects whilst conceptual tools are used to influence behaviour in one way or another.

The 'Community' component of the model puts the analysis of the activity being investigated into the social and cultural context of the environment in which the subject operates.

The Rules component highlights the fact that within a community of actors, there are bound to be rules and regulations that affect in one way or another the means by which activity is carried out.

The Division of Labour component refers to the allocation of responsibilities and variations in job roles of the subjects as they carry out activity in the community.

3. COGNITIVE ERGONOMICS

Cognitive engineering is an emerging branch of ergonomics that places particular emphasis on the analysis of cognitive processes – e.g., diagnosis, decision making and planning – required of operators in modern industries.

Ergonomic interventions in the area of cognitive tasks require a thorough understanding, not only of the demands of the work situation, but also of user strategies in performing cognitive tasks and of limitations in human cognition. In some cases, the artifacts or tools used to carry out a task may impose their own constraints and limitations (e.g., navigating through a large number of GUI screens); in fact tools co-determine the very nature of the task. In this sense, the analysis of cognitive tasks should examine both the interaction of users with their work setting and the user interaction with artifacts or tools; the latter is very important as modern artifacts (e.g., control panels, software, expert systems) become increasingly sophisticated. Emphasis lies on how to design human-machine interfaces and cognitive artifacts so that human performance is sustained in work environments where information may be unreliable, events may be difficult to predict, multiple simultaneous goals may be in conflict, and performance may be time constrained. Typical domains of application include process control rooms (chemical plants, air traffic), command and control centers, operating theaters and other supervisory control systems. It focuses on the fit between human cognitive abilities and limitations and the machine, task, environment.

4. DISTRIBUTED COGNITION

The concept of distributed cognition was developed by Ed Hutchins et al. (1992) to explain cognitive activities as embodied and situated within the work settings in which they occur. Distributed cognition became a new branch of cognitive science which proposes that human cognition and knowledge representations, rather than being solely confined to the boundaries of an individual, is distributed across individuals, tools and artifacts

in the environment. The theoretical advance of distributed cognition, in contrast with traditional cognition science, is the account of cognition as a distributed phenomenon that does not reside uniquely in the heads of individuals but that relies on external resources such as social and cultural structures and factual components. It emphasizes the distributed nature of cognitive processes and the transformation that information undergoes in order to get into a specific format very appropriate for the performance of a task. The distributed properties of distributed cognition are several aspects:

- Information is distributed over different artifacts, the members of team;
- Representations are distributed over individual internal space and external environment, including artifacts and media;
- Cognitive activities may be distributed over the members of a social group;
- Cognitive activities may be distributed;
- In cooperative environment, cooperative tasks are distributed across different actors.

Distributed cognition is concerned with representational states and the informational flows around the artifacts carrying these representations. It also stresses how systems coordinate transformations on representations in goal-seeking behavior. So it is a useful approach for analyzing and designing socio-technical cooperative work. The existing applications of distributed cognition mainly are to analyze systems. Hutchins (1995) used the theory to analyze complex cooperative computational system to explain cognitive activities in these environments.

Based on research of distributed cognition, we constructed a detailed architecture of distributed cognition framework for cooperative design. Architecture of Distributed Cognition Framework for cooperative Work Cooperative work is constituted by the interdependence of multiple actors in changing the states of their individual field of work, also changing the states of the field of work of others and who thus interact through changing the state of common field of work. From the distributed cognition perspective, we can regard the cooperative work as a functional unit.

It is a collection of actors and artifacts and their relations to each other. Within the architecture of distributed cognition framework, cognition activities are viewed as computations which take place via the propagation of representational state across media. The media here refer to both individually internal (e.g. individual memories) and external representations (including different artifacts). Various information and knowledge resources are transformed to different representation states via the interactions which take place between individual internal space and external environment space.

Within Distributed Cognition Framework architecture for cooperative work, individual internal space and external environment space is included. Internal space includes intent, historical interactions, and action. External Environment Space includes Local

artifact, Share artifact, and Goal. In what follows, we will attempt to show main concepts that are essential part of the distributed cognition framework architecture for cooperative work.

