Mind Design

Steps to an Ecology of Human-Machine Systems

Thomas Hoff

Acknowledgements

Preface

We have, within the last years, witnessed horrifying tragedies within the transportation domain. Planes fall down, trains crash, boats sink, and car accidents are one of the most frequent causes of death throughout the world.

What is more, technology seems also to fail in settings that are more mundane. In his book "the trouble with computers: Usefulness, usability, and productivity", T.K. Landauer shows that the productivity has, within the western world, *decreased* by about 50% from the period 1950-1973 to the period from 1973 to 1993, and claims that this effect is mostly due to the introduction of technology. Even closer to home, technology is still anxiety provoking for most people. One of many everyday observations to support this fact can be seen at the airports. Have you wondered why most people line up, even for hours, without daring to go near the automatic check-in machines?

What has become of the grandiose promises from the heydays of artificial intelligence? What happened to the mind-machines of Newell and Simon? Where is HAL 9000? The distance between the massive technology positivism observed in the west, and the contemporary role of technology in the society, is, I believe, one of the largest paradoxes of our time.

What is particularly interesting to note, is that the parody of the AI of the 60s, seems to be recycled every now and again, both within entertainment, the financial world, and within academia. At the turn of the century, we have seen the popularity of movies like The Matrix, we have seen high hopes become sober reality at NASDAQ, and the reductionism of Newell and Simon is alive and well, in disguise of the magic buzzword *connectionism*. Universities around the world are now buying MRI – scanners on the thousands. We are, yet again (!), on the verge of discovering the mysteries of the mind.

The slogan "Vorsprung Durch Technic" used by Audi displays something that lies deep within the western mind, namely the tendency to define ourselves and our culture in terms the inherent qualities of technology; precision, logic, rationality, reliability, punctuality, determination and power. Technology is, in many respects, the totem of the western culture. Maybe this thesis should have been about Techno-Totemism. But it is not.

This thesis, on the other hand, attempts to explore what technology *might* have looked like, had it not been for techno-totemism, i.e. the prevailing idea within western culture and sciences, that humans are *literally* machines. This notion makes engineers design technological products as if humans actually were machines, or worse *imperfect* machines. The imperfect machine metaphor leads directly to the notion of "human error", which is often used in a particularly stupid fashion.

In this work I lean, on the contrary, on aspects of human cognition that are not machine-like whatsoever, and advocate a change in design focus, from an emphasis on technology to an emphasis on *ecology*. I have attempted to present my programme positively; that is, to give indications on how, in practical, real life settings, such an approach might be carried out. At certain points, however, it has been necessary to point out the difference of my approach from the traditional cognitive-based Human Factors tradition, to make my points explicit. I apologize to cognitivists and human factors specialists for occasionally making a straw man of their theory. There are many excellent contributions made by these traditions, which are not reflected in this thesis.

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Contents

Summary of "Mind Design – Steps to an Ecology of Human-Machine Systems"

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Abstract

This thesis approaches the issue of the ecology of human-machine systems from four different angles: Theoretical, experimental, developmental, and methodological. Viewed from the ecological psychology perspective and the embodied mind approach, there is an apparent gulf between the representations of computerised systems and the way the operators of such systems process that information. An Ecological Interaction Properties (EIP) framework was presented, which refers to aspects of the user, as well as to aspects of the interface. Examples show how to augment the ecology of interfaces within energy management systems, as well as within in-vehicle information systems. However, the basic level of analysis for human-machine systems is the level of *activity*, not the level of representations. Hence, to exploit the EIP- framework is necessary, but not sufficient, to create improved human-machine interaction.

Keywords: Human-computer interaction, interface design, representations, distributed cognition, ecological approach, energy management systems, abstraction hierarchy, cognitive work analysis, visualisation, in-vehicle information systems, cognitive engineering, traffic psychology, ecological interaction properties

1. Introduction

During the last decades one has, within the traditions dealing with human-machine systems (e.g. human-factors, human-computer interaction, cognitive ergonomics, interaction design, man-machine interaction), seen something of a crusade against the classical information processing approach to human-computer interaction put forth by Card, Moran and Newell (1983), as well as Wickens (1984).

Most of the criticism is appropriate, and corresponds in many respects to the disapproval of cognitivism within the social sciences in general, in particular put forth by post-modernistic relativistic traditions such as deconstructivism and social constructivism.

