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The Human-Artifact Model–an Activity Theoretical Approach to Artifact Ecologies

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RUNNING HEAD: The Human-Artifact Model

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Abstract

While devices of all shapes and sizes currently dominate the technological landscape, human-computer interaction as a field which is not yet theoretically equipped to match this reality. In this paper we develop the Human-Artifact Model, which has its roots in activity theoretical HCI. By reinterpreting the activity theoretical foundation, we present a framework that helps addressing the analysis of individual interactive artifacts, while embracing that they are part of a larger ecology of artifacts. We show how the Human-Artifact Model helps structuring the understanding of an artifact's action-possibilities in relation to the artifact ecology, surrounding it. Essential to the model is that it provides four interconnected levels of analysis and addresses the possibilities and problems at these four levels.

Artifacts and their use are constantly developing, and we address development in, and of, use. The framework needs to support such development through concepts and methods. This leads to a methodological approach that focuses on new artifacts to supplement and substitute existing artifacts.

Through a design case, we develop the methodological approach and illustrate how the Human-Artifact Model can be applied to analyze present artifacts and to design future ones. The model is used to structure such analysis and to reason about findings, while providing leverage from activity theoretical insights on mediation, dialectics and levels of activity.

Contents

1. INTRODUCTION

Today mobile devices can in many situations compete with laptops and desktop computers in providing applications and access to the Internet. Consequently, people increasingly blog, read news, play games and use maps interchangeably on multiple heterogeneous devices. All of these devices may not necessarily have a well-specified function in daily use; rather, they are used interchangeably in response to the context and conditions of use. As analysts, practitioners and designers we have to acknowledge that users juggle with multiple different interactive artifacts in their daily lives, all of which influence the perception and use of the others. Yet we wish for a theoretical framing that may help structure our understanding of individual use in relation to the shared human practice. In this paper we propose that Activity Theory can be elaborated to provide such an understanding.

1.1. Background

In line with Jung et al. (2008) we refer to the artifacts in use by a particular user as the user's artifact ecology. Over the last decade users' artifact ecologies have become increasingly complex. Traditional artifacts of all kinds are being supplemented and replaced by interactive ones, as was convincingly illustrated through Oulasvirta's (2008) studies of professionals at Nokia. The use context of interactive technologies has broadened to embrace almost all aspects of both work and leisure. New elements of human life are being included in human-computer interaction research and practice. Such elements include culture, emotion and experience. Conceptually and theoretically, the most recent wave of HCI research has focused on the cultural level ((Dunne & Raby, 2001, Bolter & Gromela, 2003), or on experience (McCarthy & Wright 2004)), although quite detached from the level of actual action. In this paper we will focus on bridging this gap between low-level interaction considerations and higher-level cultural contextualization.

In his 2001 book Dourish approached post-desktop computing from the stance that we should understand ourselves as *embodied* in technology. Such embodiment is not only an issue of culture and emotion; it is equally an issue of how our physical capacities extend and expand through technology. Dourish approaches embodiment from a phenomenological perspective, where individuals are, *inter alia*, defined by the tools they use, whether called 'equipment' in Heidegger's terms, or 'functional organs' in the terms of Leontiev's (1978, 1981) activity theory. Bødker (1991) used Heideggerian as well as activity theory, when arguing that human activity, hereby also human-computer interaction, is *mediated* by technological artifacts. She furthermore proposed that this mediation included both the cultural level and actual handling of the technology. Beaudouin-Lafon (2000) took his starting point in this idea of mediation when he proposed that instrumental interaction is a way of approaching human-computer interaction. Dourish's embodiment and Beaudouin-Lafon's instrumentality point towards an understanding of human-computer interaction, where instruments coexist and replace each other as extensions of the human body.

Ubiquitous Computing has, since it was established in the late eighties, had a tendency to make disappearing computing and seamless use the overarching goals of

the field. Chalmers & Galani (2004) point out that seamless, embodied interaction is mirrored in seamfulness, revealing differences and limitations of the technology. We agree that seamfulness should be viewed as a resource, and that seamlessness potentially contradicts learning. Similarly to Chalmers & Galani we are interested in understanding the dialectics between the interfaces that are designed, and the ways in which people build their understanding and use over time. Where both Dourish and Chalmers & Galani seem largely unaware of earlier attempts to think Heideggerian phenomenology into HCI, this paper revisits the shared history as basis for an elaboration of human-computer interaction in complex artifact ecologies.

Post-cognitivist thinking brought into HCI e.g. by ethnomethodology, in particular by Suchman (1987), has led to a useful insistence on a focus on the particularities of specific unfolding interaction. Ethnomethodological studies have been an eye-opener to many in the field with their emphasis on understanding how human beings, together, cope with messy environments and ill-suited technical solutions. However, Kaptelinin & Nardi (2006) point out that a theoretical framework is of importance to HCI to continuously avoid going back to specific, detailed accounts of particular cases. Such needs are even more predominant when we insist on studying use across computing devices, and computing devices across use situations. Hence, we find an ethnomethodological approach insufficient, and agree with Kaptelinin & Nardi in that we need theoretical frameworks in HCI.

From where we stand now, we need a theoretical framework to address the gap between culture, experience and the practical role of artifacts in embodiment and mediation. It needs to bridge between unique examples and general theoretical concepts, and even between analysis and design, i.e. between understanding the problems and possibilities of current use, and the possibilities and problems of new artifacts infused into such an ecology. To discuss these challenges we present an activity theory-based understanding of how human beings perceive and appropriate artifacts. Although the foundation for the theoretical development is not new, this paper rethinks the foundation in order to address the current situation, and proposes an enriched conceptual understanding of artifacts. We present the Human-Artifact Model as a tool for structuring design-oriented analysis, and we illustrate that it can be used to frame both comprehensive and casual analysis of observed interaction, and to frame design considerations, e.g. for prototyping. This means that the Human-Artifact Model is not intended to have a specific place in a design process, but can be used throughout design. It has been pointed out by Rogers (2004) that practitioners and designers crave simple, yet theoretically sound, tools–a challenge that we address with the Human-Artifact Model.

The model is a thinking tool for researchers, analysts and designers alike. It helps structure the insight gained through activity theoretical analyses, focusing on multiplicity of artifacts, leveled analysis and dialectical thinking. We believe in multiplicity in terms of design artifacts as well as artifacts in general, and have no aspirations for *one* complete and all encompassing design methodology. In this design-methodological landscape we suggest that the Human-Artifact Model will help deal with the challenges of complex artifact ecologies.

Central to our approach is that activity theory allows for dialectical rather than causal thinking. Dialectics is the method of reasoning that aims to understand things

concretely in all their movement, change and interconnection, with their opposite and contradictory sides in unity. There are many approaches to dialectical thinking that we will not scrutinize here (e.g. Hegel, Engels, Marx and many later philosophers). However, it is important to stress that since movement and change are essential parts of dialectical thinking, the model has a focus on development of use, and it presumes an iterative process of analysis and design.

In the remaining of this chapter we provide an overview of activity theoretical HCI. This leads to a chapter where we develop the new foundational understanding of artifacts, leading to the Human-Artifact Model. We then go on to illustrate the analytic power of the model. The paper is concluded with a discussion of related work and what we have achieved.

1.2. Activity theoretical HCI

Since the mid 1980's activity theory has been explored as a basic perspective on human-computer interaction. In an attempt to break with cognitive science-based HCI, a theoretical platform has been established, based on dialectical materialism (Hydén 1981, Engeström, 1987), and human beings acting in real-life situations (Winograd & Flores 1986, Dreyfus & Dreyfus 1986, Suchman 1987).

Fundamentally, activity theoretical HCI (Bødker 1991, Bertelsen & Bødker 2003) led to a focus on extending HCI to focus on analysis and design of artifacts for a particular work practice with concern for qualifications, work environment, division of work, etc. From HCI's classical focus on tasks, it moved attention towards actual use and the complexity of multi-user activity, in particular the artifact as mediator of human activity. The development of expertise and use in general came into focus, and resulted in a further concern for active user participation in design and for use as part of design.

Activity theory addresses more than just individual skills, knowledge and judgment, and is not restricted to the "generic" human being, since it understands human conduct as anchored in collective/shared practice. Activity theoretical HCI focuses on the appropriateness of certain tools for certain practices. It studies how the introduction of new artifacts changes practice, and how practice may change the use of these artifacts. Furthermore, it focuses on individual human development in relation to development of the culture and communities of practice in which it exists (see also Kaptelinin & Nardi, 2006). As practice develops over time, concern for the historical context of such artifacts in use is essential to activity theoretical HCI. Learning is not only a matter of how the individual adapts to particular artifacts; it is a matter of how the collective practice develops in small or larger leaps. In actual use, artifacts most often mediate several work activities, and the contradictions and conflicts arising from this multitude of use activities are essential for activity theoretical artifact analysis and design.

Human activity can be analyzed into a three-level hierarchy of activity, action and operation (Leontiev 1978, 1981). Activity deals with the level of motivation; it motivates *why* a particular set of actions, with particular material or ideal objects, is carried out. Without motive, there is no activity. The subject's reflection (in terms of expectation and evaluation) of this object motivates the activity. Motives are often tacit or unarticulated. With the division of work in society, activity may be poly-

motivated, meaning that a particular activity may have more than one motive, coming from e.g. different areas of life. To describe an activity at the activity level means to focus on the social and personal meaning of activity and its relation to motives.

Human activity is carried out through actions. These actions are governed by the conscious goals of the subject. Goals reflect the outcome of action, and vice versa, quite obviously. This reflection consists of an ongoing evaluation of the *actual* outcome of actions on objects against the *desired* outcome. Hence, goals are related to the desired future state of an object and are, thus, different from the motive. Since goals are conscious, it is through goal formulation we immediately meet human activity in an analysis. The action level is where researchers and designers meet users, when we ask them what they do. Actions are realized through series of operations. Actions are recursive structures, consisting of both conscious and non-conscious sub-actions and operations. To describe an activity at the action level means to focus on *what* the subject does and on possible goals, critical goals and particularly relevant sub-goals of subjects (Bærentsen & Trettvik, 2002).

Operations are never fixed, but adapted dynamically to the conditions of the environment. Operations are "triggered" by the conditions for and structure of the action. They are performed without conscious thinking, and oriented by what Kaptelinin (1995a) calls an unconscious *orienting basis*. Operations are cultural-historically developed or have naturally evolved (Bærentsen & Trettvik, 2002). They result from appropriated use of tools, educated manners towards other human beings, or movements in the physical world according to concrete physical conditions. To describe the activity at the level of operation means to focus on *how* the activity gets carried out, the concrete way of executing an action in accordance with the specific conditions surrounding the goal. A summary of these levels is presented in Figure 1.

The activity theoretical tri-partition should not be understood as means for static categorizations of analytical findings. Instead it provides three sets of analytical glasses, each of which focuses on an important aspect of human activity: Motivation (by asking *why?*), goal-orientation (by asking *what?*) and function (by asking *how?*). It is important to sustain the dynamic relationship between these three aspects. Stating that something is an operation is not interesting without asking the following questions: What action has been operationalized in the first place? Where are its limits? When does it break down?

The notion of motive forces the analyst to look beyond the apparent. Motive embodies the unspoken and unconscious. In our design case below we see how a central, albeit unspoken, motivation for the actions of two people solving assignments with a geographical map was to establish a common orienting basis. For these actors to successfully work together in solving the given assignments, the artifact needed to support such a common orientation.

This theoretical grounding seeds an exploration of mediation, multiplicity and development that we pursue in the following.

Levels of activity	Mental representation	Realizes	Level of description	Analytical question
Activity	Motive (need)–not necessarily conscious, but may become conscious	Personality	The social and personal meaning of activity, its relation to motives and needs	Why?
Action	Goal–conscious	Activities (systems of actions organized to achieve goals)	Possible goals, critical goals, particularly relevant sub-goals	What?
Operation	Condition of actions (structure of activity)–normally not conscious, only limited possibilities of consciousness	Actions (chains of operations organized by goals and concrete conditions)	The concrete way of executing an action in accordance with the specific conditions surrounding the goal	How?

Figure 1. Activity as a hierarchically organized system. The table is adopted from Bærentsen (1989) and (Bærentsen & Trettvik 2002), and shows the relation between the three levels of activity, regarding their conscious or unconscious mental representation, what elements of human activity that the level realizes through action, the way in which the level may be analytically described and the analytical key question.

2. ARTIFACTS

Activity theory was originally introduced in HCI to point out that the relationship between the human being and the computer is not a simple subject-object or subject-subject relationship: Instead of studying the relationship between the user and the computer as something that the user works *on*, or communicates *with*, Bødker (1991) pointed out how we may more usefully see the computer as something that the user acts *through*, on other objects or with other subjects; a *mediator*.

Designed artifacts and their role as mediators have been at the core of this way of thinking. A further, overriding concern for the following discussion is to move the focus away from one artifact alone towards *artifacts* in plural. The challenges of interaction beyond the desktop computer, force us to be able to conceptualize the interplay between artifacts: How the use of one artifact may influence the use and perception of another, and how human understanding and the use of artifacts at large influence an artifact in use? In this manner the focus is on the interplay between reflection and action, rather than one or the other alone.

2.1. Artifact ecologies

Artifacts are never used in isolation, and they cannot be understood as such. All artifacts used by human beings are part of artifact ecologies, whether simple (e.g. pen and paper) or complex (e.g. tools for building a house). Hence, human activity is not just mediated through a single artifact; it is multi-mediated. Bertelsen & Bødker (2002), Bødker & Bøgh Andersen (2005) exemplify how multiple mediators for specific activities may be connected: *Chains* (e.g. a key-card produces a number that is used to open a door), *meta-instruments* (e.g. the pencil sharpener and the pencil),

levels (e.g. driving the car by cruise control on the freeway using only the wheel to control the car, versus curb-side parking where several mediators are used to move the car-wheel, rear-view-mirror, clutch, brake, etc.) and *co-occurring mediators* (e.g. the pencil and paper). In environments of many interchangeable artifacts, *substitution* (Brodersen et al. 2007b) is a similarly relevant relationship, emphasizing how and under which circumstances one artifact may replace another. An artifact ecology often consists of multiple artifacts built for similar purposes, but with slight variations and no clear delineation of when to use which artifact. The specific choice of artifact that the user may make is situated and depending both on the material conditions of the activity and on the specifically intended outcome. Examples are sets of clubs for golf or brushes for artistic painting.

From an activity theoretical perspective, artifact ecologies are defined from the point of view of activity. Primarily we look at ecology as connected to purposeful, goal-oriented action of some kind, and not as truly endless action possibilities of the environment. The artifacts used on a regular basis by users in relation to a given activity constitute the *current* artifact ecology of use (see also Jung et al., 2008). In addition, the *historical* artifact ecology plays an important role when appropriating new artifacts, since it is what shapes the user's perception of other artifacts. Such past experiences are elements of the orienting basis (see 2.5). The historical artifact ecology consists of all the artifacts that previously have been applied to realize the activity.

Within artifact ecologies, multiple overlapping activities take place with multiple motivations and purposes. A number of artifacts offer overlapping uses at various levels of activity: A fountain pen and a pencil may both be used for writing a note on a piece of paper. However, they are held and handled quite differently, have different durability, social connotations, and produce writing of different aesthetics and longevity. Jung et al. (2006) show how each interactive artifact in the user's artifact ecology influences how the other artifacts are used. Having both a laptop and a workstation may result in the laptop being used only for work and the workstation entirely for entertainment, even though each device in isolation is capable of both.

The examples from Jung et al. (ibid.) primarily illustrate how artifacts influence one another at the level of actions: *What* is done with which artifact. The well-known story of why we use qwerty keyboards on laptops and cell-phones today, illustrates that artifacts similarly influence each other on the *how* level: The qwerty keyboard was originally designed to prevent the arms of a typewriter from getting entangled when the typist went too fast. Hence, frequent key-combinations were spread out on the keyboard. This concern is no longer relevant for computer keyboards, and though other layouts of keys have proved more efficient, we are somehow stuck with QWERTY, mainly because many resources have been put into training typists. Also, that moving between keyboards of different layouts creates a significant cognitive load. In activity theoretical terms this requires otherwise non-conscious operations to be executed as conscious actions. With these examples in mind, we propose that it is important to address the artifact ecology from all three levels. We return to this in section 2.6.

While we propose to address artifact ecologies primarily as collections of artifacts that are determined by looking at empirical situations, artifact ecologies in addition

define a wider space of action possibilities. These action possibilities are formed by experience and relate to every artifact that the acting subjects have come across in realizing similar activities. In this dialectical field of tension we find the *potentials* as well as *problems* of relying on *past experiences* and *similarities* from other artifacts.

The focus of artifact ecologies helps address development through the historical artifact ecology in relation to the current ecology, and to future action possibilities with new artifacts.

2.2 The ideal of the artifact

Evidently, a computing device, like any other thing in our surroundings, can simply be regarded as an object; something that can be looked at, picked up, or even used for something unanticipated, e.g. thrown to break a windowpane. However, this is likely to happen mainly if the "user" has either no past experiences whatsoever with a similar device, or if the user is desperate and caught with no other alternative. One additional situation where computing devices are objects of attention is design, where they constitute the *material*, which gets transformed into some sort of workable computing device.

This role in design points to an important quality, which makes computing devices more than just objects: They are *artifacts*, i.e. they are designed or shaped by human beings with a particular purpose or use in mind. It is this question of artifactness that drives HCI: How do we design computing artifacts that work (better) in use? How do we shape artifacts to fulfill particular purposes that are (more or less) well understood?

In the following we leave the focus on multiplicity for a short while to focus on the relationship between an artifact and its user. Beguin & Rabardel (2000) introduce the term *instrument* to address this relationship. An artifact becomes an instrument through the activity of the subject. The artifact may be perceived as a hammer given its physical properties, but only when used for hammering does the artifact become a "hammer" instrument. In other situations the artifact may be a "weapon" or a "bottle opener" instrument.

