DTU Library

Affordances in activity theory and cognitive systems engineering

Albrechtsen, H.; Andersen, H.H.K.; Bødker, S.; Pejtersen, A.M.

Publication date:
2001

Document Version
Publisher's PDF, also known as Version of record

Risø-R-1287(EN)

Affordances in Activity Theory and Cognitive Systems Engineering

H. Albrechtsen, H.H.K. Andersen, S. Bødker,
A.M. Pejtersen

Risø National Laboratory, Roskilde
August 2001

Abstract For the last decade, the Gibsonian concept of affordances has attracted much attention within Human-Machine Interaction (HMI) and related research communities. The application of Gibson's ideas in HMI has lead to the notion of direct manipulation of interface objects. Previously, the focus has been on design for low level interaction modalities. To incorporate the concept of affordances in the design of human computer interaction it is necessary to systematically unravel affordances that support human action possibilities. Furthermore, it is a necessity that Gibson's theory of affordances is supplemented by careful analyses of other human modalities and activities than visual perception. Within HMI two well established perspectives on HMI, Activity Theory (AT) and Cognitive Systems Engineering (CSE), have discussed such analyses and design of action possibilities focusing on providing computer support for work situations. Within these perspectives, the primary unit of analysis in HMI is human work activity and the socio-cultural context in which this activity is carried out. Thus, they emphasise the actors' purposeful activity as the most important design rationale. According to previous views in HMI, notably those that have been put forward by Norman and Gaver, affordances are in the foreground, whereas the system or work area is in the background. AT and CSE share the view that the actors' perception of foreground and background shifts dynamically according to the actors' situational context in purposeful activity. AT and CSE follow the original notion by Gibson on the actor's dynamic shifting between foreground and background of the environment. Furthermore, their work- and actor-centred approach to analysis and design of information systems opens up to an extension of Gibson's original ideas to cover deeper semantic and pragmatic aspects of the ecology of work, as compared with the previous applications of Gibson's theory in HMI.

ISBN 87-550-2927-2
ISBN 87-550-2928-0 (Internet)
ISSN 0106-2840

Print: Pitney Bowes Management Services Denmark A/S, 2001

Contents

1 Introduction *6*

2 Background *7*

2.1 Gibson: affordances, perception and information pickup *7*
2.2 Affordances in HMI *8*
2.3 Intuitive interfaces *11*
2.4 The deep structure of affordances *12*
2.5 Current interdisciplinary discussions of Gibson's affordance concept *13*

3 Activity theory and affordances *15*

3.1 The social-historical dimension *16*
3.2 Learning *17*
3.3 Tools as functional organs *19*
3.4 Different foci in use activity *20*

4 Cognitive Systems Engineering and affordances *21*

4.1 Skills Rules Knowledge (SRK) *21*
Skill based behaviour *22*
Rule based behaviour *22*
Knowledge based behaviour *23*
4.2 Affordances are structured: developing the early principles of Ecological Interface Design (EID) *24*
4.3 Affordances are intentional: developing the early principles of Ecological Information Systems (EIS) *26*
Structured affordance spaces in EIS *27*
EIS and loosely coupled domains *28*
EIS affordance spaces for the actors' strategies and intentions *29*
Future work: Affordances are social intentions - ECIS *30*

5 Discussion *31*

5.1 Applications of Gibson's affordance concept in HMI - advantages and disadvantages *31*
5.2 Conceptual and intentional affordances *32*
5.3 Perception-action versus interpretation and understanding *33*

6 Future work *34*

References *45*

Preface

This report covers the research on affordances and HMI carried out in the project on Theories and Methods within the Centre for Human-Machine Interaction (CHMI), during 2001. The research on affordances was initiated at a joint workshop on "Affordances, Actions, Signs and Constraints", held by CHMI at Molslaboratoriet, 2000, which involved all partners of the centre. The major topics of this workshop are documented in the report "Theories and Methods" (CHMI, April 2000) by A.M. Pejtersen, S. Bødker & P.B. Andersen. The aim of the present report is to revisit the concept of affordances in the light of activity theory and cognitive systems engineering. This research is carried out in the CHMI project on Theories and Methods.

We gratefully acknowledge the support of the Danish National Research Foundation for the present report. We want to thank William W. Gaver, Royal College of Art, London, U.K., for valuable discussions and insights on the affordance concept in HMI. In addition, we acknowledge the constructive comments by Klaus Bærentsen, Aarhus University, Denmark, Bonnie Nardi, Agilent Technologies, Palo Alto, USA, Wendy McKay, INRIA, Le Chesnay, France, Polle Zellweger, Xerox Palo Alto Research Center, USA and Raya Fidel, University of Washington, Seattle, USA.

1 Introduction

In 1950 the American psychologist J. J. Gibson laid the foundation for the ecological approach to psychology that is based on the concept of direct perception. According to Gibson, action and perception are linked through real world objects that afford certain forms of action possibilities for particular species or individuals. During evolution the perceptual apparatus of humans has become capable of picking up affordance information directly from the environment without further cognitive processing.

For the last decade, the Gibsonian concept of affordances has attracted much attention within Human-Machine Interaction (HMI) and related research communities. The application of Gibson's ideas in HMI has lead to the notion of direct manipulation of interface objects. That is, focus has been on design for low level interaction modalities. This has lead to many interface improvements, but this focus may also constrain the work within HMI in several ways. One example is dynamics, that we as humans are able during use to discover new action possibilities. Another example is individual physical and psychical differences - as adults we perceive action possibilities that are hidden for the child. A third example is the significance of motivation - children who are not very hungry start to play with the food.

To incorporate the concept of affordances in the design of human computer interaction it is necessary to in a systematic way to unravel these and other aspects of human action possibilities. Furthermore, it is a necessity that the theory of affordances is supplemented by careful analyses of other human modalities and activities than visual perception. Within HMI two well established perspectives on HMI, Activity Theory (AT) and Cognitive Systems Engineering (CSE), have discussed such analyses and design of action possibilities focusing on providing computer support for work situations.

Gibson worked in a psychological domain, and it is important to bear in mind that HMI is not psychology, and that it is not of primary concern to HMI research how animals survive in their natural environments, neither is it of primary importance to understand what perception is to the human being. The primary importance lies in how we may understand the relationships between human beings and computer-based artifacts, and how we design affordances so as to improve on human computer interaction in work. This is not unproblematic, however, and many questions have to be answered:

(1) How has Gibson's affordance concept been applied or extended within current HMI research, and what kinds of advantages and shortcomings have been identified? (2) Is there a contradiction in terms, with respect to Gibson's original theory of direct-perception-action, and recent developments in HMI research for affordances? (3) How can affordances in information systems articulate semantic or pragmatic levels of the users' work problems and environment? In Bærentsen’s (2000) terms such conceptual affordance is often presented to the user through linguistic instruction explanation. On the other hand Bærentsen argues that many systems requires reading and symbolic processing and that many aspects of these often menu based systems would support user navigation far better if they instead offered graphical displays of dynamic information based on Gibson ideas. Would it possible in the light of AT and CSE to detect and explain conceptual affordances (or intentional affordances as we prefer to name them) is such a way that they can be delegated to a perceptual level? (4) How do AT and CSE view possibilities of going beyond the 'grand divide' between perception-action on the one hand and interpretation/understanding on the other hand? (5) How do AT and CSE view possibili-

ties of extending the original concept to cover concepts like social interaction, cooperative work and inter-subjectivity in HMI design and evaluation?

In the next chapter we introduce the basic concepts of affordances and discuss the use of the concept within HMI from a broad spectrum of theoretical perspectives, including ecological psychology, semiotics and epistemology. The following chapters present the AT and CSE approaches to the Gibsonian ideas. In section (5) we discuss and sum up on previous and current definitions and two of the approaches in CHMI. Section (6) concludes on the discussion and points at new questions, opportunities and conceptions of affordances.

2 Background

The concept of 'affordances' was originally coined by American psychologist J.J. Gibson (Gibson, 1979). The concept of affordances is an important element in Gibson's ecological theory of direct perception and action which constitutes an alternative to the information-processing paradigm that previously dominated research in the psychology of perception, in particular in the United States. Gibson's theory broke with previous dualistic conceptions of the relation between an actor and the environment, held by for instance cognitivism and behaviorism (Zaff, 1995). In Gibson's view, it is the very mutuality1 between actor and environment that constitutes the basis for the actor's perception and action:

> "An affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behaviour. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer" Gibson, 1979, p. 129)

Hence, the primary unit of analysis is not the actors nor the environment as distinct categories, but the *total ecosystem of actors and environment*. According to Gibson, *affordances* are material properties of the environment that can support the actor's existence and survival, such as fruits, vegetables, cattle and prey. That is, properties that can be acted upon, for instance be harvested, hunted, cooked and eaten.

2.1 Gibson: affordances, perception and information pickup

But if the existence of affordances is vital to survival, then how can the actor perceive that the necessary affordances exist within the environment? Within this question is the ontological dimension of whether affordances exist per se, independently of the actor's perception. Furthermore, the question implies an epistemological dimension: how does the actor perceive an affordance, and how

1 The application of the term "mutuality" here should not be confused with the extended conception of 'mutuality' as a kind of singular "natural law" for construction of meaning and values, an extension suggested, for instance, by some ecological psychologists observation by Reed, 1996)

does the actor decide to perform or not perform an action relative to a perceived affordance. Gibson addresses this question from a primarily epistemological perspective when he says:

> "The central question for the theory of affordances is not whether they exist or are real but whether information is available in ambient [arrays] for perceiving them" (Gibson, 1979, p. 140)

Gibson also uses the ecological concept "niche" to discuss the *mutuality* aspect of affordances:

> "The niche implies a kind of animal and the animal implies a kind of niche" Gibson, 1979, p. 128)."

A certain niche is occupied or utilised by a certain species of animal. A niche refers to *how* an animal lives not *where* it lives. Gibson suggests that a niche is a set of affordances that constrains possible behaviour with respect to what we are able to do in a certain niche. He also notes that a niche with all its affordances in terms of physical, chemical and geological conditions of the surface of the earth existed before animal life began and that these had to be invariants for life to evolve.

So, in addition to the tenet of *mutuality* between the actor and the environment, Gibson claims the necessity of *available information about affordances* in order for their perception and information pickup to occur. According to Gibson, the existence of such "collocative or exploratory contexts" for affordances is a crucial element of the ecology. Such contexts are in Gibsonian terms 'invariants' and 'invariant structures' (Gibson, 1979, p. 73). Because of the mutuality of actor-environment, invariants are not perceived in the environment only, but are also perceived for the actor him/herself:

> "When a man sees the world, he sees his nose at the same time; or rather, the world and his nose are both specified and his awareness can shift. Which of the two he notices depends on his attitude*; what needs emphasis now is that information is available for both*" (Gibson, 1979, p. 116, our underlining)

2.2 Affordances in HMI

Gibson's notion of affordances has been subject to a great deal of interest by HMI research. Within this research, understandings of what affordances *are* and what they are *for* vary from design approaches, based exclusively on Gibson's introduction of the concept, to approaches that are in addition based on socio-cultural and/or engineering frameworks to guide design and evaluation in HMI. Ecological psychologist W.W. Gaver has explored Gibson's original notion of affordances for the design and evaluation of user interfaces in HMI (cf. for instance, Gaver, 1991). Gaver defines affordances as:

> "… properties of the world that are compatible with and relevant for people's interaction. When affordances are perceptible, they offer a link between perception and action; hidden and false affordances lead to mistakes" " (p.79).