5. COMPARISONS

The activity is a unit of analysis more social, which has a collective nature and goes beyond the traditional border of psychology. So, the term activity in cognitive ergonomics, although apparently inherited from the early activity theorists, does not more refer to the same notion. The activity in cognitive ergonomics refers to activity as the activity of an individual or the activity of a group of people. The new activity theorists made a broader interpretation of it, also including socio-economical and organisational aspects. So, when analysts of both approaches study the activity, they are actually examining two different realities. Engestrom (1993) as a modern activity theorist describes the activity as a systemic whole including the subjects, the community and the objects, and the relations between those components in the transformation process of the object into outcome. The relation between subject and object is mediated by tools, the relation between subject and community mediated by rules and the relation between community and object by division of labour. That is something close to what distributed cognition theorists call the functional system. The system is described as a collection of individuals, artefacts and their relation to each other, which includes the interaction between actors and tools but also actors with each other. Those two concepts seem relatively close because they both take as unit of analysis a systemic viewpoint and because both are focusing on the interactions within the system and its different components. Attention is on how the system works and what are the actions processes of the group. They also examine the group information process and the way information circulates and is elaborated within the group. One major concern in distributed cognition is to look at how the system behaves. Distributed Cognition analysis will focus on information propagation and more specifically on information transformation.

Tools and interactions human-tools are some components of the system. In activity theory, tools are mediators in the relation between subject and object. The tools are what allow the subject to transform the object

into outcome, they are then used by individuals to reach their objectives. In distributed cognition, tools are considered as representational media, as supports of representational states. By media, Distributed Cognition theorists intend means by which information is represented and transformed from one representational state to another, from an informational input to output of the system. Therefore, we may see a similarity between the theories because they both see tools as means of transforming 'something' (object or input) into 'something else' (outcome or output). Also, when in Activity Theory analyst talks about a tool as re-mediating the actions, or in Distributed Cognition about "cognition-aid", both approaches study how a tool may modify (or re-mediate) the actions, in other words how a tool (external representation in Distributed Cognition) change the nature of the task.

Moreover, the case studies highlight another similarity between Activity Theory and Distributed Cognition when the analysts try to identify the functions tools in the system. Activity theorist try to see if the tool emphasizes human engagement with other human being through the artefact (defining as a medium), and when in Distributed Cognition the analysts talks about "communication-aid", somehow, they both are looking at how tools in the system. Nevertheless, some differences may be pointed out. In Distributed Cognition, the emphasis given to tools is on their representational features and the role the various form of representations (low-high technology, individual-shared) may play in the co-ordination of work activities. The interest Distributed Cognition has for tools does not consist in the description of them per se, but rather in the description of interaction inside the system between internal representation (inside people's head) and external representation (supported by tools).

The theory of Vygotsky (1978) makes the distinction between two kinds of tools: technical one (to manipulate physical object - e.g. a hammer) and psychological ones (to influence other people or themselves - e.g. calendar or advertisement). Therefore, Activity Theory seems to apprehend tools in a larger extend than only supporting representational state as Distributed Cognition does. Concerning interaction human-tools, Hutchins (1995) is giving us some clue about how to understand the difference between media and mediator when he says mediating technologies do not stand between the user and the task, rather they stand with the user as resources used in the regulation of beha-