Placing the computing device as something that the user acts through, on objects of interest or with other subjects, points to the role of a *mediator*. The mediator stands between the user and the object of interest, and in this role it helps the user act on the object of interest, in ways she could not act without using the mediator. The hammer helps the user drive a nail as one of the many mediators of house building; the telephone conveys our conversation across distances, and the web browser helps browse web pages or plan a road trip for the summer. A mediator that works well allows the user to focus on the object of interest when carrying out the necessary acts supported by the capacities of the mediator. A mediator that does not work well causes *breakdowns* and draws the user's focus towards the artifact as such. Whether or not a breakdown occurs during use, depends on the actual material conditions of use. It does, however, also depend on the quality of the action repertoire possessed by the user, which we will return to.

We use the concept of *mediator* to capture that certain mediation takes place between a subject and an object through an object or artifact, while the concept of

instrument is used to capture what is actually done with the artifact or object by the users. Accordingly, mediation is not a simple matter of transparency, or making things "go away". However, we need a concept to talk about the quality of mediation, to address the dialectics between seamlessness and seamfulness, between transparency and breakdown. This leads us to the concept of *functional organs*.

Kaptelinin (1995b) defines functional organs as functionally integrated, goal-oriented configurations of internalized operations and external mediation. An artifact can become a functional organ to a user when a certain combination of artifact and internalized routines are present in a given use situation. Hence, it is a dialectical concept encompassing both aspects of the subject and the artifact. The fork and knife become functional organs in the activity of cutting and eating food. Thus, the fork and knife augment the human capacity with regards to eating. Artifacts that become functional organs become part of human beings, moving the boundaries of the human being "outward", similarly to how Polanyi (1961) describes the blind man "seeing" with his cane.

In the same manner as Heidegger's concept of 'vor handen' (Dreyfus & Dreyfus 1983), functional organs are both ideal and actual states. An artifact becomes a functional organ the moment it is applied as an instrument to a degree, where the user is able to think through the artifact. Appropriating an artifact as a functional organ enables the human user to perceive and reason upon the world through the artifact, even when she is not necessarily holding it in her hands. The ideal of functional organs is when we are capable of exhaustively exploiting the action possibilities of an artifact in a given activity. This is indeed an *ideal*, since it is impossible to achieve in the fullest extent. However, the blind man and his stick, as well as some virtuous violinists and lifelong Emacs users, actually seem to have this sort of relationship with their artifact.

Breakdowns are due to either insufficient capacities or possibilities in the artifact, or lack of available action possibilities, either culturally or in the individual repertoire of action possibilities, are easier to identify in use than is the functional organ. This is an argument for hands-on experience in design (Bødker 1991). However, it also helps understand why the cultural level of experience is important in design, as is the use of action repertoires across artifacts.

To inform design of interactive artifacts so they can become functional organs to the user is seen as one of the core goals of HCI. This state of appropriation of an artifact is often referred to as transparency or seamlessness. The concept of functional organs indicates that transparency in use is a phenomenon that is a product of the dialectics between the artifact and the human being.

This section has focused on the role of artifacts in use, and the inner dynamics of the relationship between the artifact and its user. Before we proceed to understand the levels of activity, we need to approach development.

2.3 Development in artifacts

The dynamics of human activity is essential to activity theory and the Human-Artifact Model. As a matter of fact, over the recent years we have seen quite a few examples of the application of activity theory within HCI and CSCW (e.g. Turner et

al. 1999, Cluts 2003) where the theory basically was used to map out the multiplicity of artifacts and activities, whereas the dynamics were poorly understood. A noteworthy exception from this is Bryant et al (2005), who focus specifically on development of use. Activity cannot be analyzed once and for all. Rather, activity is continuously changing in interplay with other activities, artifacts used, etc.

Bærentsen (1989) illustrates the dialectical relationship between activity and tools in an artifact historical analysis of the development of hand-weapons from the time of bow and arrow to current automatic rifles. Bærentsen shows how human operations are gradually incorporated and crystallized into artifacts, and how this development shapes both the goals and motives of human users. The introduction of hand-muskets made re-loading far more complicated than placing an arrow on a string; nevertheless its speed was outweighed by the sheer firepower and the status of using muskets. The operational level of the use of the weapons changed radically. The routine for reloading moved from putting an arrow on a bowstring over stuffing a musket, to inserting a clip into an automatic rifle. While the development of weapons has contributed to changing the society, the central goal of the development of the weapon has not changed; that is to be able to shoot down an enemy from a distance. However, the human action possibilities keep developing in a dialectical relationship with e.g. these weapons, and in this manner the future cannot be fully anticipated (Engeström 1987).

Historical analyses are significant to the activity theoretical framework. Engeström (1987) proposes artifact-historical analyses as part of the methodological cycle of work development. This methodology focuses on developing a particular activity, and identifies the artifacts that are historically central to the focal activity. The historical development of activity implies a development of artifacts and environments. Modes of acting within such activities are historically crystallized into artifacts; in this sense the historical development of activity can, in a non-deterministic manner, be read from the development of artifacts mediating the practice (Bærentsen 1989).

To summarize, artifacts are fundamentally crystallizations of activity (Leontiev 1978, 1981). Activity is crystallized into artifacts in two ways: Firstly, they are externalizations of operations with earlier artifacts, and secondly, they are representations of modes of acting in the given activity. At the same time, the artifacts shape the activity in which they are used. This way of thinking sets apart activity theoretical HCI from more static or causality-focused approaches. Human shooting skills and knowledge are activated when shooting, e.g. when determining the distance to the target and holding the handgun. At the same time human skills and knowledge are reflected in this shooting, and are changed as a result of the specific shooting experience (Hydén 1981).

Based on this richer understanding of dynamics and development, we proceed to address the levels of activity and what that means for our understanding of artifacts.

2.4 Levels of activity and artifacts

To conceptualize what is externalized in an artifact, Bødker (1991) proposes the analysis of interactive artifacts through three kinds of aspects to match the three levels of activity: *The physical aspects*, *the handling aspects and the subject/object aspects*:

The physical aspects are the conditions for the physical manipulation of the artifact and embody the assumptions of the user's physical morphology and motor functions. Breakdowns at this level typically result in that what otherwise were operations on a motor level becomes conscious actions, and object of reflection. The human adapts to the forms and shapes of the artifact, and a mal-adaptation may prevent the forming of certain operations. The handling aspects embody the assumptions of how the given artifact should be handled. The western forks and knifes embody in their design both the possibility of cutting and lifting certain shapes and textures of food, and an assumption of the western traditions of how to eat properly. Breakdowns at the handling level can be the result of improper training of the user or incorrect assumptions by the designer. The subject/object-directed aspects constitute the conditions for operations directed toward objects or subjects that we deal with in the artifact or through the artifact. They embody the assumptions of the actions the artifact is designed to help the user realize. Breakdowns in use at this level are typically products of a mismatch between what the user actually wants to do and what is possible to do with the given artifact. Different parts of the subject/object-directed aspects relate to different subjects or objects, but it is also part of these aspects to support the shift between subjects/objects. In (shared) electronic calendars, the physical aspects relate to e.g. the screen size, and to whether new appointments are added through pointing with a mouse or pen, or by typing on a keyboard. This focus allows for an analysis of e.g. the limitations to screen size, or the suitability of a pen-based PDA solution. The handling aspects relate to how appointments and meetings are added, whether e.g. multiple, simultaneous appointments are possible, etc. The subject/object-directed aspects address how it is possible to e.g. plan for both a single user and a group, and shift between these foci.

In summary, the aspects help distinguish and summarize elements of the artifact. They address their change and interconnection. By bringing the aspects together as a leveled analysis, it is furthermore possible to focus on their contradictory elements. We move on to refine the understanding of the levels further.

Bærentsen & Trettvik (2002) combine and extend the use of Gibson's (1979) affordances with activity theory. They identify three types of affordances to match the levels of activity, action and operation: Need-related, instrumental and operational affordances. The need-related affordances relate to what motivates people. The instrumental ones relate to the socio-culturally shaped action possibilities in instruments and objects surrounding us. Finally, the operational affordances, Gibson's original level of affordances for movement in the four-dimensional physical world, are the action possibilities relating to human beings' naturally evolved, ecologically determined patterns of behavior and conditions. Bærentsen & Trettvik identify the lowest level in the operation hierarchy, where human beings get confronted with the operational affordances. They describe how, at the operational level, some of these affordances are learned and can be conceptualized, whereas others come out of human adaptation to the environment (the adaptive operational level). This is the difference between the adaptive level, defined as the level of human low-level response to natural conditions, and conscious operational level, which addresses the human repertoires of cultural-historical ways of interacting with the environment. Wynn (1994) presents similar levels and looks at learning of tool use.

Bærentsen & Trettvik are critical to Norman's (1999) attempt to solve the confusion of how affordances in this way had far been used in HCI: "*As we see it, the problem with affordances stems from attempts to adapt it to the dualistic Procrustes bed of cognitivism with the result that it is reduced into something fundamentally foreign to Gibson's use of the concept. In this guise the properties of "affordances" can only exist as mysterious and magic properties of objects*" (Bærentsen & Trettvik, 1999, p. 52). Hartson (2003) falls into a similar trap when he develops his leveled analysis of artifacts based on affordances. The basic problem of his analysis is the assumption that "anyone immediately and directly perceives the signification and function of an object" to use the phrasing from Beguin (2007). Furthermore, while he analyses cork screws using a leveled separation quite similar to that of Bærentsen & Trettvik, the use of the term cognitive artifact seems to indicate that cognition is separate from action. He similarly discusses an alien corkscrew, indicating that there is a "correct use" that is separate from e.g. the past experience of the human user, which is in contrast to Gibson's ideas (see our further discussion of this example in 2.6.1). Gibson invented the notion of affordance to talk about action possibilities, which he addressed in terms like stairs being walkable, chairs being sitable, doors being openable and doorknobs being turnable, etc. He strongly emphasized that affordances are action possibility not properties and do not dictate correct use (see also the discussion of the relationship between affordances and activity theory in Kaptelinin & Nardi, 2006, or Beguin & Clot 2004).

Instead of pursuing the complex discussions of Gibson's affordances, we match Bødker's (1991) aspects with the three types of affordances. This makes it possible to better understand how current mediators are integrated in the functional organs of the human users. We may address which possible and desirable types of uses that are afforded, and those, which are not. This mapping requires a re-interpretation of Bødker's aspects. Bødker's physical aspects encompass Bærentsen & Trettvik's *adaptive operational* affordances, and we use this term since 'physical' can be slightly misleading. In Bødker's three aspects, the need-related or activity-related level is missing, and since Bærentsen & Trettvik convincingly argue for its importance, we include this level. This aspect deserves a terminological comment: We have previously used the term motive as a synonym for need as the term is used here. In order to not confuse matters further, we continue talking about motive and the *motive-related* level. We use the term *instrumental*, as introduced by Bærentsen & Trettvik, instead of Bødker's subject/object directed aspects. However, we use Bødker's *handling* rather than conscious operational. The matching of activity levels, affordance and aspects is summarized in Figure 2.

Affordance	Aspects	Activity level
Need-related		Activity – Why?
Instrumental	Subject-object directed aspects	Action – What?
Operational – Conscious – Adaptive	Handling aspects Physical aspects	Operation – How?

Figure 2. Summary of affordance, aspects and activity levels. Bærentsen & Trettvik's (2002) affordances are aligned with Bødker's (1991) aspects of the artifact and the activity levels, illustrating the need for introducing motivational aspects, and revising the vocabulary further.

Beaudouin-Lafon (2000) proposes to address the relationships between the instrumental and operational aspects of artifacts. Specifically, he develops three ways of assessing WIMP interface components such as scrollbars, text fields, buttons, etc. This is done with attention to the integration of the instrumental, handling and adaptive aspects. The *degree of indirection* includes s*patial offset* and *temporal offset*. Spatial offset is the distance on the screen from the logical part of an instrument to the object it operates on. This is similar to the relationship between handling aspects and instrumental aspects in our terms; e.g. a dialog box can be far from the object that it acts upon and has a high spatial offset. Temporal offset refers to the time it takes from when an action is initiated to an effect is visible. The *degree of integration* refers to the compliance between the controlled dimensions of the input device and the logical instrumental dimensions, the relationship between handling aspects and adaptive aspects. Beaudouin-Lafon argues that when it comes to WIMP interaction, the more direct relationship between handling aspects adaptive aspects, the better interaction. Lastly, the *degree of compatibility* is a measure for the similarity between the physical actions of the user on the input devices, and the logical actions of the instrument, similar to the relationship between adaptive aspects and instrumental aspects. According to Beaudouin-Lafon, dragging an object has a high degree of compatibility, while typing in the position of an object to move it on the screen has a low. Beaudouin-Lafon points out ways of working with the four aspects for specific kinds of interfaces. The three degrees do not immediately lead to general measures, and cannot be generalized beyond WIMP interaction. We return to the concern for generalizations in 2.5.

The four aspects serve to focus on actual use on the one hand, and on the assumptions made about use in the artifact, the action possibilities and constraints, on the other. The creation of action possibilities is the designers' concern, no matter how the action possibilities are created. Hence we address this in terms of how aspects influence the ways designers may create action possibilities. We have enriched the notion of functional organs by identifying four aspects, related to the levels of activity. We have also pointed out that in specific settings it is possible to

systematically address the relationships between the four aspects. In continuation of the argument of section 2.3, there is action and understanding at all these levels, and a final and static sorting of interface features into the four aspects will not suffice.

2.5 The orienting basis and quality of actions

Functional organs encompass both artifact and user. Hence, if we are to discuss the quality of this duality, we need to explain the relationship between the artifact, its aspects, and the user's capabilities and experience. This is the focus of this section, where we discuss the *orienting basis* of the user and the qualities of action possibilities.

Users' shared capacities and experiences are not only based on individual acting and learning in the world. Human beings are born into a cultural situation that makes today's human beings capable of acting differently with technology than those born a century ago. In addition, human beings get to share particular practices through schooling, etc. When getting trained as a carpenter or nurse one gets to share the praxis of carpentry or nursing. At the same time each individual, who is part of praxis, continues this praxis. He or she changes it as well by developing new ways of doing things, and new artifacts (Kaptelinin & Nardi 2006). This praxis allows us to talk about more than just individual skills, knowledge and judgment. When we look in further detail at the relationship between the user and the artifact in the following, it is on this background: There is no user without other users who share experience with artifacts and materials, understanding, etc.

We turn to Gal'perin (1969) in order to understand the human capacities and experiences. He presents the *orienting basis* as central to support the application of actions and operations across different artifacts and objects of work. The orienting basis guides actions, and is shaped through experiences. Where the aspects above help address what the artifact is intended or may be used for, the orienting basis similarly addresses the capacities with which the human user meets the artifact. There are three ways in which the orienting basis is constituted. These reflect both how the orienting basis is created and how it may potentially be applied: *Domain independent general actions*, *reusable knowledge within a specific domain* and *trial and error*.

One example of domain independent general actions is bike riding. Once learned, this may be carried out for work, everyday transportation or leisure activity. Other examples are addition or multiplication of numbers, to be used for many kinds of purposes once learned in its general form, or writing and sending email messages for work or friendship. Examples of reusable knowledge within a specific domain would in contrast be emailing learned only within a particular work context; hammering and drilling while working with wood and plywood only; playing the bass as rock-and-roll instrument, but not as an instrument for jazz.

Examples of actions learned through trial and error are division of integers by ten without understanding the general principle of the position system; playing "Autumn Leaves" on the double bass by heart after locating one tone at a time on the instrument. If an action has been developed through trial-and-error, there is less chance that it can be reused to develop other quality actions, since fundamental understanding may be missing. Generality and reusability of actions are important factors when it comes to addressing the action possibilities available in the orienting

basis of the user. The quality of a specific action may, according to Gal'perin (1969), be assessed through the following:

- Generality, i.e. the ability to recognize, among of an object's properties, which are the properties relevant to completing an action.

- Support for abbreviation, i.e. the ability to skip operations as part of the performance or an action. Operations can be abbreviated either consciously or unconsciously. Conscious abbreviation is natural and non-harmful, e.g. skipping intermediate results in the process of solving a problem. Harmful abbreviation is the opposite unconscious skipping of intermediate results or actions, due to lacking knowledge or experience with the consequences.

- Mastering, i.e. the independent reproduction of an operation with new material achieved within the action.

Consider the example of a double bass student who has no formal theoretical music training, and must learn to play the walking bass line of "Autumn Leaves". One strategy would be to listen to a recording and then imitating what is played. However, when asked similarly to play a walking bass line for "Summertime", the double bass student would have to repeat the process of listening and imitating. Another student, who has trained chords and scales, would immediately be able to play along to any of the two songs just by seeing chords–as well as easily transposing the song to another key–something that would be difficult for the first student. Hence, the second student has an orienting basis that is characterized by a larger degree of domain independence (even though it is all about music), and more domain specific knowledge than the first student who had primarily learned through trial and error. The actions of the second student are both more general and mastered. He may be able to do useful abbreviation, whereas the first student is likely to "cut the wrong corners". At some point, however, the first student may still be able to generalize from all the songs imitated to obtain an equal understanding of walking bass as the formally trained student. As a matter of fact several great jazz musicians are autodidact. Through playing double bass the student builds domain knowledge with playing stringed instruments in general. This would make her capable of applying her orienting basis to new types of string instruments. For instance, a double-bass student might be able to generalize and concretize tone intonation and left hand vibrato and apply these to a violin.

Gal'perin argues that familiarity is what triggers the establishment of an orienting basis. Bardram & Bertelsen (1995) refer to this with the concept of initial familiarity, which they argue can be constituted in interface design both through playing on simple affordances or e.g. interface metaphors. The nuanced view of affordances from Bærentsen and Trettvik (2002) conceptualizes the dynamics of this familiarity.