The "soft-cognition" approaches, in particular the Activity Theory approach to human-computer interaction (Nardi, 1996), and the situated cognition approach (Suchman, 1987; Rogoff and Lave, 1984) have made seminal contributions to the field of human-machine systems. These approaches have in concert with the general post-modernistic trend, however, lead contemporary interaction design (in particular User Centred Design (Nielsen, 1993), Participatory Design (Schuler and Namioka, 1993), and Usability Engineering (Faulkner, 2000)) to disregard knowledge concerning fundamental cognitive properties of the user. Roughly presented, the arguments they put forth are as follows: a) Because any user's interaction with a particular product depends on that particular user's history (e.g. knowledge of the particular product, computer skills, general attitude towards technology), emotions, personality, context, and so on, one cannot predict beforehand how the user will perform when interacting with the product. Because of this, one needs to evaluate the product by way of usability testing and iterative design loops. b) Because formal task-analysis is inadequate to account for the context conditioned variability of real life, one needs to study the activity in situ, and/or include members of the end user group in the design team, and/or to arrange user workshops during the development of the design.

This, in itself, is tolerable. However, the problem is that this approach supports an evolutionary design process, in which technology progresses by building on former devices and technology as well as recycling outdated metaphors. This problem arises because users, designers and developers have great difficulties in separating the task from the artefact. In other words both users and designers seem to think that the execution of a task has something to do with a particular device. Both iterative usability testing, rapid prototyping and user workshops suffer from the problem of device-dependency, and are therefore not an appropriate tool for creating innovative (or revolutionary) design. This is particularly problematic because the fundamental schema for interface design was laid down long before user centred design arose. Hence we are spinning down a path believing that technology is truly progressing, but in reality, the increments are minute. True progress is occasionally being made by creative designers (this creativity is sometimes referred to as "design sensitivity" in the product design environment). This creativity, or design sensitivity, is something of a black-box, in that it is based on a hunch, rather than directed through theory or models of humans in general.

Even though the cognitive approach has been strongly criticized by various fields dealing with human-machine systems, the approach is nonetheless very important because it raises the fundamental issue of the general mental mechanisms and processes valid for *all* users. The question posed by the cognitive approach was appropriate and well timed, but the answers it provided, at least for answering the pressing human-machine issues, were flawed. How and why they were flawed will be elaborated upon at several points throughout this thesis.

The main question remains; are there fundamental facts about the cognitive and perceptual apparatus of humans that are real and stable across gender, race, age, expertise, context and so on, which are strong and sufficiently stable to provide a firm foundation for the design of human-machine systems? The answer is yes.

The answer is not to be found within the classical information processing approach, and not by way of the narrow strains of the laboratory. In this thesis I will explore the answer by pursuing the ecological approach to visual perception (Gibson, 1979) and its derivatives, which go under the heading "Ecological Psychology" (Reed, 1996). Additionally, the embodied-mind approach of Lakoff and Johnson (1999) will be central. These approaches are covered in the papers, and will not be presented in an introductory form here. The above references are excellent introductions to the general approaches.

1.1. Structuring of the thesis

This thesis approaches the issue of the ecology of computerised systems from several different angles. The thesis is structured according to the following questions:

Paper 1: How well do complex computerised systems conform to the ecology of the cognitive apparatus of the operators of these systems? That is, do the representations of these systems fit the perceptual and cognitive system, as viewed from an ecological point of view?

Paper 2: If complex computerised systems, in general, do not conform to the ecology of the cognitive apparatus of the operators of these systems, how could one go about designing systems which are better tailored to fit the perceptual and cognitive system, in the real and practical setting of energy management systems (EMS)?

Paper 3 and 4: If one can design systems which are better tailored to fit the perceptual and cognitive system, as viewed from an ecological point of view, would it be possible to detect subjective and objective differences in performance of drivers using such interfaces in a driving simulator environment?

Paper 5: Do the insights developed in the former papers relate to practical design tools, or are new categories and terms necessary in order to facilitate an improved ecology of human-machine systems?

In order to show how the ideas presented in this thesis have evolved over the past years, I have chosen to present the papers chronologically. Hence, I have also deliberately avoided updating in the earlier papers ideas that became clearer in the later papers. One example of this is the direct-indirect subscales of paper 4, which are referred to as ecological interaction properties in paper 5.

