Activity Theory vs Cognitive Science in the Study of Human-Computer Interaction

Annette Aboulafia (1), Edward Gould (2), Thomas Spyrou (3)

(1) Dept. of Psychology, University of Copenhagen, Amager, Njalsgade 88, 2300 Copenhagen S, Denmark, annette@vax.psl.ku.dk
(2) Dept. of Business Systems, University of Wollongong, Northfields Ave, Wollongong, NSW, 2522, Australia, e.gould@uow.edu.au
(3) Dept. of Mathematics, University of the Aegean, Research Lab. of Samos, 83200 Karlovassi, Greece, tsp@aegean.gr

Abstract

This paper discusses the shortcomings of the cognitive science approach to understanding human cognition particularly in its relationship to human computer interaction. Its failure to distinguish between the psychic and the information processes in human and machine has led to a view of the computer as a 'replacement' for the human in intellectual spheres and the implication that a computer program is a theory of human thinking. An alternate psychological approach, namely Activity Theory, is suggested as a more broad based and durable framework for understanding 'humans interacting with computers' as it details the importance of work activity as the unit of analysis and emphasises the contextuality of computer use.

1. Introduction

The study of human computer interaction (HCI) has heavily favoured the exploration of the cognitive processes due no doubt to what is seen as the qualitative new form of artefact embedded in the use of the computer - the automation of brain work compared to the automation of hand-work. This paper explores two different approaches to the study of cognitive processes, the well known cognitive science approach and the lesser known Russian developed activity theory. We will show-that many of the problems associated with the information processing model of cognitive science, evident in such areas as expert systems and artificial intelligence, can be seen to be related to the incompleteness and narrow base of this approach. Activity theory, on the other hand, takes a broader view of the 'technisation' of human operations and places HCI within this wider framework. Computerised automation, where the operational aspects of human mental work are removed from the 'human sphere' and transferred to technology, are part of, and not significantly different to, the transference of human physical work to technology which has been going on for thousands of years. When operations are carried out by technology, they still realise the wishes of the subject, and hence involve the human psyche. Activity theory is explained in detail in a later section but first we need to look at the problems associated with the current cognitive science approach.

2. Cognitive Science and Artificial Intelligence

Cognitive science emerged in the mid 1970s out of a realisation that a multi-disciplinary approach was required if we were to understand higher mental processes and structures. It attempts to bring together what is known about the mind from many academic disciplines: psychology, linguistics, anthropology, philosophy, and computer science. The assumption is that all important human insight can be reduced to principles and rules - that machines can think (McCorduck, 1979). Cognitive science asks about thought and thinking, about consciousness and computation.

In line with cognitive science the concept of cognitive psychology emerged in the USA and UK as an outcome of computer technologies by assuming that the computer can provide a new paradigm for psychology. Cognitive psychology therefore, analyses human mental processes with the aim of understanding human behaviour. Information theories of perception, attention, memory, emotions and personality are developed. Humans are viewed as an 'active process of information eternally striving to sum up and interpret the incoming data and to interpret and reproduce the information stored in its memory through a variety of algorithms and strategies' (Tikhomirov. 1988). In this trend Psychology at large was declared a science of information processing. Although AI, cognitive science and cognitive psychology have different aims and methods of investigation, they basically all share an understanding of human thinking as information processing. In addition they interpret cognition or intelligence as the most important constituent property of the psychic processes. When using the concept of cognitive approaches in the following we do not distinguish between the three of them.

Artificial Intelligence (AI) aims at creating computer software and hardware that imitates the human mind or functions of the human brain. The role of the computer is to replace the human in intellectual spheres, such as mathematical calculations, manipulation of numbers and letters, decision-making, problem-solving, and so on. According to Feigenbaum (1977) some work towards the construction of intelligent artefacts such as expert systems, which purport to be models of experts' problem solving and expert knowledge automatizised in information programs. Others view artificial intelligence as 'theoretical psychology' seeking information processing models of human thoughts leading us to a view of AI as the study of 'cognitive' phenomena within the machine.