Like the aspects of artifacts, the orientation can be broken down into levels of activity. At the top-level, activity is driven by a motivational orientation. The motivational orientation is partly subconscious, meaning that human beings are not in-situ aware of their motivation. Goal orientation encompasses the user's repertoire of actions. Applying the understanding of chords to play "Summertime" *prima vista* is

an example of this. The handling orientation refers to the users' culturally developed operational means for realizing actions that have become partly sub-conscious. Such means include the way of holding the bow for classical bass, according to the German school and the French school. The adaptive operational orientation is the low-level response to physical conditions; e.g. tweaking one's left-hand intonation for a set of new strings. This leveled analysis helps us provide a symmetrical model where the human side mirrors the artifact and *vice versa*.

Actions always take place as specific constellations of actions combined with a constellation of operations. One particular action may have one high-level intention supported entirely through operations, and in another case the sequence may consist of many conscious actions with low-level and fragmented operations. In between are many possible combinations. Our concern lies within the whole repertoire of action possibilities: To write a short note on a sheet of paper, the writer may pick up the nearest pen and write what is needed, presuming that a functioning pen is nearby, and there is no particular need for color, clarity, etc. In other instances, while the writing with various kinds of pens may still be operationalized, conscious choices regarding for instance color may have to be made. In a third instance, the actual writing may not be operationalized quite as much, and choices regarding the size of the characters must consciously be made, for example if the only available pen is a fountain pen or a carpenter's pencil.

With the above perspective it is possible to address the quality of the action repertoire, and not only the individual action: A golfer who successfully applies all clubs in the golf bag and who knows, or is able to assess, when to apply which club (and master the pitch, the put, etc.) has an overall set of actions and operations of a higher quality than the golfer who only masters the 7-iron, no-matter how skillfully the last golfer may apply this. While both may still encounter limitations to their technique, and have problems if new types of golf clubs are introduced, there is a difference between their action possibilities.

Bryant et al. (2005) describe the development of the use of a particular mediator, Wikipedia. This development is by no means a simple operationalization of actions and the authors carefully document the users' development of the orienting basis from being a newcomer to becoming a Wikipedian. They characterize the differences between these two groups, and suggest that there are patterns in how users move from being newcomers to becoming Wikipedians. The users change their perception of Wikipedia and no longer act upon a random collection of articles. Instead, Wikipedians primarily see Wikipedia as a community of co-authors. In becoming Wikipedians, users move from a local focus on individual articles to a concern for the quality of the content as a whole. In summary, the development of use involves new goals, new roles, different tools, and especially new motives.

Conceptualizing the orienting basis helps address users' past experiences and how these get activated when introducing new artifacts, as in the case of Wikipedia. The three approaches–applying domain independent general actions; reusable knowledge within a specific domain; and trial and error–indicate how the human user is prepared to take up the new artifact. Generality, etc. gives yardsticks to compare the quality of actions, and hence the possibilities and problems relating to the use of new artifacts or existing artifacts in new situations. From the perspective of designing new artifacts,

the orienting basis points towards choices, e.g. whether to target general action possibilities or specific reusable knowledge within a specific domain; or leave the new user entirely to trial and error exploration.

In the preceding sections we have provided a theoretical foundation for a more nuanced understanding of artifacts, their relationship with their user and their mediation of human activity. By emphasizing the dialectical relationship between designed artifacts and user's orienting basis, we have argued that transparency is not simply a matter of artifacts disappearing in use. Later, artifacts become functional organs to the user through learning in use, hereby shaping the user's orienting basis. Depending on how the existing orienting basis of the user has come into being, e.g. how general actions are, the user is equipped differently as to face the new artifact, or an existing artifact in a new setting. The theoretical foundation provides concepts for analysis at different levels of interaction and underlines the dynamics between them.

2.6. The Human-Artifact Model

We present the Human-Artifact Model as a way of structuring the above insights so that they may be applied in actual analysis and design. The Human-Artifact Model is to be used to summarize empirical findings. It may also be used to analytically reason about the dynamics between the levels of interaction and the relationship between the aspects of the artifact and the orienting basis of the user, the possibilities and problems of a functional organ (see Figure 3).

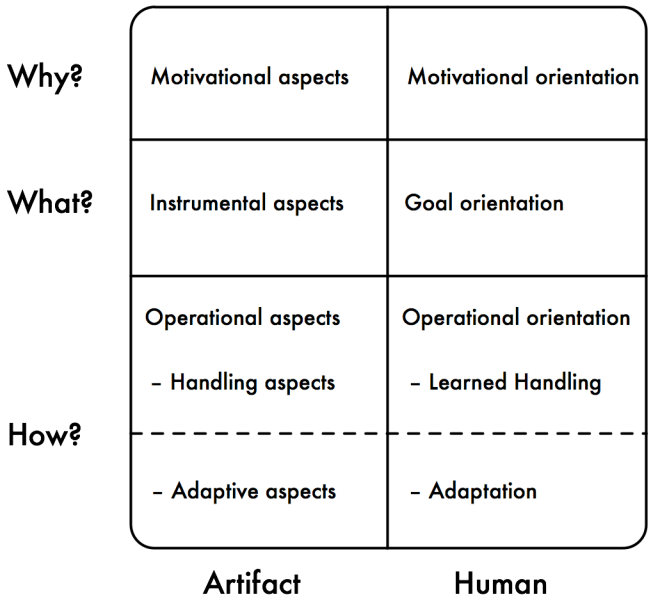

Figure 3. The Human-Artifact Model. The left hand side of the figure ties to the artifact; the aspects. The right hand side is the human side, and ties to the user's orientation. Both sides are expressed vertically through the levels of activity. We use this figure as a building block in our analyses in the rest of the paper. The two sides are sometimes reversed to create a better overview.

The Human Artifact Model provides a form, where each field can be addressed one at the time by summarizing empirical findings, and by singling out particularly critical issues or findings to match or contradict those of other fields. If the starting point is in the human side, the Human-Artifact Model can be used to structure the analysis of human practice and orienting basis in terms of the four levels. Following this, a particular current or future artifact may be added on the artifact side. This approach makes it possible to address e.g. the quality of actions, and possible new designs. Or on the contrary, the starting point may be the artifact, where the four levels are again important for structuring the analysis. The human side can consequently be analyzed as regards potentials and problems of matches with the artifact, raising e.g. issues regarding the development in use. In the analyses it is possible to move back and forth between these two perspectives, to focus on one level at a time, and to address tensions between fields, across sides and levels, e.g. in breakdowns. The Human-Artifact Model makes it possible to analyze the actual human use of an artifact reflected in the ideal, well-integrated functional organ. This makes it possible to identify trouble spots and areas for development.

While the Human-Artifact Model is to be applied to analyze use of an artifact, this artifact is not analyzed in isolation. The orienting basis side of the Human-Artifact Model, that is the user side, is an accumulation of experiences with other artifacts in the user's artifact ecology; some of these historical and some current, some individual and some shared (Figure 4). The Human-Artifact Model embraces the possibility of change, and as such it is a useful starting point when facing HCI as a design discipline, rather than as something providing static analyses of technologies in use. Similarly, the artifact side crystallizes and accommodates many uses and many users (Figure 5).

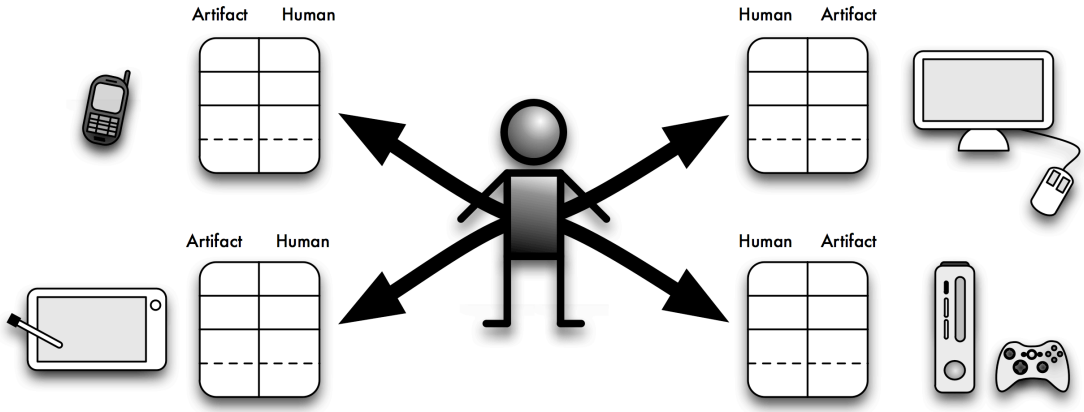

Figure 4. The Human Being surrounded by artifacts. The human being, in the context of other human beings, accumulate experiences with artifacts in the artifact ecology. Some of these artifacts are historical, some current.

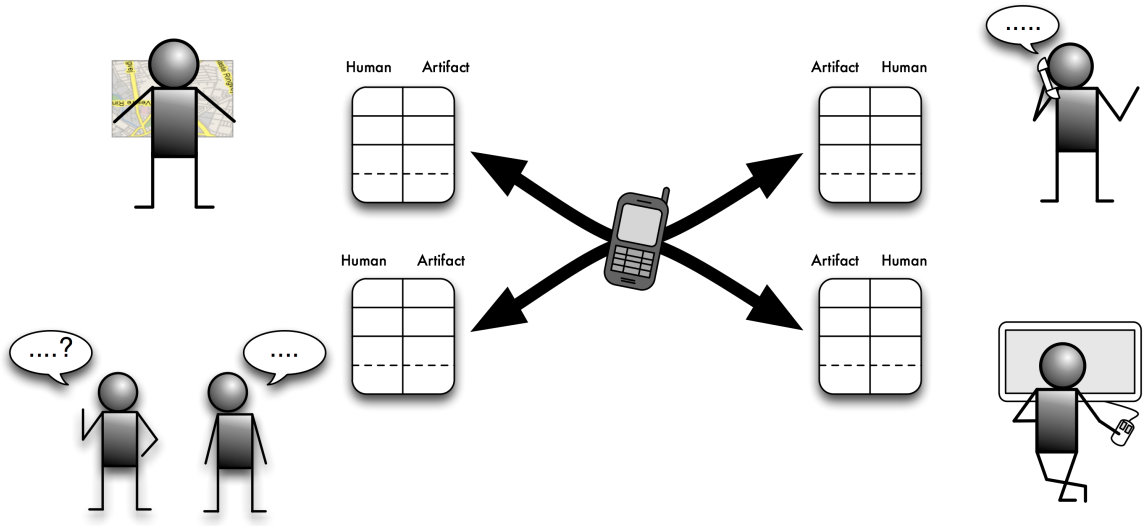

Figure 5. The artifact surrounded by users and uses. The artifact is the meeting place for several activities and actions by the user(s). The aspects influence these activities, and the artifact gets used through repertoires of actions and operations developed across these activities.

Two brief examples

We illustrate the use of the Human-Artifact Model for the analysis of concrete artifacts using two examples. These examples illustrate what issues and concerns are emphasized through the model. We return to more complete examples in section 4. We borrow the example of a corkscrew from Hartson (2003), and clarify some differences in his approach and ours. We also discuss the use of Wikipedia from Bryant et al. (2005), as this adds further dimensions to the Human-Artifact Model analysis of the corkscrew.

Hartson (2003) compares the affordances of two corkscrews; a winged corkscrew based on the principle of levers, and a more advanced corkscrew with two modes based on the principle of tightening a nut on a bolt. On the bolt-based corkscrew there is a locking mechanism enabling the user to turn the nut clockwise, so that the bolt (with a pointy spiral in the end) is screwed into the cork. In the second mode the mechanism is unlocked, and the cork is extracted from the bottle by continuing to turn the nut clockwise. By this, the bolt moves up and out of the bottle.

Hartson's findings are based on informally observing a group of people trying to open wine with the corkscrews. He argues that the winged corkscrew has, in his terminology, acceptable cognitive affordances, while the bolt-based corkscrew has non-obvious cognitive affordances. Cognitive affordance in his definition is "... *a design feature that helps, aids, supports, facilitates, or enables thinking and/or knowing about something*" (Hartson 2003, p. 319). Hartson does not, however, provide a vocabulary to help point out why some affordances are obvious or acceptable, while others are non-obvious or unacceptable.

Now, consider the two corkscrews analyzed with the Human-Artifact Model (Figure 6). Starting with the instrumental layer, both are designed towards helping the user achieve the action of uncorking a wine bottle. Hence the instrumental aspects are

simple: Uncork a bottle. The adaptive aspects of both corkscrews embody assumptions of human fingers to turn a handle–and in the one case–to press down levers. They both have a physical shape, weight and materiality lending them well to human operation.

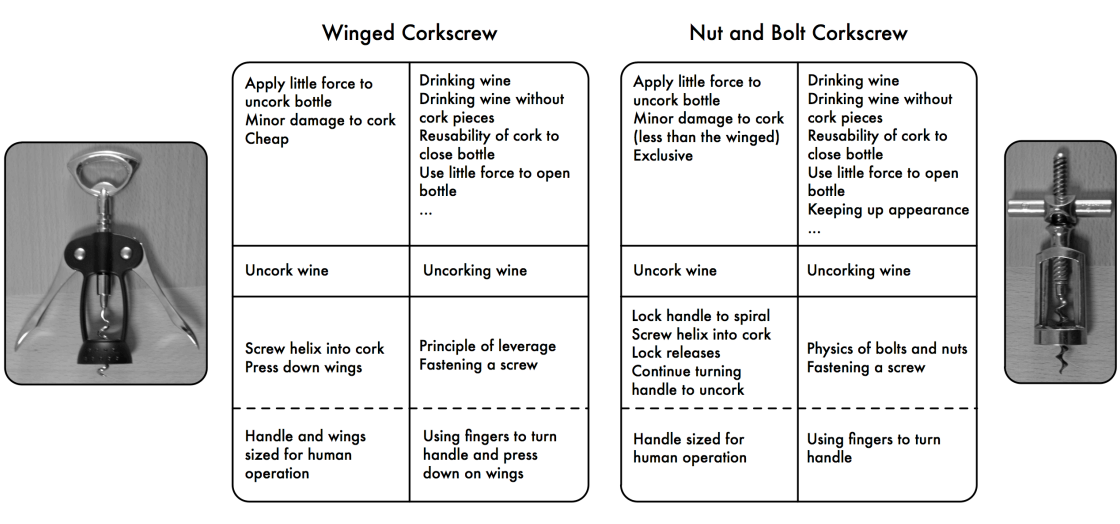

Figure 6. Comparing two corkscrews. The examples are summarized in the form of the Human-Artifact Model. Contrasted with each other, there is a difference between the two at the motivational level, which is more important than indicated in Hartson's analysis. The two corkscrews furthermore assume experiences from two quite different handling principles, that of leverage versus that of bolts and nuts.

The two corkscrews differ most in the handling aspects. Both pullers are based on a basic idea of how to uncork a bottle, that the pointy spiral should be aligned to the centre of the cork. The winged corkscrew assumes that the user is familiar with the principle of leverage; e.g. using a plank to move a large stone. This is something most people learn at an early age; hence it can be expected in all potential users' orienting basis. The bolt-based corkscrew, however, assumes familiarity with the handling of a bolt and nut, something (assumedly from Hartson's informal studies) that is not as common a knowledge as the principle of leverage. Hence, Hartson's observed users meet breakdowns in the immediate handling of the corkscrew. However, when the user realizes the nature of the handling, the two corkscrews become equally easy to use.

To complete the analysis, the motive-related aspects of the two corkscrews embody the assumptions of pulling a cork with ease and avoiding the cork to splinter, along with an underlying idea that some uses may be more exclusive or fancy than others. Ease, technical quality and exclusiveness are reasons why more mechanically advanced corkscrews sell. They also point out why an analysis of a corkscrew in use at a music festival where users focus on being outside and getting drunk, may be entirely different. These motives are not necessarily conscious in actual use. Having learned to use the bolt-based corkscrew, this screw, according to Hartson, is much more efficient and reliable than the winged one, and the user's orienting basis is naturally changed. The next time the user is to fasten a nut on a bolt, although unrelated to wine bottles, she may recall the handling of her bolt-based corkscrew.

Applying the Human-Artifact Model as an analytical lens emphasizes the dialectical relationship between subject and artifact, and moves the analysis beyond stating that there seems to be a non-obvious affordance, which is Hartson's conclusion.

The corkscrews illustrate how the Human-Artifact Model may be used to compare artifacts, quite directly, based upon an understanding of the cultural practices of e.g. bottle opening, other general practices as well as individual experience. Understanding the ecology of artifacts is essential for the analysis. With the Wikipedia example, we move on to illustrate how the Human-Artifact Model can be used to analyze the dynamics and development of use over time (Figure 7).

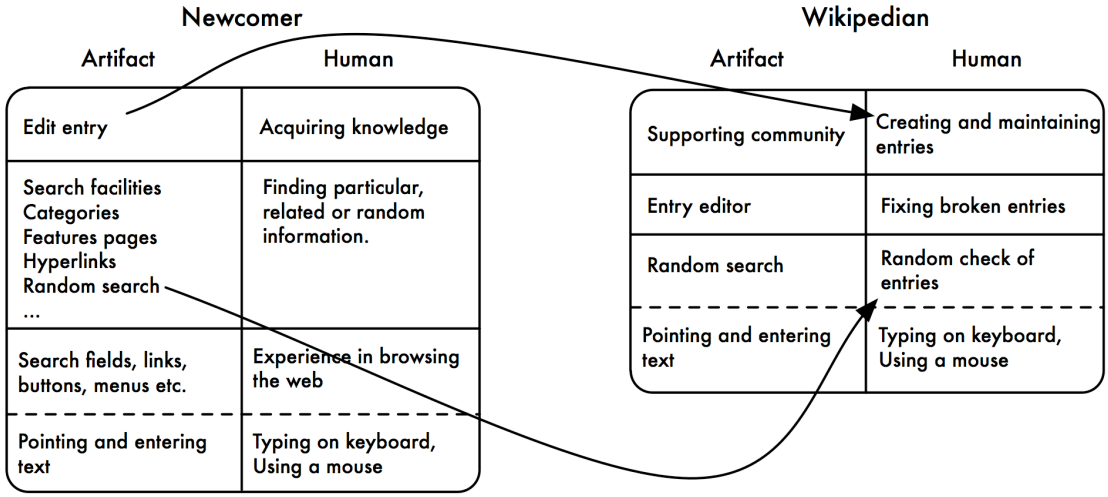

Figure 7. The Human-Artifact Model of newcomers and Wikipedians. The arrows describe the transformation from newcomer to Wikipedian where motivation is changed and operationalization has happened.