Gaver's affordance concept is put forward as an ecological alternative to the information processing paradigm in HMI research and development. Building from Gibson's linking of affordances with their immediate environment, i.e. how affordances must be collocated with the necessary information, or invariants, in order to be perceived and acted upon by the user of an information system, Gaver (1991) proposes the following taxonomy for affordances in user interfaces:

a. Perceptible affordances:
This category of affordances in user interfaces is linked with perceptual information (or invariants). User interfaces can offer perceptible affordances because they can offer information about objects that can be acted upon; example: a button's "pressability". However, one challenge here is that affordances in an artificial environment can be misperceived. If you try to act by pressing the button on a non-touchable screen by your finger nothing happens.

b. Hidden affordances:
This category of affordances covers existing affordances in an information system, where no perceptual information is available in the interface. They then have to be learned.
Gibson notes that usually the basic affordances of the environment are directly perceivable; eg.: "but we must, *of course,* learn to see what things really are-for example...that the helpful-sounding politician is really a demagogue" (Gibson , 1979, p 142)

c. False affordances:
This category covers perceptual information on a non-existing affordance, upon which users mistakenly try to act. Again Gibson talks about misinformation for affordances. The affordances are there but are misperceived. A much-cited example is the study of children's misperception of a visual cliff. According to Gibson, however, there is no such thing as a non-existing affordance. An affordance of an object, if perceived correctly, signifies the object.

Gaver, as did Gibson, could be argued to follow a realist ontology in the sense that affordances are regarded as existent in the environment (= in Gaver's conception, the information system), independently of perception. Gibson addressed the *epistemological* perspective of affordances through introducing the concept of invariants as contextual elements, or backgrounds for affordances. An information system is an artificial environment, constructed by designers, constituting a hypothesised or potential ecology within which human-environment mutuality can be performed. Hence, Gaver's taxonomy of affordances is an important framework to understand how affordances created for an artificial environment can function to couple the user with the system. The focus of Gaver's taxonomy is, however, not primarily on the mutuality, or the user-system relations, but rather on whether user-machine interactions are supported by affordances.

Norman (1991, 1988) has more than anybody, through numerous practical examples pointed out how malfunction is easier demonstrated than well-functioning, and how artefacts often stand in the way of human use, rather than they mediate it. Through his analysis of a variety of everyday artefacts, such as door handles and light switches, Norman has probably been the most influential promoter of Gibson's ideas in HMI despite his disagreement with Gibson's notion of direct perception (Norman, 1999). Norman is in particular concerned about a widespread application of the term "affordances" as denoting elements that are added to the interface, because, as he argues as does Gaver, affordances in information systems exist independently of what is visible on the screen. ”The computer system already comes with built-in physical affordances (..) Most of this affordance is of little interest for the purpose of the application under design” (Norman, 1999). Furthermore it is argued that symbols and constraints are not affordances, and that physical, logical and cultural constraints are more important for design, along with conceptual models. Conventions, he claims, develop, affordances do not.

Norman's understanding of affordances is widespread in the HMI community. It implies a focus on artefacts as tools mediating or blocking mediation between user and environment, and is hence to some degree is in alignment with the AT conception of the relationship between user, system and work environment. Contrary to Norman, however, AT focuses on the cognitive development of the user as well as the dialectical co-evolution of user, system and work environment (Bødker, 1991, Nardi & O'Day, 1999). This last notion of dialectical co-evolution is perhaps to some degree related to Gibson's notion of mutuality. However, Norman's conception of affordances as *perceived* properties of an *artefact* that indicates how it can be used could be argued to confuse affordances with the information (=invariants) that specifies the affordances (see for instance, Flach, 1995; Amant, 1999). In Gibson's original terms, information pickup is active, direct and unmediated, and is the result of the optic flow of perceptual information (invariants) in the environment.

Furthermore, Norman's concept of HMI is based on the notion of matching between at least two distinct models or representations involved. These models include the user's knowledge structures (in Norman's terms, represented internally as "cultural constraints", "conventions" and "logical constraints") and the system's structures (in Norman's terms, represented via a "conceptual model"). Thus, he claims that "when you [the user] learn not to click unless you have a proper cursor form, you are following a cultural constraint". When Norman argues that cultural constraints and conventions develop, but that affordances do not, the socio-cultural contexts are simultaneously placed as something external, i.e. outside the confines of the system's domain, and by extension, the designer's domain. Furthermore, because of the lack of an explicit explanation or formulation of how such stable entities perform - or rather, *where* they perform (within the users' mental models, or within the system) - , affordances are implicitly relegated to a kind of "no-man's land", with little to offer/afford. This observation is in alignment with the earlier mentioned objection by Flach (1995) that Norman confuses affordances with invariants. In addition, this means that the factors constituting the background within which *mediation* by technology performs is not accounted for. Following for instance Latour (1994), Norman could be said to operate with fixed concepts of subject (user) and object (system), while at the same time excluding their explicit and implicit goals, which in itself makes it difficult to account for the mediating role of technology/information systems.

Contrary to Norman, Gaver (1991) finds that culture, experience and intentions are indeed entangled in the user-system interaction. Where Norman reduces such entanglement to a mechanistic "match" between system and user representations, Gaver finds that such contexts can function to highlight certain affordances. Gaver does not consider the learning dimension or the development in cognition for the user exploring and applying a system, however. Norman tries to explain such possible evolution as the result of internal mental processing on the part of the user. In either case, it could be argued that Gaver's as well as Norman's affordance concepts are rather short term, and considering affordances as more or less static surface phenomena.

2.3 Intuitive interfaces

Building from Gibson's original notion on the importance of available information for the perception of affordances, Bærentsen (2000) has introduced the concept of *intuitive interfaces*, defined as

> "[an interface] which is immediately understandable to all users, without the need neither for special knowledge by the user nor for the initiation of special educational measures" (Bærentsen, p. 32)

According to Bærentsen, the interface must provide an at least minimal understanding of what the system affords. Contrary to Gaver's application of Gibson's notion of invariants as being broadly defined as "available information", Bærentsen applies Gibson's notion of "ecological optics" (Gibson, 1979, p. 65). The basic idea of ecological optics is that affordances are perceived as invariant information in an ambient optic array at a point of observation. An array is an arrangement of optical information that has an invariant structure. The point of observation is surrounded completely by this optic array - it has no boundaries. The point of observation is a position in ecological space that consists of places-location or positions where an observer might be and could make an observation.

Bærentsen suggests that spatial metaphors are useful devices for representing the users' task space and their intuitive exploration, and that the perception of affordances are dependent on the degree to which users are able to know or feel (intuition) "where they are" in ecological space. This concept of affordances and invariants is to some degree related to Heidegger's concept of "thrownness", applied by Winograd & Flores (1986) as one important hermeneutic/ phenomenological concept for HMI design and evaluation. Bærentsen's concept of intuitive interfaces also links Gibson's notion of "ecological optics" with a learning aspect, inspired by activity theory, notably Vygotsky's concept of the "zone of proximal development" (Vygotsky, 1980). Thereby Gibson's original concept of ecological optics, coupling the actor's perception of dynamic visual environments with locomotion in that same environment, is to some extent expanded to cover more interpretative or perhaps semantic aspects of the user-interface mutuality, through the explicit introduction of a learning dimension. This latter dimension to some degree corresponds to the notion of adaptation and adaptive interfaces, developed by the approach of ecological interface design, EID (Vicente, 1999; Rasmussen, Pejtersen & Goodstein, 1994).

Contrary to Gaver and Norman, Bærentsen explicitly addresses the dynamic aspect of the affordance concept, for instance through underlining the importance of what space (invariants) and time means for the learning aspect of HMI. Thus, Bærentsen's view of affordances and invariants implies a more long-term view of technology, as seen from the users' as well as the designer's point of view. Bærentsen's concept of intuitive interfaces does not opt for a quick fix of malfunctioning user interfaces through affordances as add-on elements to the interface. The focus is on the understanding of the user's exploratory context in space and time, following a more hermeneutic approach to system design (Winograd & Flores, 1986), and providing important and innovative ideas for how the designer can articulate such context in the interface itself. The question of how design can support the users' understandings and learning in the long term is also addressed by Rasmussen, Pejtersen and Goodstein (1994) and Vicente and Rasmussen (1992). Bærentsen in particular mobilises the principle of situated action (Suchman, 1987) and the theory of cultural historical psychology/AT (Leont'ev, 1978)), but also mentions the ecological approach (Vicente

& Rasmussen (1992) as a source of inspiration to design principles for intuitive interfaces.

As mentioned, Bærentsen's design principles involve suggestions for spatial metaphors to articulate invariants, but in addition a mapping of events2 (or scenes) within which the user can situate her actions and choices. Through introducing actors and events and the possible couplings of such elements as units of analysis for design, it could be argued that the intuitive approach to some degree comes from a perspective seeing the artefact as "text", or narrative. The design principles hence incorporate a requirement of syntagmatic analysis for the work problem that a particular technological product is intended to address. It can be argued that the approach of intuitive interfaces incorporates high level cognitive notions of narrative units and 'the grammar of plot' (following the principles of, for instance, Propp, 1958), which is very much related to Andersen's research in narrative multimedia design (Andersen, 1993).

A further design principle works from the coupling between user, system and work task, mapped through a three level model of activity motive ('why?'), action goal ('how?') and operation conditions ('what?'), inspired by Leont'ev (1978) and Rasmussen (1986). While these theories of work activity have different historical, disciplinary and cultural roots, they are in alignment with respect to the assumption that the actor/user has *intentions and goals*, and that these intentions and goals are *situated*. That is, the users' action and intentions are not determined solely by outside factors (=socio-cultural determinism) nor by a priori "cognitive plans" (=mentalism). For the designer, this situated perspective means s/he does not perform from an "all-knowing" position, but is inscribed within the system as kind of set designer for the narratives created by the user. In short, through the introduction of design principles building on high level syntagmatic analysis of the users' domain, as well as addressing the semantic/pragmatic levels of work, Bærentsen's approach could be regarded as extending Gibson's original notion of direct perception-action for design to cover more high level cognitive levels, perhaps even taking a leap to from perception to meaning or interpretation.

2.4 The deep structure of affordances

In their introduction of the theoretical framework for ecological interface design, Vicente and Rasmussen (1992) suggest principles for the creation of design maps to cover sets of events as seen from the users' point of view. Based on interviews and participant observation of operators' work within the tightly coupled work domain of process control, Vicente and Rasmussen identified a number of recurring events and properties of the work environment which they then mapped towards Gibson's concepts of affordances and invariants. The coupling of the users' perception-action and understanding of events was addressed through positing two basic theoretical concepts, developed by Rasmussen (1983; 1986), i) the abstraction hierarchy and ii) the skills-rules-knowledge model. The generic abstraction hierarchy, which is applied to map the work domain from physical properties to high level goals, has five levels. Rasmussen and Vicente mapped Gibson's affordances towards the abstraction hierarchy, and reached an overall generic classification of affordances into three categories: why, what, and how. For instance, a surface can provide locomotion (what), with biking as means (how), and pleasure or survival being the highest

2 See for instance, Stoffregen 2000a, for a discussion of how affordances are sets of events, thereby to some degree supporting Bærentsen's design principle of how to provide the user with an organized set of scenes for navigation in a narrative space of events.

goal (why). Thus, the hierarchy functions to guide the actor from overall views of action possibilities to details of the environment.