2.1 Human Computer Interaction

Human-computer interaction (HCI) is an interdisciplinary area of applied research and design practice which attempts to understand and facilitate the creation of user interfaces. In order to understand the cognitive aspects of this interaction, the HCI field uses the knowledge accumulated within AL cognitive science and cognitive psychology. From AI research HCI may use a variety of cognitive models for representing the user, as well as the means to test these models. Cognitive science offers HCI a knowledge of what users understand and how they understand it. From cognitive psychology HCI uses the knowledge about cognitive processes and structures as well as the method of investigation: an empirical approach to the study of human behaviour (Booth, 1989). These traditional cognitive approaches embedded within HCI methods and techniques however, have a limited impact on design practice (Warren 1992).

Two related points of critiques have emerged. One argument is in opposition to the very rational conception of human beings embedded in the cognitive approaches emerged from a meta-theoretical point of view (e,g. Dreyfuss and Dreyfuss 1986). Also some empirical studies suggest that the design process is characterised by intuition and imagination as the driving force of the process, rather than a rational problem-solving strategy (Aboulafia et al 1993). In most cases the designers relied upon their intuitive understanding of the system, gained from previous experience. Another design study showed similar results. Bansler and Boedker (1993) found a gap between the way systems development is represented in structured analysis by Yourdon and DeMarco and the way in which it was carried out. Designers did not follow the design procedures prescribed but, in general, had a very pragmatic attitude towards using it.

As well as arguing against the limited understanding of problem-solving as being a rational rule-based process of thinking, the studies indicate that the way methods are used is related to the context of application. A general view by the designers in one of the studies were that a main hindrance in modelling techniques was that these techniques didn't take into account social aspects, such as team work and organisational issues (Aboulafia et al 1993). They suggested that 'a bag of tools' from which they could pick and choose, would be useful, so they could adapt different methods to their own purposes and integrate these into their own design processes.

Another criticism is related to the attempt to use the same concepts and methods as properties of both systems and human beings. Bansler and Boedker's (1993) study found a possible limitation of modelling methods 'inherent' in the methods themselves. The basic idea of structured analysis is to model organisations and work processes as information processing systems with the aim of producing detailed functional descriptions of tasks and operations. There is no distinction made between the way people act and the way machines function. Consequently, the method has a number of 'defects' such as reducing problem solving and judgement to mere rule following, ignoring informal communication, underestimating of errors, giving no help to analysing work organisation, etc. And as Bansler and Boedker (1993) stress, while is makes sense to understand a computer system in terms of data processes, it is doubtful whether it makes much sense to understand work in these same terms.

It is becoming more obvious to even die-hard AI proponents that the information processing units in humans and computers are indeed different. Much criticism therefore, has emerged of this cognitive science understanding of human cognition, and a quesion is if it possible to overcome the problem within the framework of cognitive science. The next section details one such attempt.

2.2 Cognitive Engineering

In order to compile a critique of cognitive approaches we also sought a welt developed framework for the design of interface systems which look further than the design of screen layout. We therefore chose Rasmussen (1986) who argues his case from within the cognitive approaches framework but with a good grasp of its limitations particularly for the design of supervisory control systems. This is not surprising since it is within this area of real time computer control that the differences between human and machine are most obvious particularly when computerised systems impinge so much on the infrastructure of the modern industrialised world.

Rasmussen's basic premise is that in spite of a difference in the information processes of computers and the mental decision processes of its operator some match must be found if they are work together harmoniously. It is, he says, not so much a question of whether 'holistic human perception be properly modelled by the sequential digital systems of computers but whether there exists a theoretical framework formulated independently of the tools for experimental implementation.' He begins by considering Simon's hypothesis (Simon, 1969) that the human psyche is actually quite simple with any complexity due to the environment. This view-correlates with the cognitive approaches that humans respond to stimuli in the environment, process it internally and produce some appropriate output. In other words keep the input simple and the internal process will by definition be simple. But as he points out this 'simplicity rapidly evaporates when considering the models required for real systems design.' He goes on to expound the view of Gibson (1966) that 'humans are not processing the information input from the environment - they are actively picking up the information that is relevant in the context of their current needs and goals.' It is control of this information pickup where the focus of HCI should be.