2. Methods

This thesis approaches the issue of the ecology of human-machine systems from several angles simultaneously. Theoretical, experimental, developmental and methodological aspects are considered. The approaches are emphasised differently in each of the 5 papers that constitute this thesis: Whereas papers 1 and 5 are mainly theoretical, paper 2 focuses on developmental aspects, and papers 3 and 4 are primarily experimental.

I have deliberately de-emphasised the concurrence of the methodological approach in order to explore the phenomena in question from different angles. This approach is in line with Vicente (1997), who suggests that a sound scientific approach to human factors issues is to triangulate between 1) highly controlled laboratory experiments, 2) less controlled but more complex laboratory experiments, 3) evaluations conducted in high-fidelity simulators or in the field, and finally 4) qualitative, descriptive field studies. In category 1, one has to simplify the situation by keeping constant factors that vary in the real world. Even though the control is high, the degree of generalisability is low. The opposite is true for type 4 studies, in that the situation is highly representative, but the degree of experimental control is low. In Human Factors research, it is quite obvious that context is an important factor, which should not be

regarded simply as noise. At the same time, it is equally obvious that it is important to control for third variable effects.

For novel lines of thought (which is the case for the ecology of human-machine systems approach presented in this thesis), it is decisive to identify the phenomenon as such, before any experimentation is performed: "Before one can meaningfully formalize, quantify, or experiment, one should identify a natural phenomenon that is worth investigating in more detail, and categorize the dimensions of that phenomenon to learn what factors should be manipulated experimentally" (Vicente, 1997, p.325). As such this thesis has made a full loop with respect to the phases above (although the approach has not yet reached category 1 in the strict sense of the term).

2.1. From observation to design and experimentation

The foundation of this thesis is a one-year long ethnographic field study of the operators at the Norwegian Power Grid Company Control Room in Oslo, Norway. The line of approach was action based. This means that it was participatory, that the aim of the study was never hidden from the informants, and that the knowledge derived from the study was communicated back to the operators in order to help them improve their work environment.

The information was sampled in a number of different ways, according to an activity theory approach (Nardi, 1996; Lepleat, 1991). Here, one aims to describe the prescribed, formal task, as well as how those tasks are actually carried out (termed "task description of performance analysis" by Hollnagel (1992). Additionally, information regarding the operators per se was sampled.

The description of the formal aspects of the work was described as a structural task analysis, and a time-line task analysis (Kirwan and Ainsworth, 1992). The input to this analysis was interviews (and informal talks) with the operators, video analysis of the daily operation of the grid, as well as analysis of the operator instruction manuals.

The sampling of activity, e.g. the descriptive analysis of the *actual* work was based on video analysis, link-analysis (ibid), as well as informal participation in grid operation. Information

regarding the operators were sampled by using the NEO-PI-R personality inventory, as well as perceived workload measures (NASA-TLX).

The field study was only used indirectly as an input to the thesis, as the paper is somewhat too descriptive and extensive to be included as an article of its own. Traces of it can nevertheless be found all through the thesis, as the main idea of increasing the ecology of human-machine systems evolved during the fieldwork. A more direct use of the work can be found in the "Powerdesk" case-study in paper 1, as well as in the introduction to, and development of, the Compact System State Display (CSSD) presented in paper 2. In line with the action-research approach, three complete redesign solutions (presented as CAD-models) were introduced to Statnett (the national grid authorities). Some of the suggestions made during the fieldwork are currently been implemented in the control room. Additionally, a full human-factors analysis of the working conditions is in the making.

2.2. Papers 1- 5

As mentioned above, the methods used in the field study were used as direct input to the case-study presented in paper 1. Apart from the case study, paper 1 is theoretical in that it "categorises the dimensions of the phenomenon to learn what factors should be manipulated experimentally" (Vicente, 1997 p.325). In particular, frequently used forms of representations were categorised and mapped according to a direct-indirect continuum.