The skills-rules-knowledge taxonomy (Rasmussen, 1983) was originally put forward as an explanatory framework for describing in what way an actor interprets information: i) as signals (skills), ii) as signs (rules) and iii) as symbols (knowledge level). From this generic model of the users' levels of cognitive control the designer can consider what kinds of affordances and invariants, as organised in the abstraction hierarchy for the domain, should be available to the user. The overall design idea was to provide the user with the highest possible freedom of action possibilities through articulating what physical -> goal-directed relations in the environment (=power plants etc.) constrain behaviour. As Vicente (1999) points out, the EID design principles originally introduced by Vicente and Rasmussen (1992) did not address loosely coupled work domains. Loosely coupled work domains are characterised by, for instance, a high degree of task uncertainty (for instance, case handling) and a high degree of freedom and diversity of cognitive control among the actors involved (for instance, information searching in libraries). For loosely coupled domains with a high degree of task uncertainty, implying a high degree of strategic dependence on human experts, the actors' knowledge level, their learning, cognition, strategies and tasks, are crucial units of analysis (cf. also, Whitley, 1983). Pejtersen has demonstrated this in the design of a multimedia information retrieval for fiction mediation in Danish public libraries (Pejtersen, 1980). An important feature of this latter system is visual access to information about the topical content of fictional works, through a variety of classification schemes. These schemes function as semantic maps to guide the user to the contents of the books, by addressing several levels of semantic information, ranging from high level intentional values of users and authors to more low level attributes of readability and physical form. Thus, the means ends abstraction hierarchy was extrapolated to more deep level connotative information than was previously addressed by the EID approach, together with the ecological principle of direct perception-action in the graphical interface.

2.5 Current interdisciplinary discussions of Gibson's affordance concept

Vicente, Rasmussen, Pejtersen and Bærentsen's research implies an extension of Gibson's notion of affordances and invariants for the design of complex socio-technical systems to cover more connotative or semantic aspects of the user-system ecology, as compared with, for instance, Norman and Gaver. Is there a contradiction in terms, with respect to Gibson's original theory of direct-perception-action, i.e. action unmediated by high-level representations like language or symbols, and such recent developments in HMI research for affordances? Ongoing discussions within ecological psychology might suggest that previous understandings of Gibson within their field have focused too narrowly on unmediated action. Behaviour or actions are not only products of perception but also products of cognition, decision-making, intentions and values. Gibson's theory of direct perception action has functioned as a radical break with cognitivism as well as behaviourism. Hence, Gibson's theory of affordances has been mobilised by researchers within psychology and within the HMI community (notably, by Gaver) as a distinct and fairly radical perspective, coming from a more or less explicit agenda of breaking with previous research paradigms in HMI. By sticking to a conviction that affordances are linked with direct perception-action only, little room is left for current and future discussions of how to work with expanding, adapting and developing the affordance concept by the

HMI research community. It is likely that one important background for the recent openings to new understandings and extensions of Gibson's original affordance concept within the community of ecological psychology is connected with the increasing cross-disciplinary applications of Gibson's theory, for instance for HMI, architecture, town planning etc. (see for example Reed, 1996, for examples of cross-disciplinary applications of the concept).

Recently, ecological psychologist Stoffregen (2000a) has suggested an extension of the affordance concept to cover more high level, or in Stoffregen's terms, second order categories, using examples such as 'food' (denotating a set of affordances like fruits, vegetables etc.) and 'friend' (connotating someone that can be counted on in emergency). Stoffregen couples the notion of second order affordances to Wittgenstein's concept of language games (Wittgenstein, 1953). In this context, it is interesting to observe that Gibson also refers to Wittgenstein's philosophy of language, notably to explain how information pickup occurs through invariant structures of the ecology:

> "To perceive an affordance is not to classify an object….The theory of affordances rescues us from the philosophical muddle of assuming fixed classes of objects, each defined by its common features and then given a name. As Ludwig Wittgenstein knew, you cannot specify the necessary and sufficient features of the class of things to which a name is given. They have only "family resemblance". But this does not mean you cannot learn how to use things and perceive their uses. You do not have to classify and label things to see what they afford" (Gibson, 1979, p. 134).

Furthermore, Gibson's original concept of affordances has been subject to discussion within semiotics, notably by ecological psychologist and philosopher J. Pickering (1999). From a semiotic point of view, in a Peircean sense, Gibson's original concept of affordances could be related to Peirce's concept of *firstness*, or in generic philosophical terms, first order expressions. At this level of instinctual and functional awareness by the organism, affordances of the organism-environment ecology could be regarded as types of signs to which the organism adapts its actions and (biological etc.) evolution:

> "Affordance, the directly perceivable meaning of the environment, is .. inherently attached to action. It implies a mutualist ontology in which stable relations between co-evolved things is taken as being as real as the things themselves … *In Peirce's terms, affordance is a sign for which the organism acts as interpretant to produce action in a given situation as the object. Thus organisms do not merely respond to stimuli, but act on the basis of meaning*." (Pickering, 1999, our underlining)

Within Peirce's triadic sign concept is a phenomenology comprised of three levels, where the first level (firstness) is not only a priori existing physical properties of the environment (corresponding to 'object' in Peirce's model), but also the outcome of actions carried out in the environment. The second element of Peirce's triadic sign concept is the representamen, corresponding to some extent to Peirce's concept of 'secondness'. The third element of Peirce's sign model, the interpretant, to some degree corresponds to Peirces concept of 'thirdness'. Peirce's three phenomenological levels are built into his theory of sign formation: 'representamen', 'object' and 'interpretant'. Peirce's three phenomenological levels to some degree correspond with the levels of work activity addressed by activity theory and ecological information systems.

Pickering's semiotic definition of 'affordances' is related to other semiotic theories of self-organizing systems, on how organisms evolve in mutuality with the environment through action and adaptation. For instance to concepts like 'autopoiesis' and 'structural coupling', coined by Maturana (see for instance, Maturana & Varela, 1980), and applied in HMI research by, for instance, Winograd and Flores (1986). However, Pickering's discussion is primarily intended as a contribution to ongoing discussions within ecological psychology on breaking with radical Gibsonean thinking, including suggestions of possible extensions of the affordance concept to address broader cognitive, semantic and pragmatic issues.

Is it possible that such recent interpretations and suggested extensions of Gibson, as stipulated by Stoffregen and Pickering, within the field of ecological psychology, open up to renewed discussions and considerations of whether affordances in information systems can articulate semantic or pragmatic levels of the users' work problems and environment?

How has Gibson's affordance concept been applied or extended within current HMI research, and what kinds of advantages and shortcomings have been identified, in particular by the Activity Theoretical (AT) approach the Ecological Interface Design (EID) approach.

Norman and Gaver do not address high level cognitive issues, for instance activity, culture, language and knowledge, in their application of the affordance concept for HMI. How do AT and EID view possibilities of going beyond the 'grand divide' between perception-action on the one hand and interpretation/understanding on the other hand?

Gibson's affordance concept does not readily generalise to social interaction, cooperative work and inter-subjectivity. How do AT EID view possibilities of extending the original concept to cover such factors in HMI design and evaluation? Where do affordances stop and social interactions begin? Or, rather, what are the affordances in social interactions?

3 Activity theory and affordances

Activity theory perceives the relation between human and environment as dynamic, makes us focus on biological, historical and individual development. Activity theoretical HCI has come to focus on:

- Analysis and design for a particular work practice with concern for qualifications, work environment, division of work, etc.
- Analysis and design with focus on actual use and the complexity of multi-user activity. In particular the notion of the artifact as mediator of human activity is essential.
- Focus on the development of expertise and of use in general.
- Active user participation in design and focus on use as part of design.

Activity theoretical HCI offers a set of conceptual tools, rather than ready-made techniques. This chapter will demonstrate these concepts, along with some selected techniques that we have successfully applied.

Activity theory and Gibsonian thinking share the basic idea that perception is not afferent, that it is connected with action. Only through acting do people perceive their environment. Activity theory insists that our action and perception are mediated by a variety of tools. Activity theory gives a useful handle for understanding the mediators, and how they are shaped, in a dialectical relationship with the changing practice of use. Accordingly mediation has been the key point of interest to activity theoretical HCI. At the same time Leont'ev, in his analyses of human development, points out that historically mediation was preceded by a development phase characterised by direct perception in ways that are rather similar to what Gibson describes, and that this phase still exist in all of us, as a basis for our mediated encounters with the world (Bærentsen, personal communication).

Activity theory takes purposeful acts as the basic unit of analysis of artifacts. Thus, we have to study what happens when users focus on their job (or other purposeful act) while using an artifact. According to Leont'ev (1978), human activity can be analysed into a three-level hierarchy of activity, action, and operation, each of which reflect the objective world (see figure 1). Activity is directed to satisfy a need through a material or ideal object. The subject's reflection of (including expectation to) this object is the motive of the activity. Human activity is carried out through actions, realising objective results. These actions are governed by the conscious goals of the subject. Goals reflect the objective results of action. Actions are realised through series of operations; each "triggered" by the conditions and structure of the action. They are performed without conscious thinking but are oriented in the world by a non-conscious orienting basis. Goals are different from the motive, but still realising it are only possible in human activity; in animals goal and motive are always the same.