Consider e.g. the "edit this page" function for Wikipedia entries. Bryant et al (2005) observe two different types of users: Casual readers and active members (called Wikipedians). From the Wikipedian's perspective the "edit this page" functionality is an instrumental aspect designed for the goal of editing a specific entry in Wikipedia. However, according to Bryant et al., the "edit this page" is part of the motivational aspect for the newcomer, as it constitutes the seed for the casual reader to become a Wikipedian. This is because it helps challenge the reader to start correcting flaws in the text. Hence the transformation from casual reader to Wikipedian is transforming the perception of the artifact. The designed prominence of the "edit this page" function needs to be addressed as both instrumental and motivational aspects, and the understanding of the dynamics between the two aspects, as use develops, is an important part of the strength of the framework.

Wikipedia has different means for navigating the vast amount of entries; e.g. search fields, categories, featured articles and random article search. From a Human-Artifact Model perspective these features can be seen as handling aspects. The experienced Wikipedia user rapidly operationalizes the use of these means, and they can be used based on experience with navigating web pages in general. Hence they match the learned handling of most web-users. Many of the typical actions related to the use of Wikipedia, are, however, not hardcoded into the artifact: There is no

function for bringing forth an interesting entry, however the function for bringing forth a random entry is used in this capacity. From the perspective of the casual reader this handling aspect can be used to find something interesting to read, while for the Wikipedian it is, according to Bryant et al., used to find incomplete or vandalized articles to be improved or corrected. If the random function only picked completed and well-written entries, this would probably be fine for the casual user but worthless for the Wikipedian, and would result in a breakdown between the Wikipedian's goal orientation and the instrumental aspects of the artifact.

The examples illustrate how the Human-Artifact Model helps structure and complete an analysis that compares mediators in an artifact ecology.

2.7 Summary

We have developed the Human-Artifact Model based on new readings of the activity theoretical basis and existing contributions to activity theoretical HCI. This has provided insight into mediation, multiplicity of artifacts and development, and the model sets the framing for analyses of existing and future artifacts. Mediation allows us to focus on the mechanisms in the artifact and the user background that allows the artifact to disappear from the focal awareness of the user in certain situations and re-appear in other, i.e. a dynamic focus on transparency or seamlessness. Furthermore, mediation becomes a concern at all levels of the activity, from motive to handling and adaptation, and in the dynamics between them. Multiplicity is a condition of all artifact use. With the concept of artifact ecologies, we draw dynamic boundaries and explore the relationships between artifacts in a certain setting and at all levels of activity. Development is addressed through the dynamics between the historical artifact ecology, and the current and future action possibilities in new artifacts. The functional organ helps address ideal directions to take and identifies trouble along the way to such an ideal use.

In the second part of this article we systematically explore the analytic dimensions of the framework and in greater detail through an example.

3. DESIGN

The Human-Artifact Model does not replace prototypes, scenarios and other kinds of methods that we know to be useful in design. It helps look toward the existing situation by structuring findings regarding existing activity, and it helps hypothesize about the future. The Human-Artifact Model helps to capture a structured summary of existing mediators and practices, or of the desirable or intended mediators and practices. Furthermore, the Human-Artifact Model helps to expose the tensions within and between the mediator and its use, the levels of use, and between a particular mediator in use and its surrounding mediators, in the ecology of artifacts, including those of the past and the future. The Human-Artifact Model may be used to capture the seed of a future activity and help future users understand how their practice may need to develop from there, which is what the focus on development is all about: We cannot totally predict the future use, yet we need instruments to help address this future. We are currently carrying out research to apply the Human-Artifact Model in design of technologies for citizens' services and develop further the Human-Artifact Model to structure and compare/contrast scenarios and design solutions as outlined

here. The actual study will be presented separately, here we go on to explore why such a component of design seems useful.

Stolterman (2008) points out that what designers need from theory is to become prepared for action through a conceptual and methodological basis. Bertelsen (2000) talks about theory as instruments for design, and Wilson (2010) talks in general about retooling activity, such as design. We see the Human-Artifact Model as such an instrument that may help re-tool the practices of design. However, this is not our main focus in this paper, rather we focus on the instruments as such.

Stolterman's designerly way (2008) emphasizes three elements: Sketching, iteration and alternative. These may seem somewhat in contradiction with how the use of theory has often been seen in design: To make design "right" from the start. They are, however, very much in line with the activity theoretical tradition of change-oriented research, where total prediction is impossible, and iteration necessary. Accordingly we propose that the Human-Artifact Model can be used informally in sketching as a means for structuring the iterative process, and for clear-cutting and comparing alternatives. In continuation of this way of thinking, Lim et al. (2008) in their anatomy of prototypes see prototyping as providing a set of filters to focus each prototype. Prototypes become support for design exploration, rather than being early versions of a final design (Lim et al., 2008). In our experience, the Human-Artifact Model may help provide such filters and keep track of what is explored when and with what outcome.

Carroll's (1991) task-artifact cycle is well known for its emphasis on the ongoing development of the relationship between task and artifact. The task-artifact cycle focuses on many of the same issues as the Human-Artifact Model, and evidently it is possible to see changes in the right-hand side of the Human-Artifact Model, leading to changing in the left-hand side, and vice versa. Yet the comparison of the two sides illustrates exactly the difference between a dialectical and a causal focus: The causal emphasizes how chances of one side cause changes on the other. The dialectical focus, on the other hand emphasizes how the two sides are mutually formative for good and for ill. The two sides always need to be seen together. In addition, the Human-Artifact Model gives the possibility of moving towards explanations beyond the one task-one artifact level.

In the following we develop the Human-Artifact Model further by discussing how it may be used in a design case. The design case is partly fictitious and meant to illustrate how the analyses are carried out. It is, however, based on actual analyses of three map artifacts as carried out in our past work (see Brodersen et al. 2007 a and b, and Bouvin et al. 2006).

4. DESIGN CASE

Imagine that we work for a company producing palmtops hardware and software. We are asked to design a new portable artifact for digital geographical maps. The company is open to proposals for new interaction techniques and input devices, and sees this design as breaking new grounds in terms of interaction and application areas. This new artifact is to smoothly blend into the ecology of map artifacts, whether they are paper-based, on personal computers or portable devices. Other artifacts carried by the user, such as a cell-phone, a laptop or an iPod also need to be considered. At the

same time the design is to provide something new and useful compared to its potential competitors. The artifact is to be used while on location with visual access to the local geography, and intended for local movement, e.g. walking and navigating as a tourist in a city.

In this fictitious set-up, we step into the design process where the use setting and related artifacts have been studied through observations and interviews. We now exemplify how the Human-Artifact Model is used to structure analysis of the map artifacts and reason about design possibilities. The scenario (Figure 8) describes the map use of the two friends Mary and Kate, and is used to consolidate and illustrate some examples from the study of existing map artifacts in use. These existing map technologies are a paper map, a tablet-PC based map and a map running on a cell-phone. While still an alternative, the phonebook map is a historical precursor to cell-phone and PC maps.

While fictitious, this design case is based on an empirical study (Bouvin et al., 2006), where geographical maps were studied while used on three different technologies: A paper map in a telephone book, a web-based digital map on a tablet-PC, and a digital map on a GPS enabled Nokia smart phone. The three mediators were different but shared some similarities: All three were small enough to be carried around, and could be shared between users and handed from one person to another while in use. The aims of this study were not a full-fledged detailed study of these technologies in everyday use. Rather, we wanted to target and compare map artifacts applying the theoretical apparatus of multi-mediation as it was understood at the time.

In this study we asked groups each consisting of two users to carry out simple assignments by looking at the map and out of a window. The groups had no particular qualifications regarding maps. Each group was given eight assignments where they e.g. had to locate north or identify a local school. Furthermore, they were to find the distance to and direction of the target. All assignments were created so that the users could orient themselves through buildings and objects visible through a large window thus providing a good view of the neighborhood (Figure 9). The sessions were recorded, transcribed and analyzed in activity theoretical terms. Detailed analyses are presented in (Brodersen et al. 2007 a and b, and Bouvin et al. 2006).

Mary and Kate are asked to solve four assignments using a paper map. These includes establishing north, identifying a white villa, and finding its address. Without further ado they open the paper map on the overview page, and after a short glance at the grid, they turn to the page of the more detailed map. They look up, and have a brief discussion of where, specifically, is north. They are not entirely sure. Kate locates her right hand on their current location (their home), and they look out to find a landmark to locate on the map. A familiar major street crossing at a distance is identified, and Mary puts her left hand on that spot on the map. After some hand-waving and pointing they mentally align the map with the view, even though they do not physically turn the map. They turn to the next assignment, look out to find the villa, and once that is done, Kate, still holding her right hand on home, turns to the map, while Mary keeps looking out. They negotiate the location of the villa, and try laying out the street grid known from the map onto the landscape. Mary, while placing her left hand on the villa spot on the map, compares the direction to what they identified as north, and calls: "North-northeast" without looking at the map. To work out the distance, Kate measures the ruler of the map between two fingers, and moves her fingers as a yardstick to measure the distance on the map.

Mary and Kate now turn to the cell-phone map. One assignment tells them to name and locate a big yellow building in the horizon. Mary picks up the cell-phone, while they both look out. They see the building and discuss which street it may be on. Mary looks at the map and realizes that the school is outside the current map segment. She starts an attempt to use the navigator button of the phone to pan the map. This is slow, and meanwhile the two friends negotiate how they know that street corner from passing it on their bike-rides to school. They point, they move their bodies to illustrate how the turn certain corners, and meanwhile they realize that they need to upload a new map segment on the cell-phone. They turn to the phone, holding it between them, and discuss how they may use the menu structure of the cell-phone to get to the new segment. Even this fails, and they try to answer as many of the questions of distance, direction, etc. without support from the map.

Happily relieved from the small-screen map, they solve a couple of assignments using the tablet-PC. They still struggle with the street address of the school. At first they hope that the school as such will be visible on the map. This is, however, not the case, because the map does not show e.g. public buildings. As they have now remembered the name of the school and hold a computer in their hands, they turn to Google for the address. They get the address, and need to measure the distance to the place. Kate picks up the pen with which the tablet-PC is equipped. Mary identifies an icon that looks like a distance measure. Kate tries to measure the distance by touching the two locations with the pen. However, this means drawing a line between the two locations, rather than getting a distance measure. The two friends are quite confused, and even when they are told that the pen functions as a mouse, and that they have to click at the end-points, they continue to draw lines all over the map.

Figure 8. Scenario describing the map use of the two friends Mary and Kate consolidates and illustrates some examples from the study.

In the design case, which is based on the above study, we address map use from the expectation that a new mobile map artifact will be designed, and we focus on the artifact ecology and practices of map use relevant for such mobile map use. As illustrated in the scenario (Figure 6), users' understanding of the general geography of the city and of the local area, learned while riding a bike to school or waiting at a bus stop, are important background experiences. However, we have no systematic studies of such background experience to lean on.

In the following sections we use simplified examples from our detailed studies to illustrate the details and dynamics of the Human-Artifact Model in the design case.

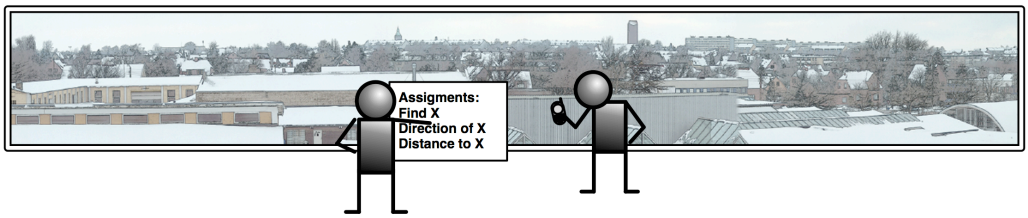

Figure 9. Example setup. Two users are standing in front of a large panorama window, overlooking a local neighbourhood. They are equipped with a set of assignments and a map device, in this picture a cell-phone map.

5. STRUCTURING A DESIGN-ORIENTED ANALYSIS THROUGH THE HUMAN-ARTIFACT MODEL

With the Human-Artifact Model as analytical frame we set out to explore mediation in terms of a new artifact that may replace existing map artifacts. We build on the possibilities and problems of existing orienting bases with existing map artifacts. We assume that the new map artifact takes on a role in the artifact ecology that is in some ways similar to, and possibly different from existing map artifacts, and in some ways inspired by entirely different artifacts and use activities. We need to uncover the possibilities and limitations of current artifacts in such artifact ecology. We address the extent to which such artifacts are, or may become, instruments for the human user. Structuring the analyses using the Human-Artifact Model is a way of addressing both the horizontal dynamics between the human and the artifact, and the vertical dynamics between the levels. At the same time it is a mean to acknowledge that the activity as such may change in parallel with, or as a result of, the introduction of the new artifact.

The levels in the Human-Artifact Model have different analytical foci, and we reduce the complexity of the analysis by systematically shifting the main focus before bringing back together the levels of analysis. In the following we sketch the methodological contents of each step, and the key concerns regarding the artifacts in use. We use the design case to exemplify the kind of analyses that result from this. For each level of the Human-Artifact Model we focus on both sides of the model: Possibilities in the artifact may or may not be used in the actual repertoire of actions

and operations, and actions and operations may be supported or prevented by the artifact, often resulting in workarounds.

The analysis starts with a scrutiny of the current activity. As a vantage point we take the three current kinds of maps. This leads to an analysis of the historical traces of past maps and uses. Finally we look ahead towards the new map artifact.

5.1 Leveled analysis

In the following we present and exemplify what kinds of analyses may be achieved at each level, and how the Human-Artifact Model may be applied. As we have already pointed out the model is based on four different levels of analysis, all addressing the entire activity. Hence, using the Human-Artifact Model is not a simple matter of sorting interaction elements into four categories. As pointed out in the introductory examples: When elements play different roles in the analyses, possibilities and problems stand clear.

It is important to note that we use the design case primarily to illustrate conceptual and methodological elements of the design-oriented analysis. Using the case as illustration means that we go into some depth with at least one finding for each level.

Goal orientation and the instrumental aspects

The goal orientation is the starting point for further investigation of the motivational level, as well as of the handling level. Therefore, the first main focus of the analysis is on the goal orientation and on the instrumental aspects, as described below.

Focus

Primarily, this level addresses *what?* What do the users do? What do they say they do? What is the artifact used for? And what may it be used for? The analysis addresses the tension between users' goals in a given activity and their expectations towards technology on the one hand, and the assumptions of goals embodied in the artifact, i.e. the instrumental aspects on the other. The analysis places the artifacts of concern in context by focusing on the artifact ecology. Specifically, it is important to understand which artifacts are used together to accomplish the goal.

Method

We use a number of methods at this level, for example in-situ interviews (Beyer & Holtzblatt 1997), and observations of actual use recorded on video (Suchman & Trigg 1991) in the spirit of conversation analysis. Taking stock of the artifact ecology through observation and interviews is important, as is an initial understanding of the users' background and related activity. Cultural probes (Gaver et al. 2004) are useful for gathering data for this analysis. The main approach is to use multiple methods to understand what is happening, and what may happen.

Example

In the map case we identified the goal-orientation as a range of rather clear-cut goals shaped by the assignments given to the participants, namely identifying north, establishing home (where are we?), identifying a target, measuring distance, and finding waypoints and direction. These goals were achieved by the users through a combination of using the given map device, and talking to each other and looking out the window.

All of the three map devices had instrumental aspects that matched this goal orientation to some degree. The paper map had a fixed scale with an associated ruler indicating a unit length. Furthermore, the map gave detailed indications of schools, car parks, bus lines etc., as well as an index for looking up streets. The maps on the tablet-PC and cell-phone were slightly less detailed. The tablet-PC map had a dedicated tool for measuring a precise distance, and the cell-phone supported establishing home (i.e. the current location) through its GPS capabilities (Figure 10).

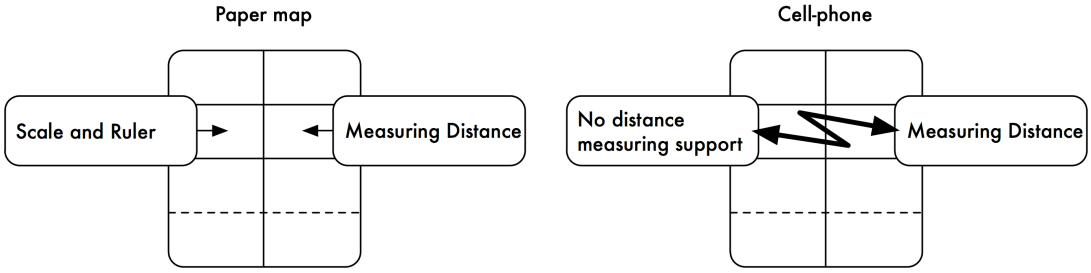

Figure 10. The instrumental level of paper map and cell-phone map. Where the paper map is used without complications at this level, the cell-phone does not support distance measuring as smoothly. Jagged arrow implies mismatch.

If we take a look at distance measuring, both the tablet-PC and phonebook maps supported the measuring of distance according to the expectations of the participants: On the paper-map a scale was given that could be used for measuring distance e.g. with fingers or a ruler. On the tablet-PC distance measuring was externalized into a tool that offered precise measuring of distance (however some complications occurred and will be discussed in the following sections). On the cell-phone no distance-measuring tool was implemented. This conflicted with the expectations of the participants. One group spent considerable time searching the map application menus, until they were finally told that such tool was not available. This is an example of a misfit at the instrumental level. The goal of measuring a distance was central to their activity, hence the lacking support on the cell-phone conflicted with the users' experience with similar devices.