To control this information pickup Rasmussen says is only possible if a person has an 'internal dynamic world model[1] and that 'the human-machine interface should therefore be based upon compatible models of the data processing in humans and in instruments' and further that 'in order to have a basis for man-machine systems design, it is important to identify manageable categories of human information processes'. From these basic premises he has devised a map of the human data processing functions showing the relationship among functions at the psychological level. He has maintained the familiar cognitive three level model viz., 'a front -end function: perception' (input), an 'internal dynamic world model' (processing) and 'a motor function' (output). On perception he notes that humans use the 'internal dynamic world model' to control input to what is essential to the actual goal. This is organised top-down in an abstraction hierarchy and essentially filters out 'noise' in much the same way as direct and peripheral vision. A great deal of attention is paid to the processing phase of this cognitive model and it is analysed in terms of mental maps, semiotics, human error analysis as well as decision theories and approaches taken by the artificial intelligence community.

What is important here is that Rasmussen, although using the traditional cognitive view of the human psyche was able to see the complications it leads to. He stated that 'humans are not simply deterministic input-output devices, but goal oriented creatures' and that 'human activity in a familiar environment will not be goal-controlled rather it will be oriented toward the goal and be controlled by a set rules that have proven successful previously.' Given the limitations of cognitive approaches this seems to be about the best one can do but it still does not provide and has not led to design strategies for the human-computer collaboration.

Others have also echoed this sentiment. Landauer (1987) has been critical of cognitive approaches for not having provided a 'tool-kit of design methods' or even a relevant body of scientific knowledge. It has also, he goes on to say 'suffered from the lack of an applied discipline in which the completeness of its accounts could be measured[1] and 'theories we have pursued have led away from rather than towards attempts to describe in lull the performance in any given task situation'. He also makes the point 'There is no sense in which we can study cognition meaningfully divorced from the task contexts in which it finds itself in the world'.

3. Activity Theory and Information Technology

Historically, Activity Theory emerged as a reaction to the gap between a materialistic view (natural science) and an idealistic view (science of the 'spirit') of human life (Leontjev, 1978). Neither of these methods for explaining the human being, captures the developmental process between a person and their environment. The theory of Activity is an attempt to overcome this problem by introducing the concept of Activity, where the subject and the object are viewed as poles of a system of activity, which emphasises the active nature of humans (Leontjev 1978).

The orisinal foundation of Activity Theory was laid down by Vygotsky (1920-30). His basic idea was that human activity is mediated by cultural signs: words and tools, which causes changes in a person's activity, and thus its mental reflection. The structure of external and internal activity thus constituting a unity. Activities are initially carried out on the external plane, and are then internalised with many psychological functions such as attention, memory, and thinking(Vygotsky 1978). Vygotsky's work was continued by A.N. Leontjev who developed a conceptual framework for the theory of Activity based on the mental reflection and the corresponding activities in the evolution of animals and humans.

3.1 Activity Theory and Cognitive Approaches in HCI

Rasmussen sees the limitations of an information processing approach to human cognition by observing a difference in the information processes of computers and human mental decision processes. His proposed model is never-the-less within the framework of the information processing paradigm with its traditional cognitive three level model: input (perception), an internal world model (that processes and controls the input), and motor output. This understanding of the human-computer system may be characterised as an 'information processing loop' where the output from the human being, enters the computer's input, and visa versa (Kaptelinin, 1994). But as pointed out by Kaptelinin, although this approach has the advantages such as providing a coherent description of the whole system of HCI within the information processing framework and able to structure the problem space in a useful way, it also has some limitations. Thus, the following analysis of Rasmussen's approach is seen as one of the cognitive approaches in general, where the human mind is understood as a specific type of an information processing unit.

Activity Theory does not reject the object research in cognitive approaches as an attempt to simulate and automatise cognitive functions of human beings. Activity Theory attacks its theoretical basis: the principle of cognitive identity between human thinking and computer simulation, e.g. the capacities of the human perception being compared with machine simulated perception (Karpatschof, 1990). Tikhomirov (1988) stresses that mental reflection of a problem situation and the search for a solution differs qualitatively from similar processes as executed by the computer. Processes and mechanisms of cognitive activity in a computer program therefore, can by no means be used as a criterion for scientific understanding of the nature of these processes and mechanisms.