Type of activity	**Directed at**	**Analysis**
Activity	**Motives**	**Why something takes place**
Action	**Goals**	**What takes place**
Operation	**Conditions**	**How is it carried out**

Figure 1. Different aspects of the activity structure

In line with the above description of human phylogenetic development, Gibsonian thinking relates to the level of operations in activity theory: Many common operations (..) are learned as a barely ever conscious habit. With them, there is nearly no use of precise discursive rules for consciousness in the sense of reflexive self-regulation. A good example is when we learn to ride a bike, where little of what it takes are rules. In contrast, activity is developed historically, socio-culturally and micro-socially. Actions are developed ontogenetically, deliberately and habitually. (Raiethel & Velichkovsky, p. 201). Wittgenstein mentions the example of children "playing train". To children in a western society this activity is motivated by the analogy to real trains moving about. To children of a remote tribe (as Wittgenstein frames the example) they can certainly learn the movements of the game, but the game never make sense to them in the same way (Wittgenstein, 1953)

3.1 The social-historical dimension

Activity theory insists that Gibsonian thinking is lacking a clear understanding of the relations between the social-historical dimension and the evolutionary-biological aspects of the concrete sensori-motor operations realising the actions of the individual (Bærentsen, personal communication). In relation to human-computer interaction, this means that activity theory insists on taking a wider look at use, that detailed interaction between a human being and a computer or

other artefact cannot be understood without understanding the purpose of the activity.
The question is would it nonetheless be possible to analyse the social-historical dimension on the basis of the affordances of an artefact? Are these affordances not a reflection of the social-historical conditions of operations, that is operations that used to be carried out by a human being, but now is objectified in the artefact? The saying " to he who has a hammer, everything looks like a nail" illustrates how our seeing and doing is dependent on our tools and on the socio-historical development.
Let us take an example from the activity theoretical analysis of the history of the development hand weapons (Bærentsen, 1988). Before the beginning of medieval times, soldiers and hunters primarily used bow and arrow. The bow and arrow let you focus on the target without thinking too much on the tool in your hand. After a while you would not even notice it - it becomes a true part of your body. You will now be able to kill with your eyes. From a Gibsonian point of view the arrow affords aiming by looking along the arrow at the target. After the invention of gunpowder, a new generation of hand weapons began to develop. The principle for these weapons where though more or less the same as for the bow and arrow. Some sort of energy is released on an object that then is thrown in a certain controlled direction. The advantage of the new weapons was that the acceleration of the bullet is far greater than the acceleration of an arrow and thus it became possible to shoot at a greater range. But the affordance of aiming somehow got lost in the first generations of hand weapons. The soldier will still be able to aim by looking along the rifle barrel at the target, but to fire the weapon attention was attracted towards getting the gun powder to explode. Then hopefully the target had not moved while the soldier was engaged in a series of sensory-motor operations to light the gunpowder. In the next generation of weapons these operations have been captured and fixated as a mechanism in the hand weapon that allows a persons full concentration on hitting the target- the affordance of aiming is once again available (Bærentsen, 1988).
These aspects of the history of the development of hand weapons are related to the discussion of the affordances of human made artifacts. Gibson (1979, 130) states that: "Man made artifacts can be seen as efforts to change and expand affordances of the environment. In changing the substances and shapes of the environment humans have made more available what benefits him and less pressing what injures him." It is a benefit to be able to shoot at a greater range, but it could be dangerous not being able to hit the target. Incorporating certain human operations into the weapon solved this conflict. In activity theoretical terms the hunters' action realises the goal to kill the prey, aiming is a condition for the operation of firing the weapon at the exact right time without any further reasoning. In Gibsonian terms the prey affords to be eaten and the weapon affords aiming at the prey. We have not even mentioned the motive here. In Gibsonian terms the motive would be something like hunger. In Activity Theory the motive is of a higher order for example the survival of the tribe.

The example could lead us to think that it could be possible to unravel socio-historical dimensions of affordances with a point of departure in activity theory, but we off course need many more examples and analyses to say anything certain about this.

3.2 Learning

In the Gibsonian world, learning is about increasing differentiation. Activity theory is likely to argue that the world in which we make the differentiation changes as well, as a consequence of our actions. Furthermore, learning as not only enriched repertoires of operations– the development of the individual repertoire of actions as well as the wider human development, are equally essential parts of the development of human activity, human skills.

On the other hand this does not mean that activity theory could not be used in detecting and explaining the role affordances in learning. Engeström (1990) has from an activity theoretical perspective studied students learning and perception of an abstract astronomic phenomenon - the phases of moon. The study showed that students when asked what causes the different phases of the moon tend to answer incorrectly that the different phases of the moon are caused by the shadow of the earth. Engeström hypothesises that the cause for this misconception should be found in cultural artefacts like textbooks and instructional practices in the educational system. Engeström shows that in fact the reason for mislearning the concept is due to poor diagrammatic illustration that lacks a dynamic model and ecology of the real phenomenon in terms of distances between and sizes of the sun, moon and the earth. In addition, the third dimension is missing - the diagrams cannot show the depth of the space in a proper way. On the basis of this "affordance" based analysis (he does not mention affordances in the book) Engeström concludes that students should be given the possibility to engage in research like activities to observe and experiment with real life phenomena. Another conclusion could be that the activity based analysis proved useful by pointing at a lack of affordances for learning a naturally observable phenomenon.

Bødker (1991) summarises investigations and discussions in the human activity literature about how human beings learn, more specifically how they develop their repertoires of operations, as follows:

1. Activity on material objects cannot be learned without practical experience.

2. Activity that has an abstract goal, such as solving a mathematical problem, is easier learned and carried out in connection with physical objects than with representations of such. Learning with representations is in turn easier than in connection with language, which is easier than activity that is totally based on mental reflection. For example, adding is first performed by children by counting physical objects, then they move on to master adding based on figures, then to a state where adding works best if they are allowed to talk, and so forth.

3. When operationalisation takes place, it is at first very situation specific, but as the human being meets new conditions, the variation of situations that can be handled by operations grows.

4. For the novice, the activity takes place at a very detailed level of actions, where each action is consciously planned. With experience, the human being moves toward an operationalised totality. This is achieved through generalisation, through operationalisation of planned actions, and through abbreviation, an operationalised skipping of certain operations due to the conditions for them and knowledge about the result. For example, for communication partners discussing a certain calculation, when the result of multiplication by one is known, instead of having to carry out the operation, then the context is obvious; in carpentry, when sandpapering is not necessary to smooth the wood because you already did well with the plane.

5. The person is brought down from one level of competence to another either due to some pedagogical questioning of the former operations and their conditions or because she is trying to apply old operations to the new artifact and is encountering a breakdown. The pace at which she can be brought back to her old level of competence or beyond depends on the artifact, on how much she can rely on the generality of her operations, on the type of education given, and on whether she can make use of experiences from other types of activity.

6. The use of an artifact is, if the artifact works well, operationalised. Ideally, learning starts out with actions toward the artifact and ends without those actions.

With respect to learning the question of when exactly an affordance is an affordance for the first time for a given individual could be raised. Do affordances gradually expose themselves to us or do they suddenly expose themselves to us just as snap of the fingers dependent on individuals different physical and mental capabilities?

Kaptelinin (1996, pp. 62) shows that when we learn to use symbolic tools we go through three developmental stages:

1. The initial phase, when performance is the same with and without a tool because the tool is not mastered well enough to prove any benefits,
2. The intermediate stage, when performance is superior to unaided performance, and
3. A final stage with and without the tool but now because that the tool mediated activity is internalised and the external tool no longer needed.

The problem here is that some external tools are not fully internalised. It is rather difficult to imaging a person hammering a nail with an internalised hammer. The last developmental stage only holds for tools that can be completely symbolised.

On could speculate whether this Vygotskian inspired view on learning could be applied to the notion on learning computer-based affordances as well. And in general what could Vygotsky's concept of "the zone of proximal development" tell us about this issue?

One answer would be that it seems to be that different affordances plays different roles through the leaning process - that new affordances will appear and others fade away alongside perceiving the new ones. Moreover other persons matter in learning to perceive new affordances - Robinson Crusoe is fiction.

3.3 Tools as functional organs

Activity theoretical HCI has insisted on understanding actual interaction, actual artefacts in use, not in isolation. Gibson, in contrast, notes that we perceive objects, though when we look at objects we perceive their affordances, not their qualities. It is striking how the analyses presented in the literature (e.g., Norman, Gaver) look at objects as a detached reflection, not as artefacts in use. As a quality criterion, activity theory insists that the artefact should not impose itself on the user in use. Yet the user cannot achieve the particular goals without the artefact, and in this sense the artefact is an important part of shaping use.

Activity theory also accepts that breakdowns happen, where the transparent interaction through the artefact stops, and where the user is confronted with the artefact as an object. A well-designed artefact, activity theory insists, supports recovery from such breakdowns. Simultaneously, such breakdowns are openings for learning, be this learning to enrich the repertoire of operations of the user, or learning in terms of reconceptualising the meaning of the artefact. In comparison, Gibsonian thinking is indeed not concerned with the latter of the two.

Gibson hypothesises that objects have some sort of universal function or meaning. From an activity theoretical perspective the functions or meanings of tools and other objects are actively created through interacting with the environment. Kaptalinin (1996) argues that the use of affordances implies that the initiative is taking by an external situation. Operations are not just triggered by conditions, but are part of the general structure of actions.

Gibson does not extend his theory much to human-made artifacts, but talks about natural substances, surfaces or mediums of the environment like air or water. Or he talks about landscapes like mountains, plains, swamps, rivers and forests. The exception is relatively small and portable tools that when used is no longer part of the environment but part or extension of the actor's body.

This is in line with the activity theoretical concept of functional organs (Leont'ev, 1981). A functional organ is a tool extension of the body. These tools can both be external like scissors that turn the hand into a cutting organ or internal like a mental model or action plans. Another point is that Gibson does not take into account that the tools embody operational forms of the history of human social activities and natural laws and that the affordance may be a reflection of this historical dimension. From an opposite perspective the question would be if not the conditions for the operations includes affordances - that affordances are inseparable from the original operational conditions and that these affordances have become part of new functional organ.

3.4 Different foci in use activity

Bødker (1991) has characterised different focuses in the computer application use activity:

The p*hysical aspects*-support for operations toward the computer application as a physical object. The physical aspects are the conditions for the physical handling of the artifact. The human adapts to the forms and shapes of the artifact. A maladaptation might prevent the forming of certain operations.

The *handling aspects*-support for operations directed at the computer application. A breakdown in these operations will make the user focus on the artifact. The handling aspects are the conditions for the transparency of the artifact that allow the user to focus on the "real" objects and subjects of the activity. This type of operation can be conceptualised (for instance in breakdown situations), as the user being forced to conduct actions toward the artifact as an object.

The *subject / object -directed aspects*- the conditions for operations directed towards object and subjects that we deal with "in" the artifacts through the artifact. Different subject / object-directed aspect relate to different subjects or objects, but it is also part of these aspects to support the shift between subjects / objects. This means that although it is possible to talk generically about subject / object-directed aspects, in a specific analysis it will make sense to identify such aspects for each relevant subject or object.

The question is how do these focus dimensions relate to the concept of affordances. Would it be possible to speak of three dimensions of affordances that can support the different focuses of the use activity presented in the above characterisation. That is, it could be worthwhile to explore such notions as physical affordances, handling affordances, and subject / object -directed affordances? The latter being the most difficult to analyse.

In general, with respect to learning and the most of discussion above, we would conclude that activity theory seem to offer more distinctive and situated concepts. More or less because activity theory encompasses such concepts as motives, purposeful activities and personal development and does not consider "statically" concepts like affordances which are there once and for all.

4 Cognitive Systems Engineering and affordances

Ecological Interface Design (EID) and Ecological Information Systems (EIS) are a response to the HCI models proposed by Schneiderman's "syntactic-semantic model" (Shneiderman, 1987) and Norman's "gulfs of evaluation and execution" (Norman, 1986). These models have the value of generality, but are limited with respect to work domains where i) actors naturally reason at various levels of abstraction and ii) decide and act at multiple levels of cognitive control (Rasmussen 1988, Vicente and Rasmussen, 1989). The theories of EID and EIS are based on field studies of real life work domains and are inspired by Gibson's theory of direct perception-action. The skill-rules-knowledge (SRK) model describes an actor's level of cognitive control during work. The means ends abstraction hierarchy describes the different levels of information content about the work domain and constitutes a multilevel and generic map to support an ecological coupling for the actor with the work domain through its implementation as a representation of its multiple levels of information. The content of information refers to different, but interrelated, abstraction levels that encompass goals and constraints, priorities, work functions, work processes and work objects, including people and tools. The relationship and mutual dependency between these two models provide the foundation of the theory of EID and EIS, together with Gibson's ecological theory of perception-action.