The goal of establishing north is interesting, because none of the three devices supported it directly. Each of the maps indirectly supported establishing north by following the convention of north being up the uppermost part of the map (the map is "north-up" in navigation terms). However, to establish north, the participants had to rely on juxtaposing landmarks from looking out the window to the map, or on their general feeling of north. Furthermore, they had to convince themselves that the map

actually was north up. The participants were often mistaken in establishing north, which lead to complications in the later assignments.

Even this "simple" map example illustrates that the artifact ecology and the orienting basis were important for what happened when a new artifact was introduced. Several artifacts were used in combination. The users could not establish north on any of the three maps without an understanding of the geography of the city, and an underlying understanding of north up (or a compass).

Motivational orientation and motive-related aspects

This level addresses the motivational orientation and the motive-related aspects of the artifact. The motivational orientation, the activity, the *why* question may, as pointed out, not be explicit to users, and as such it may not be addressable directly, for example in interviews.

Focus

This level of analysis addresses the (implicit and unspoken) drivers of the activity in question. What motivates the users to perform given actions and how is this supported, or not supported, in the artifact? What motives does the artifact support? As we have pointed out the actual use of an artifact is often poly-motivated. Such multiple motives of use need to be explored, along with the multiple motives that the artifact crystallizes and lends itself to.

Method

In-depth interviews may point towards the motivational orientation, as may analyses that contrast conversation with action (see e.g. Bødker 1993), and methods that aim at challenging and provoking a current practice such as provotyping (Mogensen 1992). This is because such methods can be used to question unarticulated assumptions. Classical ethnography can often create a good picture of what motivates people in their given activity, whereas artistic expressions of various forms may be used to probe human motivational assumptions about artifacts (Dunne & Raby 2003). This level of analysis is neither addressed by affordance-oriented HCI, Heideggerian HCI, nor by classical cognitive science. It remains to be seen whether experience-oriented approaches e.g. that of McCarthy & Wright (2004) may eventually lead to methods including this motivational focus.

Example

In the map study we had access to the conversation between users while they carried out the activity, as well as to what they actually did. Participants knew they would be handed a map-device. The motive and purpose were largely those of the assignment. Beyond the particular motivation for solving the assignments, we observed a strong (but unspoken) motivation for creating and aligning a common orienting basis between the members of the groups. This common orienting basis was established through using the maps, the discussions in the group, the view through the window and references to other activities. All of the groups used anecdotes and stories to make references to other activities where they moved through the landscape (Statements like: " I ride my bike that way every morning…" (Figure 11) were quite

common). The paper map and map on the tablet-PC provided a suitable overview of the city given the assignments, whereas the cell-phone's limited screen resulted in conflicts between the participants in knowing where and what they where looking at. The paper map supported homing by letting participants rest their fingers on the map, once they had established their current location. The small view offered by the cell-phone, which was ill suited for overview, provided an indirect mechanism for homing on a particular slice of the map. Figure 12 illustrates the difference between the quite unproblematic motivational level of the paper map, and the tensions identified in the analysis of the cell-phone.

Kate: The yellow building up there. Mary: So isn't that where you turn? Kate: It is further up? Mary: (sings) Hm, hm, hm, tsk, tsh (…). Mary: Oh what's the name of that street? I ride my bike there every morning. Kate: I don't know if we can get much closer? Mary: Ahh (sings). I cannot remember at all. The bus stop is called Polytechnics. Kate: Well yes, I pass that too, up that road, it is right after (...). Mary: Well, what is it called? The ice rink is on that street too.	They bend over the phone Mary holds the phone The both look up and on the phone Mary tries to pan Mary is concentrating on the phone, she tries to pan and zoom Mary uses cell-phone menu Kate looks out Kate gestures in the air in front of herself

Figure 11. Transcription of conversation and action between Kate and Mary

While the main motivation for people participating in the map study was an obligation towards the researchers to carry out the given assignments, maps could also be used in situations where other motivations were present; e.g. a situation where people were lost in a new city and needed to find their way. As a matter of fact it would probably be more "fair" to the cell-phone map if it were analyzed from the perspective of somebody being lost on a street corner in a major city. From the point of view of the design case, the need to create a common orienting basis was more important than solving assignments, and obviously other kinds of motivational issues, such as being lost, would be worth considering.

Even though the question of *why* is often tacit and much harder to address than the question of *what*, the map example illustrates that it is essential to understand both the (multiple) motivational orientation of users, and the motive-related aspects of the artifact. We do not have to go into detail to recognize that how a map is used depends on whether the users are solving exercises indoors with a nice overview of a known city, or they are lost, alone, on a rainy night in a narrow alley in a big and foreign city. We proceed with the design case, however, to further scrutinize the handling and the dialectic relationships between levels.

Figure 12. The motivational level illustrates differences between paper and cell-phone

Learned handling

As with motivation, handling is not necessarily articulated. It is essential to study how operations get triggered when meeting actual material conditions of the use situation. Furthermore, we address the learned operations that users possess but that are not triggered in the situation; the quality of operations, and how they are constituted; the crystallization of operations into the handling aspects of the artifact; and the handling aspects that may not be triggered in use.

Focus

This level of analysis addresses the tension between the learned routines of the users and the assumptions in the artifact of how it should be handled, i.e. the action possibilities offered with regards to learned handling.

The immediate analysis focuses on breakdowns (Bødker 1991) as indicators of trouble, when the mediation fails and the artifact draws attention to itself. Breakdowns are necessary for learning, but recurring breakdowns also points the analysis towards mismatches between the artifact and the orientation side. Breakdowns regarding the handling indicate whether or not the artifact has become an instrument to its user.

By mapping actions and operations as they unfold, one may address the repertoire of actions and operations further in relation to the action possibilities in the artifact, and the possibility of becoming an instrument: What are the typical and critical operations? What is the quality and constitution of actions and operations (generality, mastering, etc.)? Depending on how experienced users are, there is a further focus on familiarity with the artifact, and on how operations have developed. Furthermore, it is important to identify actions and operations that apply in general across similar artifacts, or independent of the specific, emphasizing the backdrop of the artifact ecology. What are the relationships between multiple artifacts in the ecology? Are they used together in juxtaposition? Chained? As meta-instruments? Etc.

Method

In order to investigate use as it unfolds with particular artifacts we use a version of Focus Shift Analysis (Bødker, 1996) adapted to the Human-Artifact Model (section 4.1.5). This analysis is a starting point for sampling and comparing instances of

interaction within and across uses. It allows designers to seek out generalizing patterns based on quantitative analysis (counting the number of instances), and qualitative analysis (focusing on differences between instances) of the data (as described in Bouvin et al. 2006). Of interest to the design case, Bouvin et al. (2006) identified patterns of how users carried out location-search based on landmarks in a manner that was independent of the specific map technology. These general patterns were, however, realized through different routines that were dependent of the actual map type.

Example

Each of the map artifacts embodied various assumptions of learned handling. In the design of the paper map it was assumed that the user would be able to connect the grid-based numbering of areas on the map to an adjacent map page, i.e. the paper map afforded grid-based navigability, or navigation. Furthermore, knowledge of how to use the printed yardstick was required in order to perform distance measurements on the map, i.e. yardstick measurability was a possibility with the paper map. All groups typically applied a rather casual transfer from the yardstick to an actual distance, e.g. they were using two fingers to layout the yardstick length on the total distance. One group was particularly artistic in applying a routine of measuring: The two members measured a known distance using a piece of paper and two fingers as yardstick. This was one example of the kinds of multiplicity of mediation that was noted in the map case. The example also illustrates that the typical action of measuring would not work if distance was critical, simply because it is not precise enough, and hence very inefficient.

We identified how a handling misfit arose from the unfamiliarity of the paper map. A group that did not understand the grid-system for navigation between maps experienced this misfit. The group had a difficult time finding the right section of the map. This was in contrast to most other groups, who identified the relevant map section almost without verbalizing it, and flipped through the map pages while keeping focus on the identification task. The members of the first group had no experience with recognizing the grid structure. Consequently, they had no operations to rely on for getting to the relevant part of the map. There was no adaptive operational conflict (we will return to this concept below), because the group members were well aware of how one would leaf through a book. However, the mere leafing of pages did not support the group members in recognizing the grid structure on the handling level, and hence was not particularly efficient (Figure 13).

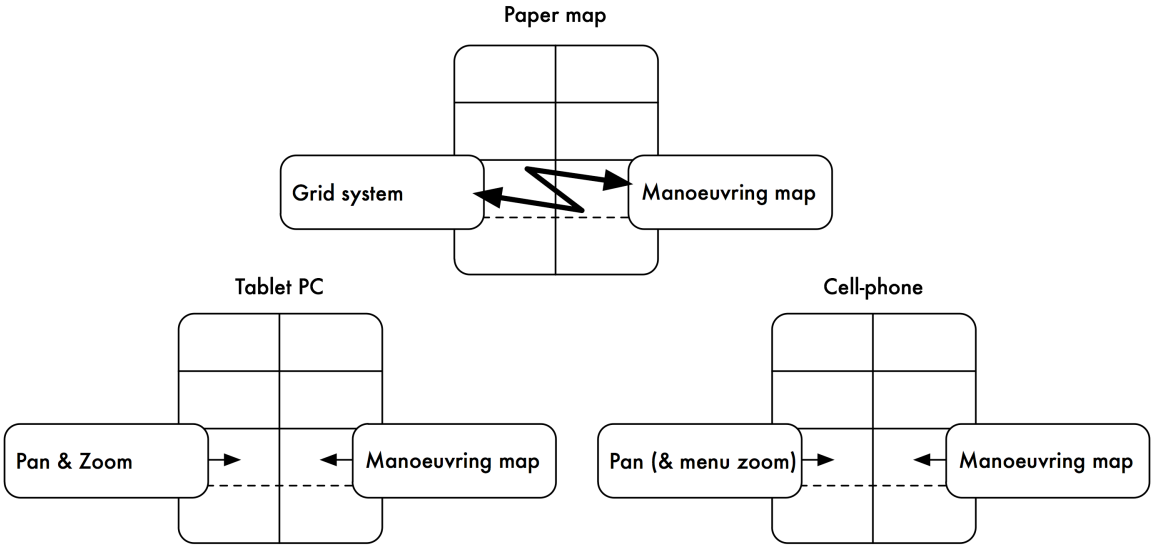

Figure 13. The learned handling level illustrates differences between the three artifacts

Where the paper map applied numbered grids to facilitate orientation on the map and across maps, the cell-phone and the tablet-PC applied panning/zooming. Panning and zooming on the tablet-PC and the cell-phone was handled in compliance with the general standard interaction for the two devices respectively. Hence participants, experienced with e.g. the PC use, clearly had operationalized its handling in actions general enough to apply for the new map use. Despite this, one interesting problem regarding distance measuring was found: The distance measuring tool assumed a handling that was "mouse-like"; the user had to click at two points between which the distances were to be measured. This conflicted with the participants' operations for using a pen. Even when they were told that they should use the pen as a mouse, they tried to draw from point to point instead of clicking. This resulted in panning and misplaced points. The pen was clearly an instrument to most of the participants. However, the operations of this instrument were in conflict with the handling aspects of the PC map, and as such the ideal of the functional organ was not fully achieved. Or, to use the vocabulary of Beaudouin-Lafon (2000), the distance-measuring tool had a low degree of compatibility with the action usually associated with the input device.

The examples illustrate why it is necessary to look further at the adaptive operational level and across levels. With this kind of setting where new artifacts are introduced into the ecology of several overlapping artifacts, the quality and constitution of actions and operations are important factors for the potential pick-up of the new artifact. The parallel analysis of several artifacts with similar instrumental aspects helps emphasize this focus.

Adaptation

In contrast to the handling level, the adaptive operational level describes human low-level responses to the material conditions of the artifacts and their surroundings. In addition, we focus on the adaptive operations that users possess but cannot or do not use the quality of operations, in particular how they are mastered; the

crystallization of operations into the adaptive aspects of the artifact and how adaptive operations are activated in use by offering certain action possibilities.

Methodologically, observations are essential as described regarding the learned handling.

Focus

This level of analysis addresses the tension between the adaptive operational routines of the users and the assumptions in the artifact of how it should be handled, i.e. the action possibilities offered regarding adaptive operational handling. What are the typical and critical operations? What is the quality and constitution of actions and operations (generality, mastering, etc.)? What immediate possibilities are offered in terms of e.g. liftability, holdability and turnability (when it comes to maps)?

Example

At this level, an important issue is how maps were used when indicating direction, hence co-orienting the two participants. On the paper map it was sufficient to place one finger on home (the users shared current location, as it was commonly known to the participants), and another in the relative direction on the map (Figure 14A). This pointing was supplemented with the movement of the finger back and forth. This kind of dynamic pointing was also used on the tablet-PC (Figure 14B), where a strategy unique for the tablet-PC was identified: Holding the pen flat over the surface of the tablet to indicate direction. As with the tablet, hand waving was the most common way of indicating direction on the cell-phone. This was supplemented with users holding their hand steady and upright, pointing the fingertips as to indicate direction (Figure 14C). Turning, holding, pointing with hands and handing over were operations general to all artifacts.

A North is in this direction–fingers give direction from "home" on the paper-map

B Giving directions on tablet-map–holding the pen flat over the surface of the tablet in the direction of choice

C Using hand to indicate direction on the cell-phone map

Figure 14. Direction on the maps

On the paper map fingers were used, e.g. for marking or remembering a target. Such marking was an integral part of all participants' map use routines. However, on the tablet-PC and cell-phone such routines were obstructed for different reasons. None of the participants touched the tablet-PC screen in the same manner as they touched the paper map. This may perhaps stem from prior instructions not to touch computer screens. Although the tablet was not touch-based, users may also have perceived that something would happen if they touched the screen (Figure 15).

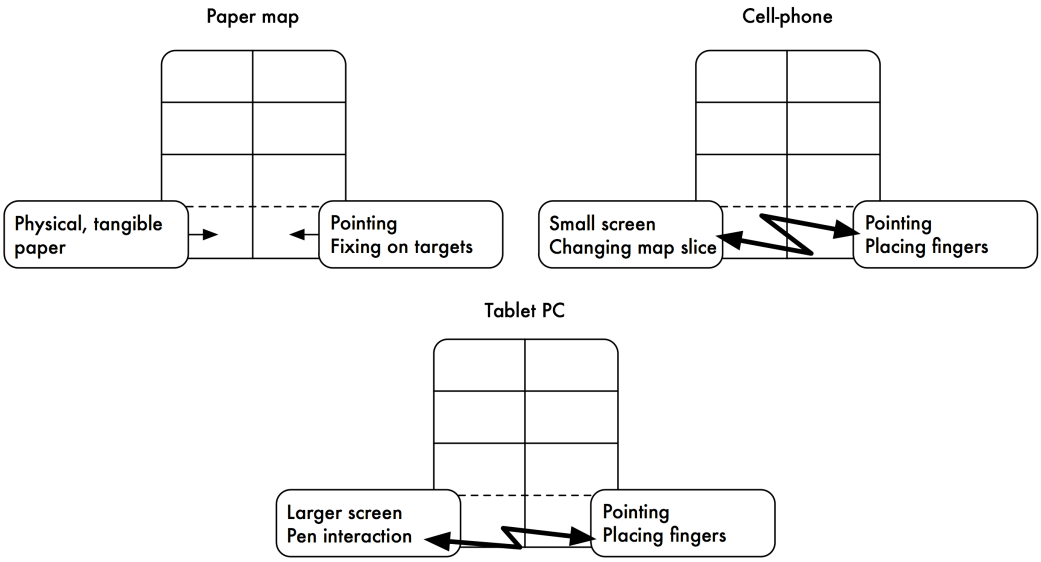

Figure 15. The adaptational handling level illustrates differences between the three artifacts

On the cell-phone the relatively small screen obstructed the routines of applying fingers on the map. Pointing on the screen simply obscured the map. However the phone was easily handed over between the participants, and turned to match the direction of north.

Gaver (1991) and Beaudouin-Lafon (2000) have analyzed the learned handling level regarding multiple instruments on one screen activated through mouse and keyboard. In Beaudouin-Lafon's analysis, the dimensions of movability of a mouse are important, as is the temporal and spatial distance between the action possibility and the objects of attention. The map examples pointed to multiple technologies where the physical and the logical were more mixed, and where holdability, turnability and hand-over-ability were important. Analyses at this level point to problems and explanations arising from the dimensions and physical action range of human beings.

In the above we have presented four analyses, addressing the four levels of the Human-Artifact Model. We have illustrated the dynamics between the human, the orienting basis and the aspects of the artifact at all these levels. We have further exemplified how the orienting basis gets shaped in relationship with other artifacts in the artifact ecology, and how the artifact similarly affords use with multiple other artifacts. The focus on multiplicity and the artifact ecology is a backdrop for the detailed focus on an artifact mediating a particular use offered by the Human-Artifact Model, and will be summarized below. The Human-Artifact Model also offers the framing of analyses of dynamics between levels. These dynamics will be the concern of the next section.

Bringing the analytic levels together: Cross-field dynamics

Even though the Human-Artifact Model helps separate issues analytically, the levels need to be brought together as described above.

Focus

In the above we have exemplified a systematic analysis of each level, and pointed out that there are fits and misfits between the human side and the artifact aspects at each level. Quality of actions is a concern for this part of the analysis, because this issue cannot be isolated to one level of the human orienting basis. Quality, as addressed through generality of actions, abbreviation by appropriately skipping operations, and mastering of extensive and high-level operations relate to the entire space of actions and operations available to the user in the use, and need to be addressed in addition to tensions between levels.

With the Wikipedia case we discussed how development in use might make specific parts of the design take on entirely new roles in the levels of the artifact. We have given examples of how breakdowns shed light on the tensions and movements between levels. In continuation of Beaudouin-Lafon (2000) we propose that it is important to systematically address the relationships between these aspects of the artifact. The *degree of indirection* addresses the relationship between handling and instrumental aspects. The *degree of integration* refers to the relation between handling and adaptive aspects. The *degree of compatibility* is a measure for the similarity between adaptive and instrumental aspects. These relationships do not lead directly to general measures. Nonetheless, when it comes to maps we propose that it would be possible to develop measures similar to those of Beaudouin-Lafon: An important issue for compatibility is the turnability of the maps to face north or in the same direction as the view; integration includes issues of homing and finger-placing, and indirection includes the relationship between landmarks in view and on the map, and issues of scale and scalability of the map in relation to the view. These degrees only scratch the surface of the relationships between aspects of the artifact, and it is beyond the scope of this paper to develop them further.