viour. This show that somehow distributed cognition stresses the active role of tools in the cognition of the system, idea that is confirmed by the fact that internal and external representations are viewed on a same level. Knowledge can actually be distributed somewhere else than in people's head, in tools for instance. So, in the relation human-tool the difference between activity theory and distributed cognition, resides in the fact that distributed cognition does leave all the human specific aspects (motivation, object) viewed by activity theorists. To give a gross image of how the approaches stresses on humans or tools in their interaction we could imagine to place both concepts on a scale and see how it would behave. In activity theory we would probably see the scale leaning on the subject side because the subject has adaptive capabilities, motivation, object oriented activities, which the tool doesn't have. In distributed cognition, it seems that the scale would be balanced because tools as well as human agents in the system are considered as representational media. We think the imbalance is not due to a too strong emphasis on tools but more to a lack of capabilities given to individuals. As there is no doubt that inter-individual interaction is the basis of co-operative work, it seems evident it is studied in each theory. The activity theorists described them as governed by rules (implicit or explicit), and related to the transformation process of the object. Ideally, these interactions would have to be analyzed from a historic-developmental viewpoint. An exchange between two persons lasting few minutes (micro-interaction) takes only sense when replaced in the larger context of the activity. In cognitive ergonomics, interactions may be seen either "vertically" following the hierarchical positions (explicit aspects) or "horizontally" spread out into informal political network of contacts (more tacit aspects). The second kind of interactions will depend on the flow of work at a given time. Work analysis in cognitive ergonomic refers not only to what is said but also sometimes to what is not said (or hidden behind the discourse).

Distributed cognition is mostly interested in interactions as a mean of following where the information is actually going (communicative pathways) and how it is transformed. The notion of interaction viewed by Hutchins and Klausen (1992) is the construction of a shared understanding of the situation in which the interactants find themselves. Interactants during their interactions may either use shared knowledge or construct a shared understanding of the situation. This

construct called the inter subjective understanding is what permits human actors to intend and find meanings of much non-verbal behaviour and in the aspects of verbal behaviours that go beyond the literal locutionary force of the utterance.

So in the three approaches transcripts of communications are the main materials that will allow the analyst to apprehend co-ordination in the system. Interactions may include the verbal communication but also non-verbal communication. For At, those interactions will serve to identify possible contradictions in the activity system. In Distributed Cognition, those interactions will enable the analyst to identify the communicative pathways and the transformation of information from one representational state to another. In Ergonomics as well the analyst will try to identify where the information has been propagated.

Activity theorists describes division of labour as a mediator between the community and the object in the transformation process of the object into outcome and define it as the explicit and implicit organization of the community.

For the cognitive ergonomists, a distinction has to be made between the prescribed division of labour and the actual and dynamic organisation of labour in reaction to events such as overflows of work, changes in individual workload. The interest on division of labour in distributed cognition reaches two levels. Firstly, these theorists will look superficially on how cognitive labour is socially distributed among the different individuals making part of the system. But things become much more interesting when the members of the system are required to co-ordinate their activities with each other when they start to interact with (Hutchins and Klausen, 1992). So, talking about explicit and implicit organisation in Activity Theory, or prescribed and actual division of labour in Ergonomics or nominal and violated division of labour in Distributed Cognition, it seems that whatever the vocabulary used in the three approaches analysts are interested by a same dichotomy: 'planned' division of labour and 'situated' division of labour.

The notion of representation is also used in the three approaches but do not necessarily refer to the same thing. In activity theory, representations are always seen as related to the action. For instance, when a worker works on a new order, she has in mind a plan

(representation) of actions and actions goals to perform. For these theorists, co-operative work requires common representations of the object of the activity and of the goal of collective actions. In other words, collective activity requires from individuals a common orientation basis (representation elaborated in order to guide performances).

The concept of operative images has had in the francophone ergonomics tradition an important success (while it does not appear as a main reference in the Activity Theory tradition). In a way the concept is not far different from what Norman (1983) suggested in saying that when interacting with their environment, with others and with technological objects, people create internal models of themselves and of the objects with which they interact. These models have to be functional in order to guide people in using objects. One of the major goal of a functional representation is to allow the subject to anticipate the result of his own action or of the mechanism that he controls. Therefore functional representations are studied by cognitive ergonomists focusing on some general characters. Firstly their finalization; representations are finalized and orientated toward a goal performance. There will be always a relation between the functional representation and the activity that the operator put into place to perform his task. Secondly the selectivity of representation; functional representations only retain the relevant properties of this activity. Cognitive ergonomists make the distinction between the figurative aspect (represented by some states of the process) and the operative aspect (characterized by operations that need to be performed). They also focus on the notion of common representations of actions and their roles in the co-ordination of the activity. Moreover, for them, distributed representations are not static, they evolve with experience and are progressively built on through exchanges between members of a task. Distributed representations have been defined as the common functional representation that guide and control an activity that is collectively performed.