From a methodological point of view cognitive approaches have attempted to replace behaviourism by introducing cognitive processes between influence and behaviour, believing that there is more information in the perceptual response than in the stimulus that prompted it into the response (Engelsted. 1994). But although Rasmussen's cognitive model enriches the analysis of human behaviour by introducing an intervening variable - an 'internal world model'- he still remains within what Leontjev (1978) calls 'a binomial level of analysis", which has methodological problems for psychological science. It excludes from the field of research the cogent process in which real connections of the subject with the object world are made. Human dialectical unity in activity is not grasped - the reality- is divided into a world of stimuli ('things') acting on the (passive) subject, and a world of responses (Asmolov 1986-87).

The notion of an 'internal dynamic world model' understood as 'an ego sitting behind doing the thinking', corresponds with some tenets of Activity Theory. However, the content and the meaning of this 'internal capacity' is different. Within cognitive approaches internal capacity is recognised as a 'work up' of sense impressions by different rules: computation, feedback and memory, which together, may be called reflection (Engelsted, 1994). A striking example is Brooks' artificial insects, consisting of simple 'reflexes' such as 'track prey', 'back off and 'avoid stuff, which are called up as a function of 'sensory input' (Churchland and Sejnowsky 1992). Brooks and colleagues built these robots in order to find out how the nervous system function in the real world. But although reflection exists and plays an important role in our mental processes, it is not the mental processes itself. Reflection remains a sense result - it cannot add something more to sense impressions (Engelsted, 1994). So even if humans do have an equivalence to 'artificial reflection', the consequential issue is that the most important type of human reflection is embedded in the activity. Even the result of Brooks' study may be interpret in this direction. Although his artificial insects was able to exhibit new-behaviour as the outcome of combining parts of the 'reflex' behaviour, these results led Churchland and Sejnowsky (1992) to suggest that '"the complexity we intuitively ascribe to internal cognitive states may actually be a matter of complexity in the world with which a relatively simple organisation has evolved to mesh".

Modelling events in one's mind is not the essence of thinking or the psyche as stressed by Leontjev's activity. Just like psychic images, he says, it is not produced by the brain but is its function, and consists of theimages realised by means of the physical organs of the subject (1978). From a phenomenological point of view, also Merleau-Ponty, mentions that the reality of perception is not based solely on the intrinsic coherence of 'representation': "The world is ... the natural setting of, and field for all my thoughts and all my explicit perceptions ...There is no inner man, man is in the world" (1962). So even though artificial intelligence in its guise of artificial mechanism, is able to sense and reflect, and, even though reflection is able to create intelligence, it does not create the psyche. Psyche is absent in the machine because these artificial mechanisms can never become psychic (Engelsted 1994).

Activity theory points to the notion of conation when defining the essential characteristic of the psyche in line with existentialism and phenomenology. The definition of psyche as a conative goal directedness is what cognitive science evades. When cognitive science continually gets into the problem that robots do not know the difference between essential and not essential, it is because machines have no activity, which sets the frame for the conative goal directedness (Engelsted 1994). Concepts such as activity, meaning, motives, emotions and cognition are closely related to conation or intentionality. These psychological phenomena can never be mechanised. Thus, art information processing approach to human cognition fails to understand the essential characteristics of human activity, and thus of the cognitive processes embedded in this activity.

Within Activity theory the 'internal capacity" is understood as an internal plane of actions (IPA) which integrates the computer into the structure of human activity (Kaptelinin 1994). The function of IPA is to 'simulate potential outcomes of possible events before making actions in reality' (ibid.) and that is far from being a simple reactive reflective mechanism. The human mind can only be understood adequately within the context of a subject's interaction with that world (Kaptelinin, 1992).

Broadly speaking we may say that cognitive approaches focus on the mental processes in the meaning of a 'thinking subject' (re Descartes), i.e. psyche is understood as a reflecting rationale, as a cognitive content, whereas Activity Theory focuses on the human activity in the meaning of an 'acting subject', i.e. psyche is understood as an act of intentionality, or conation (re Brentano). This understanding does not exclude the cognitive aspect. Activity also has a cognitive moment, but it is embedded within the activity. As such, cognitive approaches may be seen as a subset of an Activity theory approach (Kaptelinin 1994).

4. Work Activity - the context of IT and HCI

As indicated previously the limitation of modelling methods to support the design process, may be due to their lack of taking 'context' into account. However, the notion of context needs to be conceptualised. Kuutti points to the importance of focusing on work activities as the context of Information Svstems (IS) saying, 'We are never developing only IS, but the whole of the work activity where it will be utilised'(1990). But how do we conceptualise work activities?