In the following, the two core theories for EID and EIS are presented and discussed. The first theory is the skills-rules-knowledge model that was developed as a cognitive theory for information processing and perception as these activities were unfolded by operators during field studies of process control. The second theory is the means-ends model that was developed for stratified mapping of the work domain of process control, and which was later mapped towards Gibson's hierarchy of affordances with the aim of describing important stable attributes of work domains as invariants and invariant structures.

4.1 Skills Rules Knowledge (SRK)

Rasmussen (1983) introduced the SRK model as a tool for systematic description of how human intervention performs in the environment of high risk work domains, such as power plant control. It breaks with previous models for human performance, that were predominantly based on quantitative decision theory (see for instance, Tversky & Kahneman, 1974). A crucial limitation of the quantitative decision models, and in particular those that were previously created for global application, is that when implemented in real life environments, they tend to constrain or "anchor" the actors' decisions to particular previous outcomes from their choices of action, rather than pointing to alternative solutions. On the contrary, the SRK model is intended to dynamically direct the actors to choices of alternative actions that may be more appropriate to solve a particular work problem and hence also support a learning dimension. SRK follows the tenet by Rosenbluth and Wiener (1943) that human behavior is teleological by nature, but breaks with the underlying behaviourism in their view that human action is carried out as a result of stimuli, such as immediate feedback from the environment, articulated, for instance, as signals:

> At a higher level of conscious planning, most human activity depends upon a rather complex sequence of activities, and feedback correction during the course of behavior from mismatch between goal and final outcome will therefore be too inefficient, since in many cases it would lead to a strategy of blind search. Human activity in a familiar environment will not be goal-controlled; rather it will be oriented towards the goal and controlled by a set of rules which has proven successful previously (Rasmussen, 1983, p. 2).

Rasmussen's SRK model was stipulated within the information-processing paradigm. The primary purpose of the model is not to put forward a new theory of human cognition in a broad sense, but to explain, model and represent how actors read and interpret interface displays, and how this relates to the actors' situational work performance. Thus, SRK is founded on field studies and observation of actors in real life work environments in addition to theoretical frameworks for understanding human cognition and decision-making, including for instance Polanyi (1966). An important tenet of SRK is that human perception, interpretation and action rely on mental models, representing the information content about the work domain as well as the rules or strategies for action in the domain. Furthermore, SRK distinguishes between the following categories of actors' performance: *skill-, rule- and knowledge-based performance*. The following description of the SRK model retains Rasmussen's original formulations of human perception, interpretation and action (Rasmussen, 1983; 1986). The model describes the actors' performance patterns in different situations, ranging from familiar to unfamiliar circumstances within which action occurs.

Skill based behaviour

Skill based behaviour corresponds to sensory-motor performance during actions that, after the statement of a conscious intention, take place without conscious control. This type of performance is characterised by smooth, automated and highly integrated patterns of behaviour. The sensory input is not selected or observed, as the senses are only directly towards the aspects of the environment needed to update and orient subconsciously the internal map, or mental model. In Rasmussen's terms: "The man looks rather than sees" (Rasmussen, 1986, p. 101). In some cases, performance is one continuous whole or "flow", in particular for performance requiring high-level control, such as musical performance or bicycle riding, where the actor's skilled performance is due to the ability to compose from a large repertoire of automated subroutines. In Gibsonean terms, this could correspond with a situation where the actor perceives (hears, sees, feels) and acts directly in mutuality with the environment. Rasmussen, however, inserts the interpretative layer of an internal "dynamic world model" that is unconsciously updated by the actor. The purpose of updating the internal dynamic model is for the actor to "modulate" the skill in general terms. For instance, the musician in a symphony orchestra continually adapts her performance in a modular way to fit the acoustics of the concert hall, the performance of other musicians and the conductor.

Rule based behaviour

For rule-based behaviour, the composition of a sequence of subroutines is typically consciously controlled by a stored rule or procedure. This rule or procedure is either derived from previous experience, or is communicated as rules of thumb or heuristics for problem solving and planning. The performance is goal-directed. The boundary between skill-based and rule-based behaviour is not distinct, however. The skill-based performance occurs without the person's conscious attention. That is, for skill-based behaviour like bicycle riding, knowledge is typically tacit and embodied, and hence difficult for the actor to formulate explicitly. Conversely, high-level rule-based behaviour is in general based on explicit know-how. The rules can be communicated from one person to another, although the cues for releasing a rule may be difficult to describe. For instance, when the bicyclist books a ferry, s/he may know beforehand about possible routes and prices during a particular season of year, and may have knowledge of possible alternatives in case her favourite route is booked up. The actual cues for releasing the rule of "book favourite route - procedure" may be difficult to describe for the bicyclist, however.

Knowledge based behaviour

Contrary to skill-based and rule-based behaviour, coming from the actor's expertise or from communication with other actors, knowledge based behaviour usually occurs in situations where no know-how or rules for control are available from previous experience. "Knowledge" is then, in this context, defined in a restricted sense as "possession of a conceptual, structural model". In this situation, the goal is explicitly formulated, based on an analysis of the environment as well as the overall aims of a person. This behaviour can only be activated when meaningful, relational structures of information are available. For instance, the bicyclist may find out that all ferries are booked up. Because the bicyclist possesses a conceptual model of the system of bridges and public transportation in her surrounding area, she may decide to explore, by calling friends and travel agencies, or consulting maps, whether it is possible to cross the water via a bridge, on bike, walking or by train.

In dynamic and complex work domains with a large number of unfamiliar situations, actors will tend to depend on knowledge based behaviour. Experts in a familiar situation will tend to rely on rule based behaviour. Since the conscious processing is effective to cope with unanticipated problems and the subconscious processing is effective to cope with familiar events, shifts among the different types of behaviour will frequently take place. The three types of behaviour are complementary and they are all necessary to fulfil actors' goals. *Hence, most tasks will usually require simultaneous interaction and consideration of all three types of behaviour*. According to Rasmussen (1986) there is a *dynamic world model* that *mediates* the shift and focus of these three types of behaviour:

> A kind of dynamic world model is necessary to account for control of responses to the environment that are too fast to allow control by simple perceptual feedback. Often-cited examples are fast sequences in sport, musical performance, etc., and the quick draw of western gunmen, which has recently been used for military training (reference omitted). To serve this purpose, it is necessary that the internal dynamic world model simulates not only the behavior of the environment, but also of the body; i.e. it simulates the interaction (Rasmussen, 1986, p. 80)

The citation suggests that the dynamic world model would be derived and developed in the situational coupling between the actor and the environment. Thereby, Rasmussen approaches the Gibsonean principle of mutuality, with the particular purpose of understanding and modelling human work performance. Gibson, however, did not assume the existence of an interpretative layer, such as an internal world model, for mutuality to occur. According to Gibson, perception and information pick-up is direct and unmediated. According to Rasmussen, the coupling between actor and environment is always mediated. This does not mean that the internal representation is static. If for some reason, the demands of a situation change in a substantial way, the skills that the actors has developed will no longer be appropriate. Then the actor's dynamic world model is no longer appropriate and she is not able to act. This is where the advantage of conscious, knowledge based processing comes in. Using the analytical approach based on structured knowledge, a change in the task situation can be accommodated. Activation of one or the other type of behaviour will also depend on the form in which the information is presented, perceived and interpreted by the actors: as symbols, signs or signals.

4.2 Affordances are structured: developing the early principles of Ecological Interface Design (EID)

The aim of ecological interface design is to create transparent interfaces that support direct perception at the level of the actor's perception of affordances, while at the same time supporting the levels of cognitive control (skills, rules, knowledge) at which the actor chooses to perform. The mapping across interfaces that will support the actor's dynamic switching among levels of focus and control must support control of movements, acts and plans simultaneously. To do this, the EID designer creates an artificial ecological environment that implements the invariants and invariant structures of the environment as functional properties of the technological system.

The EID approach to designing and implementing the functional properties of the system is based on the means-ends model to capture affordances and invariants of the work domain and the interrelationships between these invariants. Furthermore, the approach builds on SRK to model the actor's levels of cognitive control, that is, the way that the actor can choose between the action possibilities and objects (invariants) in the environment and explore these from the perspectives of means and ends.

Rasmussen and Vicente initiated this research to address the problem of designing interfaces that would support actors' exploration of systems without imposing normative constraints for navigation, as for instance found in previous guidelines for direct manipulation interfaces. Furthermore, the intent was to explore how Gibson's theory of direct perception would be applicable for complex, high-technology work domains, such as process control, which had not been addressed by previous research on affordances for HMI. At the time where Rasmussen and Vicente (1989; 1992) initiated their work on applying Gibson's theory of direct perception-action to interface design, the concept of affordances had already been introduced to HMI, notably by Norman (1988 et passim). Prior to the formulation of the EID approach, affordances in HMI and ecological psychology were typically studied as single isolated entities (e.g., passthroughable, sit-onable, graspable). Rasmussen and Vicente worked from the assumption that in any realistic situation, a large number of inter-related affordances are available to the active organism. *Their core assumption was that affordances are structured and that this structure may convey important goal-relevant information*. Figure 2 shows Rasmussen's and Vicente's mapping of Gibson's affordances towards the means-ends hierarchy (Rasmussen, 1986). The results indicated that affordances could be structured as a means-ends hierarchy, and thereby function as a mechanism to cope with the complexity of the natural environment. The means-ends model has five levels, ranging from physical properties to high level goals and intentions.

The interrelationships between affordances and the five levels are articulated as "why", "how" and "what". These questions are generic articulations of the different kinds of views that an actor can have on the possibilities of the environment. For instance, any activity (such as biking: *how*), can be chosen as well for its goal (getting to a destination in a pleasurable and quick way: *why*) as for its physical properties (the bike is available, the road is even, not too hilly, and it is not raining too hard: *what*). The three levels of "what", "how" and "why" also correspond to the way that the designer can capture and articulate the actors' knowledge and intentions in a computational system. In AI terms, "what" corresponds to declarative knowledge, "how" to procedural knowledge, whereas "why" corresponds to meta-knowledge. From the actors' point of view, the three levels are not absolute in any sense, but rather can "slide" up or down. The most important advantage of adopting such a format to structuring the affordances of a system is that it provides a mechanism for coping with complexity. Figure 2 illustrates how higher-order affordances can help people to cope with the complexities inherent in the natural environment.