Method

Bødker (1996) developed a Focus Shift Analysis aimed at tracing and analyzing the focus of an actual unfolding use when one or more users use an artifact to mediate their relationship with one or more objects of interest. The concept of breakdown was used to understand when and for what reason the artifact as such became the object of attention of use: Shifts of focus among objects of activity and between those and the mediators emphasized the dynamics of the situation and these focus shifts were the main points of concern in the analysis. The outcome of the Focus Shift Analysis was a trail of foci that were mapped onto the levels of analysis of the Human-Artifact Model. The original work did not include the motivational level, which may, like the operational, be unarticulated. The focus shift analysis helped focus on the dynamics of the mediation in unfolding action. It was sequential and did not make the distinction and connection between the human orienting basis and the artifact clear. However, we propose that focus shift analyses can be used to investigate breakdowns

leading to the identification of structural elements to be summarized in the Human-Artifact Model (Figure 16).

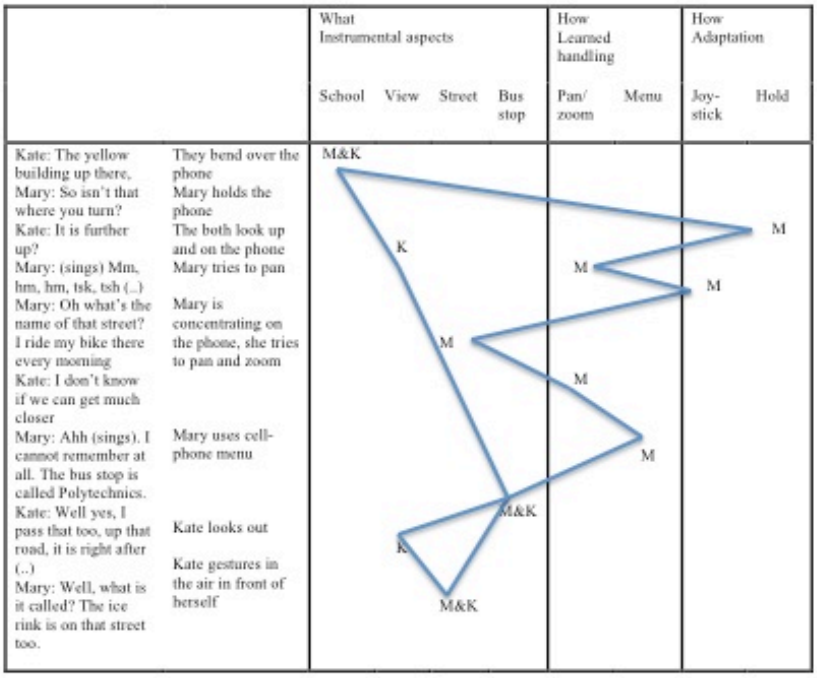

Figure 16. Simplified focus shift analysis. Kate and Mary move in and out of common focus, while Mary struggles with the handling of the cell-phone (transcript from Figure 11). The relevant objects of focus are lined out horizontally, and the unfolding action vertically. The letters M and K are used to indicate who has which focus where and when.

Example

In Brodersen et al. (2007b) we illustrated the dynamics across levels with distance measuring as example. We focused on the dedicated tool for measuring distances between two points, or along a series of segments available on the tablet-PC. As described previously, this measuring tool gave very accurate measures of distance in contrast to the routines that users applied on the paper map. Due to the dynamic map scale, the finger measuring operations of the paper map did not apply well for the tablet-PC. This was because they assumed a fixed scale across the map. As the scale changed with zooming, the distance-measuring tool provided an immediate and accurate mapping of scale to the map segment in focus, but not one easily measured with fingers. The tool of measuring distance supported what the users were trying to accomplish in terms of motive. It was an externalization of a whole range of actions and operations developed through other artifacts, and, as such, it was a quite complex mediator in itself. However, the tablet-PC map failed to support several groups in measuring distance because of an ambiguity of the pen-like input. The assumption that the pen-shaped device could be recognized as a mouse was problematic, because it forced the users to disassociate the physical shape of the input device from the act of using it. Figure 17 summarizes the artifact ecology of the tablet-PC example, and

Figure 18 sketches some of the important dialectical tensions between Human-Artifact Models in the example.

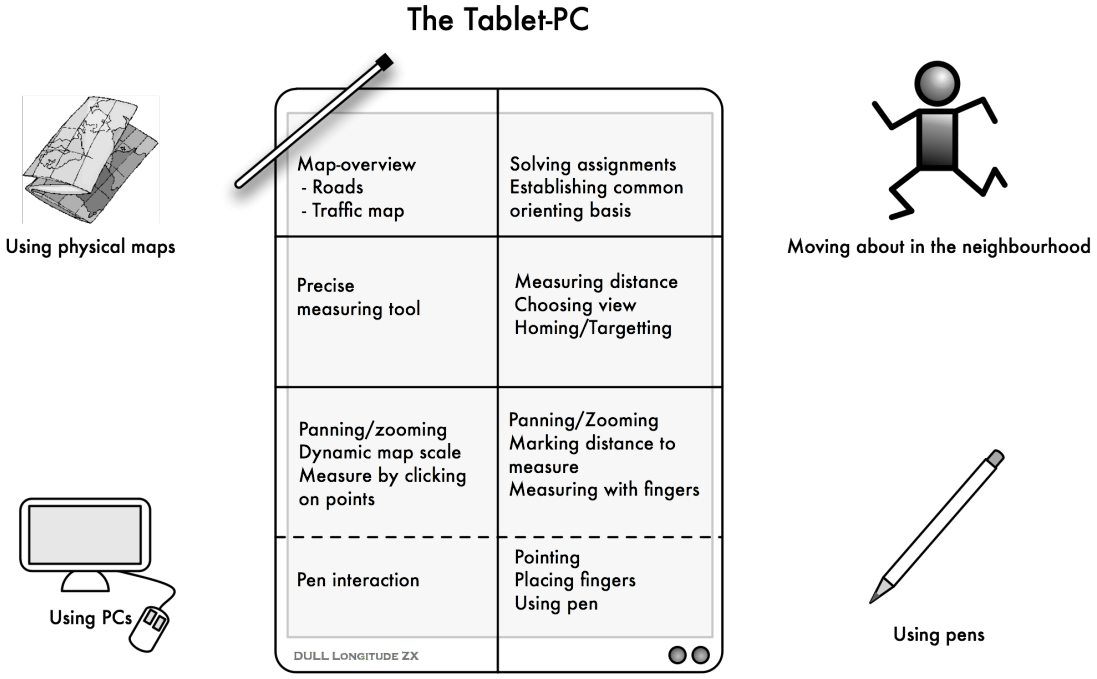

Figure 17. Summary of the artifact ecology and human artifact model of the tablet-PC example.

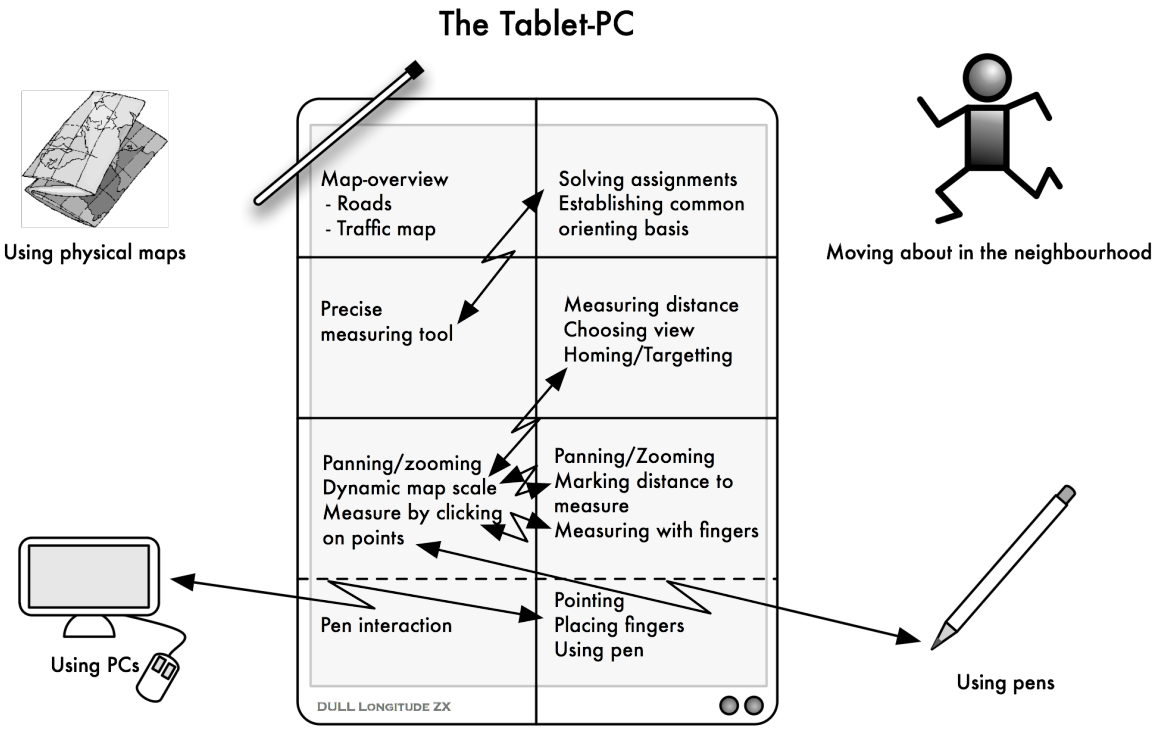

Figure 18. Sketching important tensions in tablet-PC example.

Summary

The questions of what? why? how? with the further specific focus on learned handling and adaptation, help to separate out analytical questions and concerns of understanding the levels of artifacts in use, and the potentials of the artifacts of becoming functional organs. This leveled analysis is the starting point for applying the Human-Artifact Model to structure empirical and analytical findings. Each level has different descriptions and analyses and point to different potentials and problems of artifacts in use. They point in different ways to functional organs as ideals and reality. By focusing on cross-field dynamics, the model furthermore helps explore the developmental problems and potentials of the functional organ.

5.2 Current artifact ecology, looking back and ahead

In the following we move from analyzing mediation trough the analytical levels of human activity toward making use of artifact ecologies in analysis and design.

The starting point: The current ecology of artifacts

The artifact ecology is largely understood as artifacts related to the current use at either level of the Human-Artifact Model. Artifacts co-occur, substitute one another, or are meta-instruments for other artifacts in the artifact ecology. Using the Human-Artifact Model to address how and why this happens helps focus design on the both how available artifacts may be used together, and how to build upon available repertoires of actions and operations.

Example

Figure 17 shows the artifact ecology of the tablet-PC example as it can be summarized based on the analyses above. The map co-occurred with other standard PC applications, hence underlining the double role of the pen. At a different level of analysis the three map types were partly seen as mediators intended to substitute one another.

The map study pointed out that the multiple background practices of map use needed to be analyzed further. Users understood the local geography they were looking at differently, and they had importantly different experiences as cell-phone users. Their understanding of grid-navigation and scale differed significantly, as did their experience as map users in general. These issues illustrate that it is necessary to look for multiplicity of experience and artifact ecology in such analyses. The analyses need to go beyond the specific mediation. However, the example also illustrates the difference between the quality of actions when using the three devices. For example, where one group mastered the paper map by leafing back and forth between the correct maps, holding fingers on different pages, improvising ways of measuring distance, etc., even the most skillful users of the cell-phone map ended up in breakdown situations, where they either mastered the map or the cell-phone, but not both (Brodersen et al. 2007b). In other words, the quality of their actions was neither general, nor mastered enough to skillfully include both map and cell-phone; hence the ecology of artifacts did not include both. We return to this discussion below.

Summary

Drawing the boundaries of a particular artifact ecology cannot be done *a priori*. In the map example, the understanding of the local neighborhood achieved by biking, and the general lack of understanding of map navigation turned out to be surprisingly important.

In other examples, such as ship bridges (Bødker & Bøgh Andersen 2005) and wastewater plants (Bertelsen & Bødker, 2002), the specific relationships between chains and levels of artifacts have been developed further as basis for design.

Past artifacts and practices

There are many different ways in which the history of particular artifacts and general human development and use of artifacts play into the understanding of current uses, as do the anticipation of future potential and problems when designing a new artifact. In short, these dynamics need to be addressed to deal with the developmental focus of activity theoretical HCI. Artifacts stem from an ongoing dialectical relationship with previous artifacts and practices. Hence a historical analysis enriches the understanding of observed practice and use of artifacts. Performing a historical analysis can in this context serve two purposes: First, a historical analysis of the goal-oriented activity in question can potentially explain breakdowns and misfits encountered in the analysis of present interaction. Second, studying the past may serve as valuable inspiration for future design.

A complete historical analysis of the development of a specific goal-oriented activity and the use and development of the related artifacts can be extremely voluminous and time-consuming. For this reason, we do not give detailed instructions for how to do systematic historical analyses. Instead, we outline approaches that apply either on the back of an envelope, or for more extensive study:

One approach is to identify *historical milestones* in artifacts and practices (as done in Bærentsen's (1989) analysis of the development of handguns). This analysis is carried out by asking: How, and with what mediators, has the activity in question been realized before? What were the relationships between those mediators, and how did they leave traces on human practice along the way? Identifying the milestones of the historical development of the activity can differ widely. In some cases, interviews and archaeology of written material (Engeström, 1987, 1993, Bødker, 1993) may be helpful, while the actual historical artifacts may be available for evaluation in others, such as in the case of maps.

A second approach is *artifact archeology,* more directly tracing elements of particular use of a particular artifact. The starting point of such analysis is typically a misfit in the particular use of the artifact. This may be the starting point for tracing, where the activated actions and operations come from (in terms of purposes and used artifacts) and how they have been developed. Their quality may be understood in terms of generality, abbreviation and mastering. Returning to the particular artifact in use, the artifact archeological analysis addresses what in the artifact has triggered these particular actions and operations, and what are the resemblances between the particular artifact and those identified as the roots of the actions and operations.

Bødker (1993) focuses in particular on use situations where there are differences or even conflicts between these roots at the different levels of activity.

Example

In the map example it is possible to see the paper map as an older version of the other maps. Here we sketch a simple example of the analysis. In the example we compare distance measuring on the tablet-PC with the paper map as a historical milestone.

From the study of the paper map (Bouvin et al. 2006), three observations were clear: Users used fingers resting on the map to indicate home; the gridding mechanism slicing the paper map into smaller sections was neither understood, nor used routinely by many of the users; actual distance measure was often done quite coarsely by measuring out the distance between two fingers, and then moving the fingers to the scale to estimate the ratio.

On the tablet map users never rested their fingers on the map-home. Gridding was replaced with panning, and zooming by clicking and dragging. Actual measuring could be done with great precision by mouse clicking on the endpoints of the segment to be measured. The users however, not easily adapted the latter. We suspect that barely any of the learned handling or adaptive operational features of the paper map had been considered when designing the tablet-PC map. As we have seen, users often had problems activating the distance measure of the tablet-PC. At the same time, for users of the paper map coarse measure of distance was sufficient, and they did not need anything more fine-grained for this kind of action. Just like in Bærentsen's (1989) discussion of hand weapons, users did not quite identify with the goal of tablet-PC distance measuring, as it was externalized into a tool in the tablet-PC map measure (Figure 19).

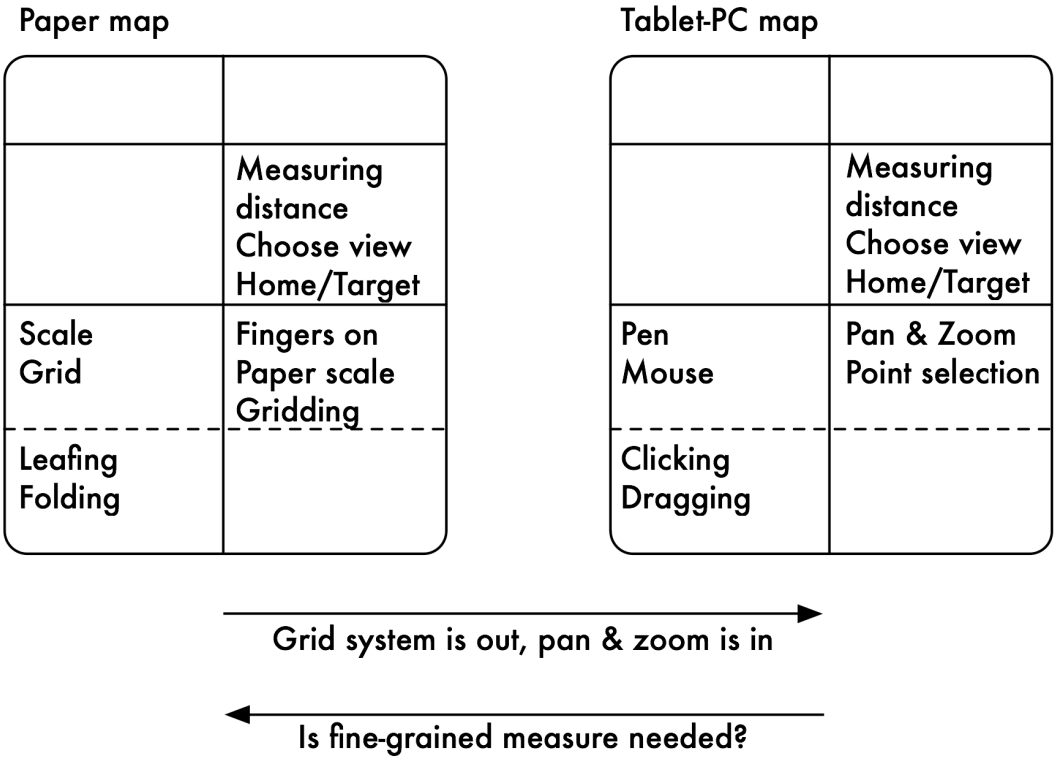

Figure 19. From Paper map to Tablet-PC map.