Distributed cognition particularly assumes representations are not only in people's head but also outside. What these theorists are calling representations, are in fact the media of representation of the information which are either an internal representation (individual memories) either external representation (computer or paper-based displays). A related concept developed in Distributed Cognition, which emphasises the dynamic

feature of representation, is the representational state. It refers to how information and knowledge resources are transformed during activity, how representation (of information) evolves with time. In other words, we can say that activity theory and cognitive ergonomics do not understand the concept of representation as distributed cognition does. On the one hand representation refers to representation of action and is mainly internal while on the other hand, it refers to representation of information and is mainly external.

Activity theory and cognitive ergonomics are sharing a same interest in the goals of the subjects. In both theories, activity refers to an entity which is purposeful directed toward a goal being internal (i.e. strategies to perform the tasks) or external (i.e. organisations), and where goals can be shared among actors or not.

Both theories have evolved their separate way. In cognitive ergonomics, the idea of global object seems to have been forsaken while the concept of goal was emphasised. In activity theory, the evolution went in the opposite direction taking into account an object of activity larger and larger considering finally that the level of activity is collective. So, in the current activity theory, every individual goal have to be submitted to a collective object and a coherence in the collective object representations is a prerequisite for an effective collective activity.

A distributed cognition analysis begins with the positing of a system goal, which is similar to the activity theory notion of object, except that a system goal is an abstract systemic concept that does not involve individual consciousness.

Unlike distributed cognition, which is considering the system viewpoint, activity theory and cognitive ergonomics starts the analysis from the viewpoint of a subject. In Activity Theory the subject refers either to one individual or a sub-group making part of the activity. Starting from the point of view of a subject is apprehending the reality by the representation the subject has of the activity object. Choosing the right subject and comparing the viewpoints of the different subjects becomes then a crucial point. Indeed, different aspects of the activity will be outlined according to the viewpoints. It is then possible to consider successively the various subjects' viewpoints in order to obtain the most exhaustive analysis of the activity and to com-

pare the coherence between the different representations of the activity. Differently, Ergonomics when concerned by the analysis of activity starts also from a subject's point of view. It looks at what the subject is doing, how he is doing it, how he is going around the rigidity of the system, how he is developing a proper expertise. The historic-developmental viewpoint explained in Activity Theory seems to be specific to this approach, which sees all practices as the result of certain historical developments under certain conditions and as a continuously developing process. When ergonomists try to identify the subject point of view, they also take into account context and history of the situation. But it seems that the main difference between Activity Theory and Ergonomics when they talk about "history" is that in the first approach, the historical development is not only an object of study but also a research methodology. In Activity Theory the present work setting and its components can only be explained by their past developments.

The cognitive ergonomics specificity relies on the distinction made between task and activity, between the prescribed (explicit) aspects of what an agent has to do and the tacit aspects of how users are dealing with the variability and the complexity of the task. But this specificity is maybe only apparent because in Distributed Cognition and Activity theory, they are also taking into account the implicit (not prescribed) behaviour of the system. Nevertheless the particularity of Ergonomics exists because the analysis of the difference between implicit and explicit, more than object of study is there a research guideline. If Activity Theory and Distributed Cognition study implicit aspect of action when they are encountered, Ergonomics goes further and tries to explain the performed activity as an adaptation of the prescribed task to work conditions of the actual setting.

A specific concept of Distributed Cognition is the horizon of observation, which is the portion of the task that can be seen or heard by each team member. Distributed Cognition theorists study how the scope of this horizon may influence communication, co-ordination and learning. Ergonomics emphasises the study of 'environmental resources' on its predominant features: visual accessibility, shareness, transparency, openness. Those may depend in some way to the Horizon of observation.

The concepts developed by the three approaches, whatever echo they may find in the others, each framework emphasises different aspects of the reality. Activity Theory unlike Distributed Cognition and Ergonomics, takes into account a larger unit of analysis going out of the boundaries of the system. Another central focus in Activity Theory concerns the mediating role of the tool in the relation between the dis-patchers and the object. Each focus is studied from a historic-developmental viewpoint.