It should be mentioned that neither the means-ends hierarchy nor the "why-how-what" model work from the notion of integrative levels (see for instance, Bertalanffy, 1968). The model is not truly hierarchical, but is rather a stratified model of independent layers with the "totality" of concepts or information available at each individual level. In other words, for each level, one dimension, or perspective, of the "world" is unfolded. Because the model is not truly hierarchical, the *relations* between the levels are not essentially nor logically given (partition, inheritance, etc.). They are given by the demands (constraints) of the work domain, and they are dynamically created and performed, mentally, physically, emotionally etc. by the actors, as modeled through the generic overlay: "why"-"what"-"how".3

1. Value Properties: Purpose, Goal			
Survival	Pleasure	Altruism	
2. Priorities: Abstract Function			
Reward Cooperation Comfort	Danger Nurturing Pain	Nutrition Copulation	Manufacture Privacy
3. Context: General Function			
Communicating Washing Fighting Locomotion	Warmth Bathing Shelter	Drinking Injury Aiding	Eating Support Punishment
4. Movement: Physical Process			
Sit-on Climb-on Stand-on Breathing Throwing	Bump-into Sink-into Grasp-able Pouring Piercing	Fall-off Swim-over Barrier Cutting Carrying	Get-underneath Walk-on Obstacle Lifting
5. Objects and Background: Physical Form			
Layouts	Objects	Surfaces	Substances

Figure 2. Affordances structured within the means-end hierarchy

3 E. Gerson has recently formulated an overview of hierarchical representations of work, and common information spaces in particular (Gerson, E.M.: Different parts for different smarts: partonomies and the organization of work. Position paper for the workshop Cooperative Organization of Common Information Spaces, 23-25 August, 2000, CIT, DTU/arranged by K. Schmidt. Available from: gerson@ieee.org)

Through this mapping of Gibson's affordances to the means-ends hierarchy, Rasmussen and Vicente formulated a model for coupling the actors' direct perception and action to a multidimensional and dynamic exploration and understanding of the environment. This model, together with the skills-rules-knowledge model, SRK, is the core theoretical framework for Ecological Interface Design. It is the basis for the development of the fundamental design principles of EID, as formulated by Vicente & Rasmussen (1992):

- Support of skill-based behaviour (SBB)
- Support of rule-based behaviour (RBB)
- Support of knowledge-based behaviour (KBB)

Briefly stated, the SBB principle addresses support of a skilled actor, where the displays of the interface are arranged to represent the different levels constituting the totality of actors' situational skills, following Rasmussen's concept of skill-based behaviour as a gradual aggregation of singular physical movements or cognitive processes. The RBB principle is to provide a consistent one-to-one mapping between the work domain constraints and the cues or signs provided in the interface. This principle is to support the actors' cognitive control of her goal-directed behaviour through displaying perceptual and diagnostic cues for changes in the environment, like changes in the state of a power plant. Through displays (visual, audible etc.) of the states of the system and the environment, together with their associated action possibilities, the actor would not need to recourse to knowledge-based behaviour. The RBB design principle is in particular crucial in high-risk work domains and situations requiring continual awareness and fast intervention, for instance within aviation and power plant control. Finally, the KBB principle is to represent the work domain in the form of a means-ends hierarchy to serve as an externalised mental model for the actor.

4.3 Affordances are intentional: developing the early principles of Ecological Information Systems (EIS)

Vicente has recently pointed out that there is presently some confusion in the literature, with regard to the definition and application of the EID approach (Vicente, 1999). Vicente mentions the so-called ecological approach to human factors (Flach, Hancock, Caird & Vicente, 1995) as a broad, cross-disciplinary research endeavour, exploring Gibson's ecological theory for many diverse application domains, for instance architecture and industrial design (furniture etc.). While EID contributes to the meta-theoretical endeavours of the ecological approach to human factors, it is, according to Vicente, narrower in scope. The focus of EID is specifically on the problem of how to design human-computer interfaces for complex socio-technical systems. Vicente discusses Ecological Information Systems (EIS) as a related approach, with respect to the application domain of complex socio-technical systems, and to some degree, as regards methodological framework applied (SRK and means-ends analysis, empirical work analysis).

As Vicente rightly mentions, EIS in particular explores the application of ecological design principles for *loosely coupled work domains* with a high degree of strategic task uncertainty and self-organisation, where the actors' levels of control, learning, strategies and tasks are crucial units of analysis. This approach was developed in the context of Risø's long-term research program on information retrieval and classification, initiated by Pejtersen (1980, 1994). This latter research program grew out of Pejtersen's development of empirically grounded methods and concepts for work analysis and tools to support fiction mediation in libraries, including domain-specific classification schemes and conceptual tools for capturing the actors' work tasks, strategies and preferences. Likewise, the results of Pejtersen's empirical work analysis of humanistic knowledge domains were integrated with the results of Risø's work analyses of other complex domains, ranging from tightly coupled domains like power plant control to more loosely coupled domains like case-handling and hospitals. The aim of this integration was to explore the potential for a broad methodological framework for work domain analysis, design and evaluation. Important results comprise a taxonomy for cognitive work analysis (Rasmussen, Pejtersen & Schmidt, 1990) and a new framework for Cognitive Systems Engineering (CSE) (Rasmussen, Pejtersen & Goodstein 1994). Risø's framework systematically guides the designer in analysis of work domains, actors and action possibilities, design of ecological interfaces using Gibson's theory of direct perception, and provides maps for possible interface designs and evaluations. *Ecological Information Systems* (EIS) are systems developed from this approach.

Structured affordance spaces in EIS

An important design rationale in the EIS approach is the notion that actors have the ability to directly perceive the state of affairs in the environment, given that the information is present in a proper format. In order to do this, the interface of a system must be transparent in the sense *that the deep structure of the* work is accessible to direct perception as an affordance space in a Gibsonean sense (see for instance, Rasmussen, Pejtersen & Goodstein, 1994, pp. 123-134; Pejtersen & Rasmussen, 1997). By "deep structure" of the work domain is meant the means-ends multi-dimensional properties of the work domain. Furthermore, the interface must support the levels of cognitive control at which the actors choose to perform (following the SRK model). The ecological interface couples all the means-ends levels of the work environment with the three levels of cognitive control. The intent is to allow the actors to dynamically switch their attention focus and control:

> "In Gibson's terms, the designer must create a virtual ecology, which *maps the relational invariants of the work system* onto the interface in such a way that the actor can read the relevant affordances for action" (Rasmussen, Pejtersen & Goodstein, 1994, p. 129; our underlining).

By "relational invariance" is meant situations where the *relation* between two or more properties or cues of the interface is invariant, where "absolute invariance" applies when one single property or cue is invariant. For EIS, "relational invariance" should not be understood in an absolute sense of universal relational invariants, but rather as recurrent situational couplings between invariants in the work domain ("sources of regularity") and invariants in the actors' task strategies and intentions. *Affordances, then, is defined is as "cues for action relevance"* (Rasmussen etc. 1994, p. 129-134).

EIS separates the representation of the *work domain* in terms of means and ends and task strategies on the one hand, and the *actors'* resources, background and preferences on the other hand. *Together, the two types of representations constitute a "dynamic world model" for the actor*. Invariants and invariant structures are identified for the work domain as well as for the actors through empirical work domain analysis. The generic invariant structure of the work domain is primarily identified through means-ends analysis. The recurrent invariants of the actors are identified through analysis of prototypical tasks and task decisions and through an analysis of the actors' professional and personal means and ends. This design principle is to ensure that the actors can be provided with action alternatives within prototypical task decision situations. The ecological information system supports the actor by displaying not only the overall work domain context, but also how and where their particular prototypical tasks and decisions perform.

EIS and loosely coupled domains

As a loosely coupled domain, the humanities constitute a specific application area for the disciplines involved in information system design. For instance, Information Studies address the humanities as a knowledge domain with high diversity in the conditions for knowledge production and documentation (paradigms, primary units of analysis, basic concepts, etc.), and hence, high diversity in requirements for the design of information systems. This diversity of knowledge production and mediation of the humanities has been explored by Pejtersen (1980, 1997) in her development of a grounded methodology for fiction mediation, retrieval and classification. The main research perspective within the humanities is the interpretative knowledge interest (Habermas, 1971), often based on historical methods of documentation. The primary sources to knowledge production and sharing are documents (texts, images, etc.), institutions (universities, schools, museums, archives etc.) and people (scholars, lay experts etc.). Currently, the humanities are gaining interest as an application area within international and national initiatives for networked access to cultural heritage in archives, libraries and museums, thus involving a variety of disciplines ranging from Computer Science, Information Studies, Linguistics to Engineering.

For networked environments that link the sites and people of loosely coupled domains, there is no object system that can function as a model for the architecture of the information system to be developed. In other words, there is no single and/or unified object system in the background that can structure the totality of context for work activity. Collections are distributed across different physical sites, ranging from library buildings, museums and archives to online databases and web sites on the Internet. Furthermore, the materiality of documents can range from paper-based documents such as books, manuscripts, images and movies, to electronic documents in databases and on the web. In addition, the knowledge background and culture of the actors is highly varied. They range from experts in mediation (librarians, archivists, teachers) and experts in the knowledge domain (for instance, researchers and teachers) to novices (for instance, adults and children searching for documents for leisure activities, learning etc.).

Thus, the overall architecture of an information system created for such loosely coupled domains comprised of heterogeneous elements (actors, sites, etc.) cannot be derived solely from existing structures and forms of the object systems (buildings, databases, organisation of information on web sites, etc.). This would correspond to restricting the architecture to the physical or technical infrastructure of the work domain. The actors of the work domains of libraries and archives *contribute* to the *totality of infrastructure of the work domain.* The actors contribute as knowledge producers (authors, literature researchers, film producers, film critics, etc.), intermediaries (librarians, archivists) and end-users (their interests and intentions, and hence, their activities and action possibilities will vary and develop within the constraints of their cultural, social and historical contexts). Thus, such loosely coupled work domains are *self-organised*. Their infrastructure evolves within the constraints of their contributing /participating actors, including the constraints of technical possibilities, socio-historical context and development, policies etc.

The architecture of an information system for such loosely coupled and self-organising work domains, then, should be created from an analysis of their total infrastructure, i.e. work domain(s), actors, and the coupling between work domain and actors, their constraints and possibilities. Recent empirical and theoretical research on infrastructures of loosely coupled domains has identified the following levels that are entangled in each other:

1. Technical infrastructure (physical localities and the linking between these);
2. Semantic infrastructure (organization and representations of documents and information)
3. Socio-pragmatic, intentional infrastructure (knowledge and intentions of contributing/participating actors and their interrelationships, coordination and collaboration forms).4

In his discussion on affordances, Gibson (1979) anticipates the issue of such multilevel self-organising systems by addressing the implications of human alteration of the natural environment (pp. 129-130):

> "This is not a new environment - an artificial environment distinct from the natural environment - but the same old environment modified by man. It is a mistake to separate the natural from the artificial as if there were two environments; artefacts have to be manufactured from natural substances" (Gibson, 1979, p. 130).

This view by Gibson of artificial environments versus natural environments should not be understood in a narrow physicalist sense. Gibson's view of natural environments is ecological. This means that it focuses on the co-evolution of actors and environments and breaks with previous deterministic and mechanistic views of nature. In this ecological perspective, artificial systems, such as information systems, are not abstract *representations* of natural environments. Rather, they constitute particular forms of materiality whose creation, through manufacturing and design, involve higher order invariants, in the same way as invariants evolve in the natural environment. Hence, the *invariants* of the ecology of distributed and loosely coupled work domains are not essentially given, but co-evolve through multilevel couplings between actors and the work domains.

EIS affordance spaces for the actors' strategies and intentions

In EIS systems, dynamic and structured affordance spaces are developed to support the actors' strategies and intentions in work activity. Such affordance spaces are not only developed from a means ends analysis of the work domain, but also from an analysis of actors' strategies, tasks and intentions. That is, the affordance spaces are created from a separate analysis of the deep structure of the work domain, from its physical properties to its goals, and from a separate analysis of the actors' recurrent behaviour, intentions and strategies (see for example Pejtersen & Albrechtsen, 2000; Albrechtsen & Pejtersen, 2000).