Summary

There is no causality stating that because users used the paper map in a particular manner, they later handled the tablet-PC map the way they did. Consequently, we cannot derive that one should design a new artifact in a particular manner. The historical analysis of the goal-oriented activity of map use indicated that with this kind of map use, users had no need for the detailed distance measure that caused breakdowns in the tablet-PC map interaction. The choice between the finger-measuring of the paper map and point-and-click measuring of the tablet-PC is probably not the way to proceed in future design. Instead designers need to consider how to make informed choices and come up with something new, given the problems and potentials of both solutions.

Looking ahead: quality and generality of action possibilities

Exploring artifact ecologies and the orienting basis of future users help identify the shared experiences upon which repertoires of actions and operations may be built. Hence, such an analysis helps focus on the design space of future mediators. One way of focusing design is building a design upon domain independent general actions and reusable knowledge within a specific domain, rather than on trial and error. The human artifact model may be used to assess the quality of actions, hence making informed choices between which to support. Scrutinizing what are the more general action possibilities and reusable possibilities from other mediators are important questions. Beguin (2007) describes design and the introduction of a new artifact into a use setting as dialogical in the Bakhtinian sense (Wertsch 1998). Design becomes a dialogue between "ones own half", i.e. the orienting basis of the users, and "somebody else's half"–the new artifact being introduced.

The model also helps address what may be the necessary familiarity provided by a new artifact, for future users. Understanding this familiarity is a matter of understanding the immediate recognizability of action possibilities based on the current and past artifact ecology.

However, no matter how careful analysis we may make, we will never be able to fully predict the future use. This is why exploratory prototyping is necessary, as is the general understanding of the dynamics between use as anticipated in design, and use as it develops. This is illustrated in our analysis of the corkscrew. Engeström (1987) points out that it is this dynamics that inevitably leads to new design processes.

Example

In the map design example we have seen that it is important to ask whether a new design should address a use that masters both maps and cell-phones, or if it is better to assume one and let the new artifact help develop a mobile map use based on this. Is it essential and possible to help users do coarse finger measuring of distance in some sort of combination with pan and zoom? A design process needs to address such questions, not least if e.g. cell-phone use is to become a necessary prerequisite for the new design.

Summary

Exploring artifact ecologies and the orienting basis of future users help make informed choices in design. Making informed choices means that the Human-Artifact Model helps assess and compare alternatives and design choices. However, it is only in actual use that we may understand the full impact of these decisions.

Summary

The artifact ecology supports understanding the roles of the current setting as well as supporting inspiration from past mediators and future possibilities. In particular it helps to assess of the quality of actions and operations and their possible use in relation to a new mediator.

5.3. Design decisions

There is no direct way in which the kind of analyses presented here can lead to a design. There is no causality between the future, the present and the past. What we are facing is a dialogical process as described by Beguin (2007) and there are three ways in which the Human-Artifact Model and the analyses may support design of future artifacts:

1. By applying the functional organ as ideal, the model points to the necessity of designing for all levels.

2. Analyses of current artifacts and the artifact ecology as such help identify from which other mediators to seek inspiration, and on what levels. Similarly, understanding the quality of actions and the construction of the orientating basis can help make design choices.

3. Due to the ongoing dynamics in use and the lack of causality in anticipation of the use of a future artifact, iteration is essential in design. It is possible to make analyses of prototypes by applying exactly the same foci and methods as proposed here for a finished design. Accordingly the Human-Artifact Model provides a set of filters to focus each prototype.

We will not go into details with how such design may be carried out systematically and in general, simply because this would lead too far. However, we will return to the design case to summarize the findings of the map study with respect to how these findings may inform design.

Example

Briefly summarized, the findings from the map study as they have been presented here, lead to a number of concerns:

1. The experience of cell-phone handling highly impacts the use of cell-phone maps, yet it is desirable to design for cell-phone savvy as well as cell-phone novices.

2. Zooming/panning was the most general strategy for map navigation (compared to grids in a phonebook), yet coarse-grained measuring seems important.

3. Landmarks were important for matching map with the actual visual view, yet direction and distance were often dealt with indirectly and implicitly.

4. Users in general want hands/fingers on the map, and have problems with joystick, mouse and pen.

These concerns open for a range of questions for vision-generation on all levels of the Human-Artifact Model.

One vision that focuses on handling in the design case can be formulated as follows: "The map should support continuous zooming and panning without the use of menus". This vision requires further sub-visions for what adaptive aspects to explore. A motive-related vision for the same map is: "The map should support fast approximation of distances". Such approximation is supported in historical map use when fingers are used on the scale of a paper map. However, the adaptive aspects of a mobile device prevent this, simply because the size of the screen and the average size of fingers make such measuring impossible. Hence a vision for solving this issue must be developed.

After our map-study was carried out Apple introduced the iPhone, which has a native implementation of Google Maps. The interface for Google Maps on the iPhone uses pan and zoom through two-finger interaction. Zooming is performed by a pinch gesture with two fingers, and panning by dragging one finger across the screen. Distance measuring is still based on inputting exact locations. Coarse measuring with e.g. two fingers is not supported. One could, however, assume that the iPhone has overcome the problem with users being afraid to rest fingers on the screen, an issue we have not verified empirically.

Aspects of the paper map can be used as triggers of familiarity in the new design. However, the designer should be aware that using e.g. the scale for distance measuring not only seems to trigger familiarity on the instrumental level (something to measure distance with), but potentially also on the lower levels (how to actually carry out the distance measuring). This could lead to breakdowns to be investigated in the next round of analysis of a prototype in use.

The new design must be explored by users through hands-on experience. Designers are facing an iterative process, where the Human-Artifact Model helps structure the findings from prototype evaluation, and consequently new prototypes.

5.4. Summary and perspective of Human-Artifact Model analysis

We have illustrated how the Human-Artifact Model serves to support analyses of specific artifacts in use in particular artifact ecologies. The functional organ serves as an ideal against which to measure the actual mediation. We have further demonstrated how the Human-Artifact Model helps designing with an anchoring in existing and past artifacts and formulating visions of future artifacts with a concern for all levels of

the functional organ. The map example illustrates how the specific insight can be systematically applied to design.

The new insights into mediation, multiplicity and development have been applied to a design case, where the concepts are used to understand the artifact ecology and the actual mediators, as well as to point towards future artifacts. Examples of mediation have been given along with examples of the mechanisms in the artifact and the user background that allow the artifact to disappear from the focal awareness of the user in certain situations and re-appear in other. It has been illustrated specifically how mediation is a concern for all levels of the activity, from motive to adaptation, and in the dynamics between them. We have addressed multiplicity and the dynamics of artifacts in artifact ecologies. Development has been addressed through the dynamics between the historical artifact ecology, exemplified by the paper map in relation to future action possibilities in a new map artifact.

The Human-Artifact Model is in itself an artifact made for analysis and design. It coexists with other such artifacts, models, methods, etc. in the artifact ecology of HCI analysis and design. It offers itself to be learned, and to be developed in use. Whether or not it becomes a mediator for analysts/designers is as yet an open question. However, it is important to emphasize that the systematic way of addressing levels, as aspects versus orientation and as dynamics across the fields, is not aimed at helping analysts/designers to put findings in boxes without thinking. Rather, the model is intended to help them stop and reflect as well. The dialectical method and tensions help look for trouble. However, they do not predetermine trouble, and consequently an actual analysis of use is unavoidable.

Recommendations regarding the design case

This paper has been mainly conceptual. As part of its foundation it focuses on the relationships between the past and the future, between analysis and design. We have used a fictitious design case to underline this dimension, and to target the applicability of the model. In the following we briefly summarize our recommendations as regards process and product for such a design case.

In order to design an application for digital tourist maps, we have demonstrated how to analyze the ecology of map artifacts, and the specific alternatives, whether paper-based or running on personal computers or portable devices. The Human-Artifact Model can be used to map out the ecology focusing on multiplicity. It helps shed analytical light on the four levels of use of specific artifacts, and hence it helps compare artifacts, and understands both general and artifact-specific patterns of actions and operations. We have demonstrated that the motivational level is important for understanding artifacts, whether these are maps, corkscrews or wikis.

The Human-Artifact Model helps addressing choices for the future by tracing back actions, operations and aspects to the past. Both general investigations of map-history and specific traces of elements and actions from the past turned out to be of interest in the design case. These do not lead to ways in which the new may causally be derived from the past, but they point to alternatives and choices to be made.

In general the concern for quality of actions has been helpful in singling out which actions and operations to design for, and which to leave out. The Human-Artifact

Model points toward the functional organ as ideal. It is necessary to design for all levels, but ultimately this design needs to be evaluated in use, and hence iterative design is necessary.

Productwise, the example has pointed towards true dilemmas in the design, such as the complications of coarse distance measuring with zoomable technologies. Our recommendation to the design case is to pursue exactly such dilemmas.

We propose a prototyping process where the levels of the Human-Artifact Model are used as filters to focus prototypes to be explored in design. The possible combination of coarse measures and zoomable technology is one such area where prototyping is needed, yet outside the scope of this paper.

6. PERSPECTIVES AND RELATED WORK

What we have achieved in this paper may be looked at from three different angles in order to finally address what it takes for the Human-Artifact Model to become a an artifact and even a functional organ in interaction analysis and design. Of the three angles the first arise from current discussions in ubiquitous computing of interchangeable use, seamlessness and context; the second from experience and emotion-based contributions to HCI, and the third angle arise from the most recent contribution to HCI coming out of activity theory (Kaptelinin & Nardi, 2006). Furthermore, we end with a discussion of the challenges facing activity theoretical HCI.

Chalmers & Galani (2004) have provided a highly inspiring analysis of heterogeneity in theory and design of interactive systems. They remind us that ambiguity and contradictory information are resources, and not problems to design and use. They look at heterogeneity and emphasize how this concept is also a positive resource for design. They point out how past activity is a resource for the current and future action. Finally they turn to the issue of limitations, boundaries or seamfulness, as we have mentioned above. They conclude their recommendations by stating that *"In the long run, we should consider accommodation and appropriation as a process that designers contribute to by selective revealing system structures, and affordances for their potential use, but it is the users who through their interaction with our system and with each other choose what to use and why"* (Chalmers & Galani, ibid. p.251). Chalmers and Galani do not bring these recommendations any further in general. Through its focus on dialectics, mediation, multiplicity and development, the Human-Artifact Model has a contribution to make regarding ambiguity, heterogeneity, history and seamfulness as a resource in design and in development of use. The Human-Artifact Model brings the focus on use and design further than Chalmers and Galani's guidelines, in particular when it comes to explaining why, and addressing how. Without repeating ourselves too much, the dialectics and materialist basis provide the foundation for understanding these contradictory resources, whereas with Chalmers and Galani's phenomenological grounding, this is less central. When it comes to how, the four analytic levels of the Human-Artifact Model, its two sides and the unfolding dynamics of these, make it possible to zoom in on where designers may make their contributions to a potential change of use, and where and how users may adapt these contributions to their ongoing development of use.

As discussed in the introduction, the tensions between seamless and seamful, and between operationalized handling of an artifact and understanding the limitations and possibilities of the artifact, are important to us, as well as to Chalmers & Galani, who take point of departure in Dourish (2001) in their discussions. We would like to pick up one element from Dourish that comes out less clearly in the above: We need to be able to address both the single artifact and the artifact infrastructure or artifact ecology. There is a tendency in the discussions of ubiquitous computing to address primarily the singular artifact, leaving the rest to the ill-specified notion of context. Abowd & Mynatt's (2000) paper is a good example of a quite interesting discussion of everyday computing, leading to a number of recommendations where context is essential. By focusing primarily on the single artifact, the multiplicity and artifact ecology remain reduced to context. Even worse, it seems that anything beyond the direct action level is actually part of the context, including motivation. While context has been in our vocabulary for about as long as post-cognitivist HCI, it has always been quite ill defined. Unfortunately, these recent applications of the notion in Ubicomp have not improved on that. We propose that it is feasible to make the artifact ecology a first-class citizen in HCI, side-by-side with the single artifact. Obviously, this will not render the notion of context unnecessary, as there is always a new context beyond a given situation. However, the Human-Artifact Model makes it possible to focus on the question of which elements of the ecology matter for our understanding of the single artifact, and vice versa.

Complex artifact ecologies pose a challenge to our HCI methods because they have often focused on complete replacements of one artifact with another, designed often from one authoritative perspective (Sengers & Gaver, 2006). When a newly designed artifact has to be designed to co-exist with a range of other interactive artifacts, there is indeed a challenge in addressing this multiplicity from cultural and emotional perspectives, as well as from perspectives of handling and affordance. Such cultural and emotional perspectives have not been in focus to our above development of the Human-Artifact Model, and need to be further discussed here. Zimmerman (2009) and Stolterman (with various collaborators, e.g. Odom et al. 2009) address human beings' passionate relationships with things. Norman (1999) connects emotions to experiences and Boehner et al. (2005) tackle the topic of emotion from a social and interactionist point of view, arguing that meaning in emotion is generated through the interaction of people, and that emotion is understood and often modified through interaction with others. Palen & Bødker (2008) point to how the multiplicity of experience influences actual interaction with artifacts in emotional situations, and hence how both the direct connection of emotions to things and the entirely social perspective lack in explanatory power, when it comes to understanding human-computer interaction in emotional situations. Palen & Bødker (ibid.) argue that the focus on emotion should not replace that of mediation; rather, a new perspective to include both is what is needed. The levels of activity, we propose in this paper, help in analyzing such situations, and the motivational level yields explanatory power to help address passion. The Human-Artifact Model helps see the double nature of artifacts as things that we may be passionate about, and the social relationships between human beings in communities of practice that may create and enforce such passion. McCarthy & Wright (2004) apply a pragmatist approach in discussing experience as people's lived lives. Their choice of theoretical anchoring in Dewey and Bakhtin is fundamentally equal to ours. The authors argue that human past experience with technology is a rich and multi-faceted phenomenon, which keeps changing when

experiences get recounted to the human being herself and to others. They also point to the fact that these experiences are important in human anticipation of future activity at all activity levels. We have not yet made any attempts of describing such trajectories of technology as experience in the Human-Artifact Model. We would, however, see this as a quite interesting step.

Kaptelinin & Nardi (2006) provide a thorough and interesting introduction to activity theory and positions in relation to other recent theoretical and methodological trends in HCI, in particular Actor-Network Theory and distributed cognition. From this, they proceed to discuss how to understand complex human use situations, with emphasis on the social and the psychological. The authors propose that what is unique to activity theory is its focus on development as a phenomenon to be analyzed, and as a tool for analysis and design. Interestingly, despite this, they do not unfold the dialectical perspective very clearly, which makes the study of development difficult, leaning towards a causality previously criticized by us. By their focus on the social and the psychological, Kaptelinin & Nardi (2006) have to some extent lost the focus on mediation and artifacts which, in our perspective, is essential to activity theoretical HCI. Despite their emphasis on the importance of development as phenomenon and as tool, they do not present a very clear design epistemology.

The essence of such a design epistemology is really what it takes for the Human-Artifact Model to become a functional organ in interaction analysis and design. In interesting similarity to most of the references in this section, we have pointed to issues to be addressed, and to methodological elements of analysis and design. When dealing with design for the highly complex, but mono-praxical domain of control rooms, Vicente (1999) complains that activity theoretical HCI has failed to give directions for the future artifact. This critique could well be extended to most of the references discussed in this section. More interestingly, however, is to understand whether the Human-Artifact Model changes this picture? Based on the design case of maps we have illustrated that it is possible to give directions for the future map. Through a historical analysis it is possible to choose which specific features of specific aspects of past maps to add to the new artifact, or to build the new artifact on. An example of this is to choose pan & zoom navigation rather than grid navigation. This example also illustrates that a concern for quality and generality of action repertoires is helpful for design. Beaudouin-Lafon's (2000) ways of measuring and qualifying relationships between the levels of aspects for WIMP/post-WIMP interaction are a further place to start. The focus may be generalized, but the dimensions seem to be quite specific to the technology. In continuation of the quote from Chalmers & Galani (2004, above), we propose that the Human-Artifact Model can help designers decide which structure and action possibilities to reveal to the users, and when. However, this is only the start. As the design choices made have no simple causalities, it is important to explore the actual consequences of design choices as use unfolds.

Activity theoretical HCI is often criticized for being too complex, and too heavily based on an array of theoretical conceptions that are difficult to understand, unless one really devotes oneself to reading the basic literature. The complexity is empirical, conceptual and methodological.

Empirically, it is evident that assumptions regarding the importance of the actual use activity, and even more, the multiplicity of interfaces and devices, lead to a more complex empirical situation than assessing a singular device in a toy-situation.

Conceptually, many approaches and lines of thought exist. However, we have worked to reduce this complexity and focused on extracting the essentials as regards understanding of mediation and artifacts. This work has parallels to research on affordances. Affordance is a highly used and much discussed concept in general, and in HCI in particular. While our lines of thought have been inspired by, and are related to the concept of affordance, we have tried to avoid discussions about the nature of affordances. An example of this is whether or not they "are there" without human action, and whether they can be designed or not. By emphasizing the relationship between the artifact and orienting basis throughout, we have tried to avoid discussing one without the other.

Methodologically, it is evident that once one insists that designing the future also involves understanding the past and the present, this adds to the methodological toolbox. However, the understanding of the fact that these elements are needed has been established in post-cognitivist HCI (e.g. Carroll et al. 1991, Carroll & Rosson, 1992), and is not often discussed. Within post-cognitivist HCI itself, however, other frameworks have been proposed, for instance the task-artifact cycle, emphasizing the interplay between the shaping of the artifact on the one hand, and the development of the task on the other. Whereas the task-artifact cycle is in some ways simpler than the Human-Artifact Model, it is more limited in three aspects as well: Whereas the Human-Artifact Model insists on a dialectical relationship between artifact and task, the task-artifact cycle tends to lead to causal explanations; the Human-Artifact Model insists that the human motivation sets a frame for understanding beyond the task; and finally, the leveled approach also gives a useful focus on discrepancies and misfits that eventually lead to a need for change at all levels of the artifact.