Leontjev (1978) has developed the inner structure of activity' based on the principle of analysis by units, meaning that all main properties are inherent in the whole. The units of activity are actions and operations characterised by a hierarchical structure. Activities are distinguished on the basis of their motive; actions, on the basis of their goals; and operations, on the basis of the conditions under which actions are carried out. The conceptualisation of these 'units' makes it is possible to identify: the reason for an activity by defining the motive of activity; the aim of an activity by defining the goal toward which the subject strives; in what ways or means an activity is carried out, by defining under which conditions the action takes place.

Technoiogy-in-use changes work conditions by increasing the level of automation. From a psychological point of view automation is understood' as 'technisation' of human operations. But although, operations may be carried out by a machine (e.g. 'technisation' of mental processes), yet they realise the action and its goal of the subject. Action and operations do not constitute any kind of 'separateness' in relation to the activity (Leontjev 1978). Consequently, the view of computer applications as 'replacements' for operations (e.g. senso-motoric level of analysis) is not sufficient for analysing work situations. The tool is not simply added on to human activity, rather it transforms it (Tikhomirov 1981). Analysis of any kind of 'work behaviour' must therefore include all three levels of analysis: activity, action and operation, the minimal unit of analysis being the activity.

Within HCI the highest level of contextualisation is usually the task level. Task analysis based on behaviouristic method identifies the outer behaviour of work activities. Although this analysis may have an important function e.g. in order to describe job requirements, the distinction between human and computer tasks, etc., such an analysis is rather limited in relation to identifying psychological processes in work activities. Focusing on the observed behaviour do not say much about the inner structure of activity, as the same observed behaviour may correspond to different motives and goals of the individual. For instance operating a computer can be a playing -, learning - or a working activity, thus having different personal sense for the subject. Thus, Landauer's (1988) suggestion for studying cognition within its task context, do not solve the problem of contextualisation. As said by Draper (1992) human procedures are not determined by the task, but on special characteristics of the case. We therefore suggest that in order for task analysis to have any real significance in design, it needs to be embedded within the work activities. Also we want to stress that because activities are in constant development, it is impossible to make a general classification of activities, actions or operations. The identification is dependent on the activity of the individual.

Apart from the possibility of analysing human behaviour from a functional point of view and not only from a phenomenological description (as e.g. task analysis), the identification of the various levels of analysis are important in order to understand cognitive processes, thought and action, etc. Machines mediate the activity of people requiring a specific Type of activity to operate them (Tikhomirov 1981).

Consequently, automation of mental processes should not be seen as a replacement of the human work, nor as a supplement, but as an reorganisation - "we are confronted with the reorganisation of human activity and the appearance of new-forms of mediation in which the computer as a tool of mental activity transforms this very activity" (ibid.).

5. End Remarks

We have been arguing for a broader conceptual understanding of the HCI research in order to overcome some of the problems embedded in the cognitive approaches to understanding the essence of human thinking. Designing tools means designing conditions, organisational structure and communication patterns for people in work situations. Thus, we need to extends the level of analysis from focusing on the human-computer interaction, towards the context of this 'interaction', i.e. the work activity.

We suggest that Activity Theory may be used as a conceptual framework for cognitive approaches. Activity theory is able to conceptualise humans in their contest, tools as mediating work activities and developmental processes. Taking on an Activity Theory approach means that Activity is the core point of departure for any kind of human research. Activity Theory, however, is not a monolithic 'theory', but more a frame to be filled out and a set of insights to be utilised - a set of basic principles evolved from a dialectic materialistic approach to understand human life (Engelsted 1994). All the principles that have been delimited in Activity Theory are no more than premises that determine the general direction of development of contemporary psychology (Asmolov 1987).

The major characteristics of human thought activity are not reproduced in artificial intelligence systems, and the development of artificial systems need not imitate the structure of human intelligence. The principal applied psychological problems are how to make sure that the persons using the computer is able to further improve their thinking. Tikhomirov (1981, 1988) suggests a new branch of psychology be developed: the psychology of computerisation, which would analyse the reorganisation and optimisation of human intellectual, communicative and creative activity as a result of the use of computers, asking questions such as 'What are the psychological conditions making this possible?' and 'How to expand the potential of artificial intelligence systems by using the psychological knowledge about thinking processes?'