In such dynamic affordance spaces, the actors' *knowledge and rule-based behavior* can be supported through the display of ecological classification

4 . See Star & Ruhlehder, 1996, for an introduction of the concept of information infrastructure and the multiple levels of self-organization of heterogeneous, collaborative work domains. Likewise, Introna (1997) has described such domains as self-organizing second order systems, where the environment is simultaneously a medium and outcome of the interaction.

schemes. Ecological classification schemes articulate the semantic and socio-pragmatic infrastructures constituting the context of the actors' exploration of knowledge in work domains. They display the invariant structures, attributes and concepts of the work or problem domain together with recurrent and dynamic relational invariant structures, attributes and concepts of the actors' task strategies and intentions.

For instance, Pejtersen developed a generic multidimensional ecological classification scheme for fiction retrieval (1980), providing a structured affordance space for actors' knowledge based behaviour. The dimensions of this scheme correspond to the invariant structures of knowledge and interests in fiction that were found during the actors' interaction, communication and coordination of mediation activity. In addition, an ecological actor specific scheme was created, based on an SRK analysis of the actors' tasks, preferences and information needs. In order to support the actors' choice of action alternatives at the knowledge-based and rule-based level, a number of different displays of invariant structures and relational invariants for the problem domain of fiction retrieval were created. The actors' coupling and switching between such structured affordance spaces constitute the situation-specific/dynamic world model of fiction for the actors.

The EIS principle of creating an affordance space supporting the actors' diverse levels of control from skills-based to knowledge-based behaviour is related the EID concept of supporting actors with a mechanism to reduce complexity. However, within the loosely domains that EIS in particular addresses, the actors have high degree of freedom and action possibilities. Therefore, the analysis and representation of the actors' levels of control, as articulated for instance in ecological classification schemes, is far more extensive and detailed as compared with more tightly coupled domains like process control. As Vicente (1999) has recently pointed out, the EIS approach expands the original EID approach by supporting the actor's strategies and intentions at all three SRK levels. Furthermore, where EID addresses analysis, design and evaluation for experts only, EIS is directed to experts as well as novices within a work domain.

One EIS idea is that it would be useful to have perception and action occur at the same level. For example, in structured high-level affordance spaces like ecological classification schemes, the actors' control of the system could proceed at any level of the means-ends representation. One can envisage a structure of display screens corresponding to the various levels of the means-end hierarchy, and within each screen, perception and action would be directly coupled at the same level of representation. To implement this idea, a control algorithm could be constructed to deal with the degrees of freedom problem associated with implementing a command at a high level of abstraction.

Future work: Affordances are social intentions - ECIS

EIS utilizes Gibson's ideas of direct perception-action for the design of ecological interfaces with high-level affordance spaces for loosely coupled domains, based on the grounded methodological approach of the CSE framework for domain and actor analysis. EIS's concepts developed from empirical studies of individual work activity, but has contributed to the study of cooperative work in hospitals, manufacturing and libraries. Risø's current EIS research is focused on work domains with collaborating, autonomous actors (teams and self-organising groups of actors), where the actors' intentions are constrained by intentional structures such as company policies, national regulations, etc. This research aims at elaborating the CSE framework with new systematic methods for analysis of cooperative work and design of ecological collaborative information systems (ECIS). This means that new tools are being developed for analysis, modelling and representation of the socio-technical complexity involved in distributed and self-organising collaborative work. The goal is to develop concepts and tools for the design of dynamic social affordance spaces in interfaces that can support the actors' coordination, knowledge sharing and communication in work. Furthermore, the goal is to develop concepts and tools for collaborating actors' co-creation and use of a shared dynamic and structured affordance space.

5 Discussion

The notion of affordances has been defined and applied from a variety of theoretical and empirical perspectives within HMI. The most known generic HMI definitions have been put forward by Norman and Gaver (Norman, 1986, Gaver, 1991) as follows:

- "Properties of the world that are compatible with and relevant for the actors' interaction, which, when *perceptible*, offer a *link between the actors' perception and action*" (Gaver)

- "Physical properties are stable properties that the designer *adds to the interface* to support human-computer interaction, based on a *conceptual model* of the system and actor. Symbols and constraints are not affordances, because *conventions for such aspects of the world develop, whereas affordances do not"* (Norman).

5.1 Applications of Gibson's affordance concept in HMI - advantages and disadvantages

Gaver's and Norman's definitions of affordances are "classic" contributions to the application of Gibson's ecological theory for HMI and are widely applied for design and evaluation of interfaces. However, the definitions imply that affordances are more or less equivalent to add-on surface phenomena in interfaces. While these definitions have the strength of generality and universality, they simultaneously imply detachment from the actors' situational use contexts. In particular, Norman's notion implies a rather reductionist perspective on affordances as static features or objects of the world/system etc., rather than dynamic properties affording action. Gibson, on the other hand, rejected the notion that the environment, objects, actors, etc. are essentially or causally given and amenable to universal attribute description and categorisation. Gibson, however, does to some degree follow an essentialist line of thought in his assumption of invariants as "hidden structures" of the environment, constituting the context for information pick-up. Nonetheless, Gibson did *not* define affordances as inherent features of the environment nor of the actor, but as dynamic elements evolving through the situational coupling between actor and environment.

Contrary to Norman and Gaver's notions of affordances, Activity Theory and Cognitive Systems Engineering emphasise affordances as specific to human work activity and its socio-historical, cultural and organisational dimensions, goals and constraints. These latter dimensions of work activity are crucial backgrounds, and hence, important units of analysis, addressed by these approaches. According to these approaches, then, affordances are not viewed as merely physical properties of the world, interface, system, etc. Rather, affordances are viewed as properties of the work environment, including computer systems, properties that support intentional or purposeful action at different levels. These levels range from high level understanding and reflections of the overall goal of an activity to more unconscious operations. Overall, according to Activity Theory and Cognitive Systems Engineering, affordances evolve dynamically, are embedded in socio-cultural contexts and are not essentially nor causally given.

5.2 Conceptual and intentional affordances

According to activity theory, the relation between the actor and the environment is dynamic, and hence the focus is on biological, historical and individual development. Human activity is mediated, for instance through language and artefacts. Human activity is purposeful or goal-directed. The actor's work, as mediated through the artefact, is carried out as operations, actions and activity. Human-machine interaction cannot be understood without an understanding of the purpose of the actor's activity and its socio-historical context. According to activity theory, affordances of an artefact are reflections of socio-historical developments and contexts. Thereby, affordances are not essentially given, nor do they merely reflect physical properties in a narrow sense. Furthermore, the actor's perception and information pickup is an effect of her learning process in activity, including the use of tools, and therefore, affordances are only affordances as long as they are understood and ready to hand or are within the actor's zone of proximal development. Thus, according to the activity theoretical approach, affordances of tools, as for instance computer systems, must be designed in close cooperation with the users. Firstly to detect socio-historical dimension of existing tool and the usual way of carrying out work in a collaborative way. Secondly to detect which part of the work should be delegated to the computers and which part should remain in the sphere of human operations. Thirdly to design new tools with a democratic perspective in mind.

Cognitive Systems Engineering sees the relation between the actor and the environment as mediated by a dynamic world model. This model constitutes an interpretative layer between information pick-up and action, which performs at a conscious or unconscious level, depending on the actor's relative skills, rules and knowledge (SRK) in a particular work situation or work domain. The dynamic world model evolves through the situational coupling between the actor and the functional properties of work environment and tools, such as computer systems. Affordances of information systems are designed on the basis of i) an analysis of the invariant functional properties of the work domain, as captured through the means-ends model; ii) an analysis of the actors' skills-rules-knowledge; iii) an analysis of the actors' diverse, but invariant strategies and intentions (coupling). Affordances, then, articulate and display to the actor her dynamic internal world model, and thereby also articulate dynamic mutuality of the actor and work environment. In other words, affordances of information systems not only function to support skill-based, rule-based and knowledge-based behaviour, but also provide an additional layer of "situational meta-knowledge" to support the actors' reflections on the outcome of actions and as well as on action possibilities. Previously, CSE has defined affordances as "cues for action relevance". This definition is in line with Gibson's original theory of direct perception-action. However, Risø's research on ecological information systems involves in-depth empirical analysis of work domains and actors from a variety of disciplinary perspectives. This means that likely, the previous CSE definition of affordances should be extended as follows: *"cues for action relevance, displayed in the context of a virtual ecology of work".*

5.3 Perception-action versus interpretation and understanding

According to the AT and CSE approaches for HMI, the primary unit of analysis is human work activity and the socio-cultural context in which this activity is carried out. Thereby, they emphasise the actors' purposeful activity as the most important design rationale. CSE, and EIS, in particular, has incrementally integrated results from field studies with the models such as means-ends, SRK and the taxonomy for cognitive work analysis, together the application of Gibson's ecological theory. The hypothesis is that it is possible to recreate the ecology of human work activity in information systems. In activity theory focus has been on analysing the hierarchy of operations / conditions, actions / goals and activities / motives. The hypothesis is that it is possible to support human work activity through information systems by facilitating: i) operations toward the computer application as a physical object, ii) operations for handling aspects of the computer application that can be conceptualised into actions and iii) operations directed towards work that is dealt with in and through the computer application.

HMI (Norman/Gaver)	**Gibson**	**Activity Theory**	**Cognitive Systems Engineering**
Affordances (foreground)	**Affordances (shift, foreground and background)**	**Affordances embedded in socio-historical contexts (shift, foreground and background)**	**Affordances cues for action relevance (shift, foreground and background)**
System (Background)	**(Mutuality)**	**Mediation through system/tool (shift, foreground and background)**	**Mediation through dynamic work world model as articulated in system (shift, foreground and background)**
Environment (Background)	**Invariant structures (shift, foreground and background)**	**Work domain, socio-historical contexts**	**Invariant structures of work domain; virtual ecology of work**

Figure 3. Affordances in HMI, Gibsonean theory, activity theory and cognitive systems engineering

According to previous views in HMI, notably those that have been put forward by Norman and Gaver, affordances are in the foreground, whereas the system or work area is in the background. AT and CSE share the view that the actors' perception of foreground and background shifts dynamically according to the actors' situational context in purposeful activity (see figure 3 below). This conception by AT and CSE of affordances is in alignment with Gibson's view of the necessity of available information (invariants) of affordances in order for their perception and pick-up to occur. The shift between the actors' focus on work problems and context, tools that mediate their activity and their coordination of work activities with other actors performs at several levels of action, communication and understanding. Hence, AT and CSE follow the original notion by Gibson on the actor's dynamic shifting between foreground and background of the environment. Furthermore, because their goals are to support several levels of action and interpretation for human activity through information systems, they extend Gibson's original ideas to cover more deep semantic and pragmatic aspects of the ecology of work.

6 Future work

The future research by CHMI on affordances will focus on:

i) how to extend the original affordance concept to cover design problems for social interaction, cooperative work and inter-subjectivity

ii) how to additionally incorporate the semiotic perspective on affordances

For the first focus of social interaction and cooperative work, our discussions will be based on results from the field studies carried out in the three empirical projects of the centre on common information spaces, ecological information systems, and elastic information systems. Our discussions will also work from cross-disciplinary work on common information spaces and collaborative classification, to which the centre has contributed extensively since the beginning with publications, presentations and research topics.