In Ergonomics we see two main focus. One concerns the individual activities and cognitive strategies developed by an individual facing the constraints of the work situation. The second one will be the collective activity system which seems very similar the functional system in Distributed Cognition.

Distributed Cognition seems more concerned by the systemic level. Actions goals and target behaviour are related to the system rather than the individuals. Regarding distributed cognition, the term cognition sounds totally inappropriate if cognition is intended in the classical way. It has never intended to describe cognition "inside people's head", studying how one person is cognitively managing the task but is much more interested in looking cognition "outside people's head" (or "system cognition"), how the system with its components is managing a given situation.

6. CONCLUSIONS

These theories point at some common elements in the system, so using the three approaches would be redundant. The way analysts look at the setting is imprinted by the concepts of the theory. By emphasising certain aspects of reality and dropping some other, the results of the analysis may be seriously modified. One option is to choose one of the three approaches. According to us, the choice of a theory should not depend on the analyst's background but be oriented by some features of the work setting to analyse and by the objectives of the analysis. This then requires to explicitly define criteria to make a choice. The other option is to use a hybrid approach integrating aspects of the three frameworks. In this case, we should be regarding at some possible incompatibilities that may arise among the concepts used.

To go deeper in the work of comparison we have start grossly here with a case-based comparison on the concepts and the focus of each theory, it could be useful to define some criteria. The first step consists of analyzing the goals of the work analysis. The second step involves transforming two kinds of goals (analysis goals and process goals) in a set of criteria. Then, with well-established criteria, we would be able to identify which theory is the most (or at least the less) suitable for a specific work setting taking into consideration the analysis process.

Activity theory and distributed cognition are very close in spirit, as we have seen, and it is our belief that the two approaches will mutually inform, and even merge, over time, though activity theory will continue to probe questions of consciousness outside the pur-view of distributed cognition as it is presently formulated. But cognitive ergonomics is a quite away from them.

But we see many differences between Activity Theory and Distributed Cognition as well.

1) Activity Theory has named its theoretical constructs well. Even though some names may conflict with common use of the terms, naming is very powerful – both for communicative as well as descriptive reasons.

In contrast, few theoretical constructs are explicitly named in Distributed Cognition are not presented in a way that gives them same the rhetorical force of naming as seen in Activity Theory. This is important because names are often what you manipulate in a theory.

2) In Activity Theory, the perspective of the individual is at the center of everything. Activity theory focuses on the cognitive process of an individual situated in a social, cultural, historical, and artifactual world.

In contrast, Distributed Cognition focuses on the socio-technical system, which usually (but not necessarily) includes individuals. Distributed cognition uses the same theoretical language for both people and artifacts.

3.) Dealing with process is built into the structure of how Activity Theory is presented. Activity system diagrams keep process in the foreground for both reader and analyst. This is somewhat ironic, since a static diagram represents essentially dynamic relationships between the key components.

In Distributed Cognition, process(ing) is so central to the analysis that it may be less obvious to the uninitiated. Unlike Activity Theory there is no iconic structure applied to each situation. Instead, it is built into the process of analysis, and may or may not be represented in the products of that analysis.

Activity theory seems the richest framework for studies of context in its comprehensiveness and

engagement with difficult issues of consciousness, intentionality, and history. The empirical studies from all three frameworks are valuable and will undoubtedly mutually inform future work in the three areas. Human-computer interaction studies is a corpus of knowledge that identifies the properties of artifacts and situations that are most significant for design and which permits comparison over domains, generates high-level analyses, and suggests actual designs. However, with a concerted effort by researchers to apply a systematic conceptual framework encompassing the full context in which people and technology come together, much progress can be made. A creative synthesis of activity theory as a backbone for analysis, leavened by the focus on representations of distributed cognition, and the commitment to grappling with the perplexing flux of everyday activity of the situated action perspective, would seem a likely path to success.

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