References

Aboulafia, A.. Nielsen, J.. Jorgensen.. A.H. (1993). The Ambiguous Reality and Formal Methods in User Interface. Design, Interchi'93 Research Symposium. Amsterdam. April 1993.

Asmoiov, A.G. (1986-87), Basic Principles of a Psychological Analysis in 'The Theory of Activity', Soviet Psychology, Winter 1986-87 Vol 25, nr 2, p 78-102.

Bansler. J. P. and Boedker, K.(1993) A Reappraisal of Structured Analysis: Design in an Organisational Context. In: ACM Transactions on Information Systems, Vol. 11, No.2, April 1993.

Booth, P. A. (1989) An introduction to human-computer interaction. Lawrence Erlbaum Ltd.

Draper, S.W., Activity Theory: the new direction for HCI? In: Int. J. Man-Machine Studies (1992), 37,p 812-821.

Dreyfus, H.L. and Dreyfus S.E., (1986) Mind Over Machine, Free Press (Macmillan), NY

Churchland, P.S., Sejnowsky, T.J. (1992) The Computational brain. The MIT Press, London.

Engelsted, N. (1994) Floden og svommeren eller hvad psykologi egentlig drejer sig om? Virksomhedsteori i udvikling, Mammen & Hedegaard (eds.) Psykologisk skriftserie, Aarhus universitet. Vol. 19, no. 1, pp 11 -42.

Engelsted, N., (1993) At a crossroads - An introduction, in: The Societal Subject, Engelsted et al (eds), Aarhus University' Press. 1993.

Feigenbaum, E. A. (1977) The art of Artificial Intelligence: themes and case studies of knowledge engineering. 5th IjCAI-77, 1014-1024.

Gibson J. J. (1966) The Senses Considered as Perseptual Systems, Boston, Houghton Mifflin.

Kaptelinin, V. (1992) Human-Computer Interaction in Context: The activity Theory Position, Proceedings East-West Intl.Conference on Human-Computer Interaction, St Petersburg, Russia.

Kaptelinin, V. (1994) Activity Theory: Implications for Human Computer Interaction. In: Brouwer-Janse, M.D., Harrington, T. (eds.) Human-Machine Communication for Educational Systems Design. NATO ASI Series. Series F: Computer and Systems Sciences, v.129. Berlin etc.: Springer-Verlag, 1994. pp. 5-16.

Karpatschof, B.(1990) The control of technology and the technology of control, The 2nd International Congress for Research on Activity Theory, Lahti, Finland, 22-25 May, 1990 and in Activity Theory 11/12. 1992, pp. 34-40.

Kuutti. K. (1990) Activity theory and its application to information systems research and development. In: 1SRA-90 precedings - vol. I, IFIP TC 8 WG 8.2. Working Conference on the information systems research arena of the 90's, Copenhagen, 1990.

Landauer, T.K. (1987) Relations Between Cognitive Psychology and Computer System Design, in J.M. Carroll (Ed), Interfacing Thought, Cambridge. Mass, MIT Press

Leontjev, A.N. (1978) Activity. Consciousness, and Personality, Prentice-Hall.

McCorduck, P. (1979) Machines who think. Freeman and Company, San Francisco

Merleau-Ponty, M. (1962) Phenomenology of Perception, Routledge & Kegan Paul Ltd.

Rasmussen, J. (1986) Information processing and human-machine interaction - an approach to cognitive engineering. North-Holland Series in System Science and Engineering, Vol. 12. North-Holland.

Simon, H.A., (1969) The Sciences of The .Artificial. Cambridge, Mass. MIT Press.

Tikhomirov. O.K. (1981) The Psychological consequences of computerization. In: J. V. Wertsch (ed). The Concept of Activity in Soviet Psychology. M. E. Sharpe. Inc., Armonk. New York.

Tikhomirov, O.K. (19S8) The Psychology of Thinking, Progress Publishers

Vygotsky, L.S. (1978) Mind in Society: The Development of Higher Psychological Processes, Harvard University Press.

Warren, C.(1992) Panel session at the HCI'92 Conference. York, UK: HCI- Where's the Practice? In: Int. j. Man-Machine Studies (1992), 37, p 811-812.