As regards the second focus of incorporating semiotics, our discussions will be based on results from the field studies carried out in the three empirical projects of the centre. A further basis will be the theoretical results from the discussions of mediation in Activity Theory and Semiotics, as well as on theoretical work on semiotic understandings of Gibson's ecological theory and implications for HMI.

References

Albrechtsen, H. & A.M. Pejtersen (2000). Bringing classifications closer to home. Paper presented at the *International Workshop on Classification Schemes in Cooperative Work, Philadelphia, held 1 December 2000*, arranged by K. Schmidt, K. Simone & S.L. Star, in connection with CSCW2000 (available from hanne.albrechtsen@risoe.dk)

Amant, R.S. (1999). User interface affordances in a planning representation. *Human-Computer Interaction* 14, pp. 317-354

Andersen, P.B.; Holmquist, B. & J.F. Jensen (1993). *The Computer as Medium*. Cambridge University Press.

Bertalanffy, L.v. (1968). *General Systems Theory. Foundations, Developments, Applications.* New York: George Braziller

Bærentsen, K. B. (2000). Intuitive user interfaces. *Scandinavian Journal of Information Systems* 12, pp. 29-60

Bærentsen, K. B. (1988) Mennesker og Maskiner, In, "*Et virksomt liv*"/edited by M. Hedegaard, Aarhus Universitets Forlag, Århus, 1988.

Bødker, S. (1991). *Through the interface*. *a Human Activity Approach to User Interface Design.* Hillsdale, NJ: Lawrence Erlbaum Associates

Engeström, Y. (1990) *Learning, Working and Imaging Twelve Studies in Activity Theory.* - Helsinki: Orienta-Konsultit Oy

Flach, J. (1995). The ecology of human-machine systems. A personal history. In: In: *Global Perspectives on the Ecology of Human-Machine Systems*/edited by J. Flach, P. Hancock, J. Caird & K. Vicente. - Hillsdale (N.J.): Lawrence Erlbaum, pp. 1-13.

Gaver, W.W. (1991). Technology affordances. *Proceedings of CHI 91*, New Orleans (LA), 28 April - 2 May 1991 (pp. 79-84). - New York: ACM

Gerson, E.M. (2000). *Different parts for different smarts: partonomies and the organization of work.* Position paper for the workshop Cooperative Organization of Common Information Spaces, 23-25 August, 2000, CIT, DTU/arranged by K. Schmidt. Available from: gerson@ieee.org

Gibson, J.J. (1986). *The Ecological Approach to Visual Perception.* Hillsdale (NJ): Lawrence Erlbaum.

Habermas, J. (1971) *Knowledge and Human Interest* - Boston: Beacon Press.

Introna, L. (1997). *Management, Information and Power: a narrative opf the involved manager,* Basingstoke: Macmillan.

Kaptelinin, V. (1996). Activity Theory: Implications for Human-Computer Interaction, In (Ed.) B., A., Nardi, *Context and Consiousness*. Cambridge: MIT Press, pp.103-116.

Latour, B. (1994). On technical mediation. Philosophy, sociology, genealogy. *Common Knowledge*, 3, pp. 29-64

Leont'ev, A. (1981). *Problems in the Development of Mind.* - Moscow: Progress

Leont'ev, A.N. (1978). *Activity, Consciousness and Perso*nality. - Englewood Cliffs (NJ): Prentice-Hall

Maturana, H. R. & F.J.. Varela (1980) *Autopoiesis and Cognition: The Realization of the Living*. Dordrecht: D. Reidel, 1980. (Vol. 42: Boston Studies in the Philosophy of Science)

Nardi, B. & N. O'Day (1999). *Information Ecologies. Using Technology with Heart*. MIT Press.

Norman, D.A. (1999). Affordances, conventions and design. . *Interactions 6 (3)* pp. 38 - 43

Norman, D.A. (1991). Cognitive artifacts. In: *Designing Interaction: Psychology at the Human-Computer Interface*/edited by J.M. Carroll. - Cambridge (UK): Cambridge University Press, pp. 7-38.

Norman, D.A. (1988). *The Psychology of Everyday Things*. Hillsdale (N.J.): Lawrence Earlbaum.

Pejtersen, A. M. & H. Albrechtsen (2000). Ecological work based classification schemes. In: Dynamism and Stability in Knowledge Organization. Proceedings of the 6th International ISKO Conference, 10-13 July 2000, Toronto, Canada/edited by C. Beghtol, L.C. Howarth & N.J. Williamson. - Würzburg: Ergon Verlag, (pp. 97-110).

Pejtersen, A.M. & J. Rasmussen (1997). Ecological information systems and support of learning: coupling work domain information to user characteristics. In*: Handbook of Human-Computer Interaction*/edited by M. Helander et al (pp. 315-346) - Amsterdam: Elsevier.

Pejtersen, A.M. (1994). A framework for indexing and representation of information based on work domain analysis. In: *Knowledge Organization and Quality Management: Proceedings of the 3rd International ISKO Conference*/ edited by H. Albrechtsen & S. Ornager. – Frankfurt: Indeks Verlag, pp. 251-262

Pejtersen, A.M. (1980). Design of a classification scheme for fiction based on an analysis of actual user-librarian communication and use of the scheme for control of librarians' search strategies. In: *Theory and Application of Information Research*/ edited by O. Harbo & L. Kajberg. – London, Taylor Graham, pp. 146-159

Pickering, J.J. (1999). The self is a semiotic process. *Journal of Consciousness Studies*, 1999, Vol. 6, No. 4, pages 31 - 47.
http://www.warwick.ac.uk/~psrev/Self_jcs.html

Polanyi, M (1966). *The Tacit Dimension*. New York: Doubleday & Company

Propp, V.Y. (1958). *Morphology of the Folktale*. - Bloomington: (originally published in Russian, Leningrad, 1927)

Raiethel, A. & B. M., Velichkovsky (1996). Joint Attention and Co-Construction of Tasks: New Ways to Foster User Designer Collaboration, In *Context and Consiousness* edited by B., A., Nardi, The MIT Press, Cambridge, Massachusetts, 1996, pp.199-233

Rasmussen, J. & A.M. Pejtersen (1995). Virtual ecology of work. In: The Ecology of Human-Machine Systems/edited by J.M. Flach et al. (pp. 121-156). - Hillsdale (NJ): Lawrence Erlbaum.

Rasmussen, J.; Pejtersen, A.M. & L. Goodstein (1994). *Cognitive systems engineering*. - New York: Whiley.

Rasmussen, J. (1986). *Information processing and human-machine interaction*. New York: North-Holland.

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man and Cybernetics* 1 (3), pp.

Rosenbluth, A.; Wiener, N. & J. Bigelow (1943). Behavior, purpose and teleology. *Phil. Sci*. (10), pp. 18-24

Schneiderman, B. (1987). Designing the User Interface : Strategies for Effective Human-Computer Interaction. - New York: Addison-Wesley. (New third edition available in 1997)

Star, S.L. & K. Ruhleder (1996). Steps toward an Ecology of Infrastructure: Design and Access for Large Information Spaces. *Information Systems Research* 7 (1), side 111-134

Stoffregen, T.A. (2000a). Affordances and events. *Ecological Psychology* 12 (1), pp. 1-28

Stoffregen, T.A. (2000b). Affordances and events: theory and research. *Ecological Psychology* 12 (1), pp. 93-107

Suchman, L. (1987). *Plans and situated action*. - Cambridge (MA): Cambridge University Press.

Tversky, A. & D. Kahneman (1974). Judgement under uncertainty: heuristics and biases. *Science* (185), pp. 1124-1131.

Vicente, K. (1999). *Ecological Interface Design: Progress, Limitations and Challenges*. Available from the author; email: benfica@mie.utoronto.ca

Vicente, K. & J. Rasmussen (1992). Ecological interface design: Theoretical foundations. *IEEE Transactions on Systems, Man and Cybernetics*, 22 (4), pp.

Vygotsky, L. (1980). *Mind in Society*. Cambridge (Mass.): Cambridge University Press.

Vygotsky, L. (1966). The development of higher mental functions. In: *Psychological Research in the USSR*/edited by A.N. Leontyev, A.R. Luria & A.A. Smirnov. - Moscow: Progress, pp. 11-45.

Whitley, 1983. From the sociology of scientific communities to the study of scientists' negotiations and beyond. *Social Science Information*, 22 (4-5), pp. 681-720

Winograd, T. & F. Flores (1986). *Understanding Computers and Cognition*. - Reading (Mass): Addison-Wesley.

Wittgenstein, L. (1953). *Philosophical investigations*. New York: MacMillan Company.

Zaff, B.S. (1995). Designing with affordances in mind. In: *Global Perspectives on the Ecology of Human-Machine Systems*/edited by J. Flach, P. Hancock, J. Caird & K. Vicente. - Hillsdale (N.J.): Lawrence Erlbaum, pp. 238-272.

Bibliographic Data Sheet			**Risø-R-1287(EN)**
Title and authors			
Affordances in Activity Theory and Cognitive Systems Engineering			
H. Albrechtsen, H.H.K. Andersen, S. Bødker, A.M. Pejtersen			
ISBN			ISSN
87-550-2927-2 87-550-2928-0 (Internet)			0106-2840
Department or group			Date
System Analysis Department			August 2001
Groups own reg. number(s)			Project/contract No(s)
Sponsorship			
The Danish National Research Foundation			
Pages	Tables	Illustrations	References
37	3		49

Abstract (max. 2000 characters)

For the last decade, the Gibsonian concept of affordances has attracted much attention within Human-Machine Interaction (HMI) and related research communities. The application of Gibson's ideas in HMI has lead to the notion of direct manipulation of interface objects. Previously, the focus has been on design for low level interaction modalities. To incorporate the concept of affordances in the design of human computer interaction it is necessary to systematically unravel affordances that support human action possibilities. Furthermore, it is a necessity that Gibson's theory of affordances is supplemented by careful analyses of other human modalities and activities than visual perception. Within HMI two well established perspectives on HMI, Activity Theory (AT) and Cognitive Systems Engineering (CSE), have discussed such analyses and design of action possibilities focusing on providing computer support for work situations. Within these perspectives, the primary unit of analysis in HMI is human work activity and the socio-cultural context in which this activity is carried out. Thus, they emphasise the actors' purposeful activity as the most important design rationale. According to previous views in HMI, notably those that have been put forward by Norman and Gaver, affordances are in the foreground, whereas the system or work area is in the background. AT and CSE share the view that the actors' perception of foreground and background shifts dynamically according to the actors' situational context in purposeful activity. AT and CSE follow the original notion by Gibson on the actor's dynamic shifting between foreground and background of the environment. Furthermore, their work- and actor-centred approach to analysis and design of information systems opens up to an extension of Gibson's original ideas to cover deeper semantic and pragmatic aspects of the ecology of work, as compared with the previous applications of Gibson's theory in HMI.

Descriptors INIS/EDB

Available on request from Information Service Department, Risø National Laboratory,
(Information Service Department, Risø National Laboratory), P.O.Box 49, DK-4000 Roskilde, Denmark.
Telephone +45 4677 4004, Telefax +45 4677 4013