7. DISCUSSION

In many ways the perspective of this paper has its roots in the tool perspective, presented in the 1980s by Ehn & Kyng (1984, 1987). The tool perspective was introduced to address quality of the mediated interaction between the human users and their materials and products. This perspective was introduced as a contrast to the systems perspective where human users were addressed as components of larger systems. In the current paper we expand on the tool perspective to address ecologies of artifacts and the introduction of new such artifacts into such ecologies. This perspective has consequences for the software and hardware architecture explored elsewhere (Klokmose & Beaudouin-Lafon, 2009). It remains a research question whether it is possible to technically design software where instruments may truly be substituted for each other and used beyond the intention of the designer, etc. in the manner that we propose here from the perspective of use. When it comes to classical systems, however, these potential problems expand even further, basically because systems are designed less from the perspective of use. It is not obvious that the Human-Artifact Model has anything to offer if e.g. a group of designers want to work on substituting a part of one or more existing systems with something new.

The activity theoretical basis of the Human-Artifact Model makes certain assumptions about the human psychological development and its relationship with artifacts and materials, as well as other human beings. Whereas there seems to be many indications in recent brain research (e.g. Rizzolatti & Graighero, 2004, Thomasello et al., 2005) that such assumptions are indeed valid, they can obviously be questioned. Both the issues of the material grounding and the dialectical approach are constantly being questioned philosophically. Both the non-reductionist unpredictability and the focus on development certainly cause concrete methodological challenges, which have made researchers shy away from the approach.

A specific problem regarding the current state of our own research is how we may experiment with and evaluate design processes, methods and outcomes where the Human-Artifact Model are applied. The specific conditions of the process and product are important, as are the past tools and experiences of the designers, and the way they learn and appropriate the Human-Artifact Model as a tool. Simple comparative studies with easily identifiable pre- and post- conditions are not an option, and action-oriented processes where the Human-Artifact Model gets seeded into design processes are to be preferred. We have done a couple of small-scale explorations of this nature, yet more work needs to done to account for the benefits of such design processes.

Fundamentally, we perceive what we have achieved so far as an attempt to retool design processes. In particular, we have used the basic ideas of the Human-Artifact Model in a design process with student designers, where it was also used to structure mood-boards, scenarios and personas. This work will continue and parts are currently under publication. However, what we have not yet addressed is actual designers' appropriation of the model. Hence we have not provided ecological evidence to whether the Human-Artifact Model can have effect on design practice, nor whether the model can have an effect on an actual artifact design. In short, how does the Human Artifact Model impact *design* and how does it impact *designs*? These two questions are interwoven and can be addressed in parallel. Future work would entail doing (preferably many) actual artifact designs where the model is applied throughout the design process. Addressing *designs* could be based on qualitative evaluations on dimensions such as generativity, e.g. letting practitioners identify insights and ideas that may be attributed to the model. Addressing *design* would be addressing the process, e.g. to look at how The Human-Artifact Model could influence a prototyping process, a perspective that we are working on. To address both Rogers' (2004) and Stolterman's (2008) call for more accessible models and methods, we need to assess whether and how the model can be constructively applied, with little or no prior knowledge of activity theory. This would entail an iterative development of a non-academic presentation of the model aimed towards practitioners.

8. CONCLUSION

In this paper we have revisited the conceptual base of activity theoretical HCI in the light of an expanding landscape of multiple heterogeneous interactive devices used interchangeably and in combination. We have presented the Human-Artifact Model and discussed how the application of the model leads to a more nuanced understanding of mediation, multiplicity and development, and hence interaction in

general. The Human-Artifact Model helps address multiple artifacts; how they replace each other or work side by side in changing use settings; and how they may be put together and taken apart in changing configurations. The Human-Artifact Model embraces possibilities and problems at all four levels of activity. The ideal of the functional organ is highly dependent on the multiple background practices of the users, i.e. on other functional organs in the ecology of artifacts surrounding the use activity. In this article we have thoroughly demonstrated that what sets the Human-Artifact Model apart is its insistence on dialectics rather than causality, this way addressing the tensions between levels and multiple artifacts as resources and potentials, and not only as problems. These two key elements from activity theory, dialectical analysis and the activity theoretical tri-partition, help designers focus specifically on how past operations and experiences with other artifacts may be used to inform design.

Development and learning are important concerns, even in situations where artifacts are picked up and used without extensive training, so as to avoid simplicity of singular artifacts as the only design goal. Through the Human-Artifact Model it is possible to address, both analytically and design-wise, the purpose of artifacts and their role in the artifact ecology, while maintaining attention to the concern for unanticipated use.

The Human-Artifact Model is grounded in theory, comprehensive, and yet minimalistic. It is conceptual and seeks to give designers simple theoretical tools, as asked for by Stolterman (2008) or Rogers (2004). Based on our current experience, the Human-Artifact Model does not have a specific place in a design process, but can be used throughout design. It is intended as a thinking tool for researchers, analysts and designers alike.

Notes

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References

Abowd, G. & Mynatt, B. (2000). Charting Past, Present and Future Research in Ubiquitous Computing, *ACM Transactions on Computer-Human Interaction*, vol. 7, pp. 29-58.

Bærentsen, K. B. (1989) Mennesker og maskiner. In Hedegaard, M.; V. R. Hansen & S. Thyssen (red.): *Et virksomt liv. Udforskning af virksomhedsteoriens praksis*. Århus: Aarhus Universitetsforlag, pp. 142-187.

Bærentsen, K. B. and Trettvik, J. (2002). An activity theory approach to affordance. In Bertelsen, O., Bødker, S. & Kuutti, K. (Eds). *Proceedings of the Second Nordic Conference on Human-Computer Interaction*, New York, NY: ACM Press, pp. 51-60.

Bardram, J. E. & Bertelsen O. W. (1995). Supporting the Development of Transparent Interaction. In Blumenthal, B., Gornostaev, Y. & Unger, C. (Eds.). EWHCI `95 Selected Papers. *Springer Lecture Notes in Computer Science*, vol. 1015. Berlin: Springer Verlag, pp. 79-90.

Beaudouin-Lafon, M. (2000). Instrumental interaction: an interaction model for designing post-WIMP user interfaces. *Proceedings of ACM Conference on Human Factors in Computing Systems* (CHI'2000), pages 446–453. ACM Press.

Beguin, P. (2007). In search of a unit of analysis for designing instruments. *Artifacts* 1(1), 12-16.

Beguin, P. & Clot, Y. (2004). Situated action in the development of activity, *@ctivités*, 1(2) 27-49

Beguin, P. & Rabardel, P. (2000). Designing for instrument mediated activity, *Scandinavian Journal of Information Systems*, vol. 12, pp. 173-190.

Bertelsen, O. W. (2000). Design artefacts: Towards a design-oriented epistemology, *In Scandinavian Journal of Information Systems*, vol. 12, pp. 15-28.

Bertelsen, O. & Bødker, S. (2002). Interaction through multi-artifacts. In Bagnara, S., Pozzi, S., Rizzo, A. & Wright, P. (Eds.). *ECCE 11 - Cognition, Culture and Design*, Rome, Italy: Consiglio Nazionale delle Ricerche, pp. 103-111.

Bertelsen, O. & Bødker, S. (2003). Activity Theory. In Carroll, J:M: (Ed.). *HCI Models, Theories, and Frameworks: Toward an Interdisciplinary Science*, ch.11. San Francisco, CA: Morgan Kaufman Publishers, pp. 291-324.

Beyer, H. & Holtzblatt, K. (1997). *Contextual design: A customer-centered approach to systems designs*. San Francisco, CA:Morgan Kaufmann Publishers

Bødker, S. (1991). *Through the Interface. A Human Activity Approach to User Interface Design*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Bødker, S. (1993). Historical analysis and conflicting perspectives - contextualizing HCI. In Bass, L., Gornostaev, J. & Unger, C. (Eds.). Human-Computer interaction. 3rd International Conference, EWHCI '93, *Springer Lecture Notes in Computer Science* vol. 753, pp.1-10.

Bødker, S. (1996). Applying activity theory to video analysis: How to make sense of video data in HCI, in Nardi, B. (ed.) Context and consciousness. *Activity theory and human computer interaction*, Cambridge, MA: MIT press, pp. 147-174.

Bødker, S. & Andersen, P. B. (2005). Complex mediation. *Human Computer Interaction*, 20(2): 353-402.

Boehner, K. DePaula, R., Dourish, P. & Sengers, P. (2005). Affect: from information to interaction. In Bertelsen, O. et al. (eds). *Critical Computing -Between sense and sensibility,* ACM, pp. 59-68.

Bolter, J.D. & Gromala, D. (2003).*Windows and Mirrors: Interaction Design, Digital Art, and the Myth of Transparency*. Cambridge, MA: The MIT Press.

Bouvin, N. O., Brodersen, C., Bødker, S., Hansen, A., & Klokmose, C. N. (2006). A comparative study of map use. *In CHI '06: CHI '06 extended abstracts on Human factors in computing systems*, New York, NY, USA:ACM Press, pp. 592-597.

Brodersen, C., Bødker, S. & Klokmose, C.N. (2007a). Quality of Learning in Ubiquitous Interaction. *In ECCE 2007 Proceedings of European Conference on Cognitive Ergonomics*, Morrisville, NC: lulu Inc, pp. 121-129.

Brodersen, C., Bødker, S. & Klokmose, C.N. (2007b). Ubiquitous Substitution. Interact 2007, *Proceedings of 11th IFIP TC 13 International Conference*, Berlin: Springer, pp. 179-192.

Bryant, S.L., Forte, A. & Bruckman, A. (2005). Becoming Wikipedian: transformation of participation in a collaborative online encyclopedia. *Proceedings of the 2005 international ACM SIGGROUP conference on Supporting group work*, November 06-09, Sanibel Island, Florida, USA. New York, NY: ACM Press, pp. 1 – 10.

Carroll, J. M. & Rosson, M. (1992). *Getting around the task-artifact cycle: how to make claims and design by scenario*. ACM Transactions of Information Systems 10(2): 181-212.

Carroll, J.M., Kellogg, W. & Rosson, M.B., (1991) The Task Artifact Cycle. In Carroll, J.M., (Ed.), *Designing Interaction: Psychology at the Human-Computer Interface*, Cambridge: Cambridge University Press, pp. 74-102.

Chalmers, M. and Galani, A. (2004). Seamful interweaving: heterogeneity in the theory and design of interactive systems. *In Proceedings of the 5th Conference on Designing interactive Systems: Processes, Practices, Methods, and Techniques*. DIS '04. ACM, New York, NY, 243-252.

Cluts, M. M. (2003). The evolution of artifacts in cooperative work: constructing meaning through activity. *In Proceedings of the 2003 international ACM SIGGROUP Conference on Supporting Group Work* (Sanibel Island, Florida, USA, November 09 - 12, 2003). GROUP '03. ACM, New York, NY, 144-152.

Dourish, P. (2001). *Where the Action Is: The Foundations of Embodied Interaction*. Cambridge, MIT Press.

Dreyfus, H. L. and Dreyfus, S. D. (1986) *Mind over Machine–the power of human intuition and expertise in the era of the computer*, Glasgow: Basil Blackwell.

Dunne, A. & Raby, F. (2001). *Design Noir: The Secret Life of Electronic Objects*. Birkhuser.

Engeström, Y. (1987). *Learning by expansion*. Helsinki: Orienta Konsultit.

Gal'perin, P. Y. (1969). Stages in the development of mental acts. In Cole, M. & Maltzman, Y. *Handbook of contemporary soviet psychology, New York: Basic Books*, Inc. pp. 249-273.

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

Gaver, W., Boucher, A., Pennington, S., and Walker, B. (2004). *Cultural Probes and the value of uncertainty*. Interactions, Volume XI.5, pp. 53-56.

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Mahwah, NJ, USA: Lawrence Erlbaum Associates.

Hartson, H.R. (2003). Cognitive, physical, sensory, and functional accordances in interaction design, *Behavior and Information Technology*, vol. 22, no. 5, 315-338

Hutchins, E. & Klausen, T. (1996). Distributed cognition in an airline cockpit, Engeström, Y. & Middleton, D. (eds.) *Cognition and Communication at Work*. Cambridge: Cambridge University Press, pp.15-34.

Hydén, L.-C. (1981). Psykologi och Materialism. *Introduktion till den materialistiska psykologin*, Prisma. (In Swedish. Psychology and Materialism. An Introduction to materialistic psychology)

Jung, H., Stolterman, E., Ryan, W., Thompson, T., and Siegel, M. (2008). Toward a framework for ecologies of artifacts: how are digital artifacts interconnected within a personal life?. *In Proceedings of the 5th Nordic Conference on Human-Computer interaction: Building Bridges* (Lund, Sweden, October 20 - 22, 2008). NordiCHI '08, vol. 358. ACM, New York, NY, 201-210.

Kaptelinin, V. (1995a). Activity theory: implications for human-computer interaction. *In Context and consciousness: activity theory and human-computer interaction*, chapter 5, pp. 103-116. Cambridge, MA, USA:MIT Press.

Kaptelinin, V. (1995b). Computer-Mediated Activity: Functional Organs in Social and Developmental Contexts. *In Nardi, B. (Ed.) Context and consciousness: activity theory and human-computer interaction*, chapter 3, MIT Press, Cambridge, MA, USA, pp. 103-116.

Kaptelinin, V. & Nardi, B. (2006) *Acting with technology*, Cambridge, MA: MIT press.

Klokmose, C. N. and Beaudouin-Lafon, M. (2009). VIGO: instrumental interaction in multi-surface environments. *In Proc. ACM Conference on Human Factors in Computing Systems* (CHI'2009), pages 869–878. ACM Press.

Leontiev, A. N. (1978). *Activity, consciousness, and personality*. Englewood Cliffs, NJ: Prentice-Hall.

Leontiev, A. N. (1981). The Problem of Activity in Psychology. *In Wertsch, J. V. (Ed.). The concept of activity in Soviet psychology*. Armonk, NY: Sharpe, pp. 37-71.

Lim, Y., Stolterman, E., and Tenenberg, J. (2008). The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Trans. Computer-Human Interaction* 15, 2, 1-27.

McCarthy, J. and Wright P. (2004) *Technology as Experience*. MIT Press.

Mogensen P. (1992). Towards a provotyping approach in systems development. *Scandinavian Journal of Informantion Systems* 4, 31-55.

Norman, D. A. (1999). *Affordance, conventions, and design*, interactions, v. 6 n. 3, pp. 38-43, May/June 1999.

Norman, D. A. (2002). Emotion and design: Atrractive things work better. Interactions Magazine, ix (4), 36-42.Polanyi, N. (1961). *Knowing and being. Mind, New Series*, 70 (280), 458-470.

Odom, W., Pierce, J. Stolterman, E. & Blevis, E. (2009). Understanding why we preserve some things and discard others in the context of interaction design. *In CHI '09: Proceedings of the 27th international conference on Human factors in computing systems*, pp. 1053-1062.

Oulasvirta, A. (2008). *When users "do" the Ubicomp*. Interactions, Vol. 15, 2 (March + April 2008), 6-9.

Palen L., Bødker, S. (2008). *Don't Get Emotional, Affect and Emotion in Human-Computer Interaction: From Theory to Applications*, Springer-Verlag, Berlin, Heidelberg, pp. 12-20.

Rasmussen, J. (1986). *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering*. New York, NY: North-Holland.

Rasmussen, J., Pejtersen, A.M. and Goodstein, L. (1994). *Cognitive Systems Engineering*. New York, NY: John Wiley & Sons, Inc.

Rizzolatti, G. & Craighero, L. (2004). *The mirror-neuron system*, Annu. Rev. Neurosci. 27, 169-92.

Rogers Y. (2004). New Theoretical approaches for Human-Computer Interaction. Annual *Review of Information, Science and Technology*, 38, 87-143.

Sengers, P. & Gaver W.W. (2006). Staying open to interpretation: engaging multiple meanings in design and evaluation. *Designing Interactive Systems Proceedings of the 6th conference on Designing Interactive systems*, pp. 99-108, ACM Press.

Stolterman, E. (2008). The nature of design practice and implications for interaction design research. *In International Journal of Design*, 2(1), pp. 55-65.

Suchman, L., & Trigg, R. H. (1991). Understanding Practice: Video as a Medium for Reflection and Design. In J. Greenbaum & M. Kyng (Eds.), *Design at Work: Cooperative Design of Computer Systems*. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 65-89.

Suchman, L. (1987). *Plans and Situated Actions*, Cambridge UK: Cambridge University Press.

Tomasello, M., Carpenter, M., Call, J., Behne, T. & Moll, H. (2005). *Understanding and sharing intentions: The origins of cultural cognition, Behavioral and brain sciences* 28, 675-735

Turner, P., Turner, S., and Horton, J. (1999). From description to requirements: an activity theoretic perspective. *In Proceedings of the international ACM SIGGROUP Conference on Supporting Group Work* (Phoenix, Arizona, United States, November 14 - 17, 1999). GROUP '99. ACM, New York, NY, 286-295.

Vicente, K.J. (1999). *Cognitive work analysis. Towards safe, productive and healthy computer-based work*, Lawrence Erlbaum, Mahwah, NJ.

Wertsch, J.V. (1998) *Mind as action*. Oxford University Press, New York, NY.

Wynn, T. (1994). Layers of thinking in tool behavior. *In Gibson, K.R. & Ingold, T. (eds.9 Tools, language and cognition in human evolution,* Cambridge University Press, Cambridge, UK, pp. 389-406.

Zimmerman, J. (2009). Designing for the self: making products that help people become the person they desire to be. *In Proceedings of the 27th international Conference on Human Factors in Computing Systems* (Boston, MA, USA, April 04 - 09, 2009). CHI '09. ACM, New York, NY, 395-404.