Paper 2 presents a full-scale design work, which serves as an example of how the challenges presented in paper 1 might be met in the practical setting of energy management systems. Design methods are very different from what is usually termed "methods" in the social science tradition, and will not be elaborated further in this context. By and large, development projects have no natural place in the social sciences, except that it might be viewed as a very extensive preparation for experimentation and evaluation. The CSSD-system is, however, not empirically evaluated here. One reason for this is that studies have shown that direct comparison of systems of this complexity is virtually impossible (Vicente, 1999). Work practice will develop over years in order to fit the local contextual demands of particular operators in particular settings. Work practice refers here to a descriptive account of what operators *actually* do, as opposed to a normative account of what they *should* do. That these two descriptions differ widely (because the operator needs to account for unanticipated

events), is one of the most well established, and most important insights of the last decade of human-factors research. Because of this fact, one cannot predict up front how operators will use such systems. In interface testing one evaluates a normative task (rather than a real task) in a generic, artificial environment (rather than a particular environment), with operators whose expertise reflects general knowledge (rather than context-specific knowledge) of the task and the artefact at hand. It is very difficult to meaningfully generalise from such testing, to the performance of operators possessing context-specific knowledge, performing real tasks in particular environments. Hence, evaluations of complex sociotechnical systems should rely on the assessment of particular operators in particular settings, preferably by way of ethnographic analysis of activity, rather than objective measures (as one would in principle have no other data to meaningfully compare these data with). Because the CSSD- system is not yet fully implemented in a real operational setting, an evaluation on the basis of these criteria is currently not possible. However, in the spring of 2002 the CSSD-system was sold to Siemens AG, and is currently being implemented at RWE-net, which is one of the largest power operators in Europe. A thorough analysis of the practical contributions of the CSSD-will be possible within due time.

In this thesis, the focus lies on the properties of the human-machine system, which do *not* depend on particular users in particular environments, but on users in general. Because the results from evaluations of complex sociotechnical systems are strongly contaminated by effects that do not depend on the operator per se, and are very hard to hold experimentally constant, one should look for settings that are less complex and easier to experimentally manipulate. They should nonetheless be sufficiently similar, so that it is possible to meaningfully generalise to more complex environments.

The use of in-vehicle information systems (e.g. systems that provide the driver with information regarding driving, as well as other functions like mail, internet, CD, radio, GPS etc.) are similar to the operation of large-scale systems like EMS-systems in that one or a few users attempt to supervise a process (the process of power flow or the process of driving). Furthermore, requests for information are given as input and information is displayed to the operator as output. Even though the tasks are somewhat similar, the task of operating an in-vehicle information system is not as dependent on practice as is the operation of large-scale systems. Hence, the former is a more viable setting for experimentation. Important theoretical

and practical implications of papers 1 and 2 were further explored in paper 3 and 4, which aim to empirically validate these aspects.

The experiments of papers 3 and 4 are very similar in terms of experimental set-up. Both are within-subjects experiments, in which the manipulated variable is the interface of the in-vehicle information system. Both experiments were carried out in a full-scale driving simulator at Sintef Civil and Environmental Engineering in Trondheim, Norway. Paper 3 investigates the effect of a traditional graphical user interface based system (the WAP technology), and a speech-recognition system developed for the purpose of the experiment, on subjective workload (NASA-TLX) as well as objective measures of driver performance. Paper 4 investigates the effect of a graphical user interface based Personal Digital Assistant (PDA) and a Tangible User Interface (TUI) on subjective workload and subjective preference of the interface. In comparison to paper 3, more emphasis was put on design and development in paper 4. The Tangible Car Display (TCD) was designed and developed solely for the purpose of the experiment.

Paper 4 revealed that some of the concepts used in the first four papers (e.g. the solid-graphical-tangible taxonomy) needed to be defined with greater precision in order to be useful for more rigorous experimentation. Hence, paper 5 is a theoretical paper, which restructures the original taxonomy, and suggest that it ought to be replaced by so-called ecological interaction properties.

By paper 5, the thesis has gone full circle by returning to type 4 issues. The theme of paper 5 is, however, a lot more concrete than that of paper 1, and paves the way for type 1 experiments. Whereas paper 1 is inadequate for operationalisation of specific hypothesis, the concepts derived from paper 5 call for a series of controlled experiments.

2.3. Audience

If one reads the current work as a coherent thesis, rather than as five separate papers, it is important to note who the intended audience of the different papers are: Papers 1, 3 and 4 are directed at human-factors and ergonomics specialists. Papers 3 and 4 are also directed at the transportation environment (e.g. research groups, national transportation authorities, or commercial producers of in-vehicle information systems). Paper 2 is also directed towards the

general human-factors environment, but is more specifically addressed to the Cognitive Engineering environment as an example of how the ecological interface design (EID) approach of Vicente and Rasmussen (1992) can be implemented in EMS- systems. Paper 2 is also directed to research groups interested in EMS visualisation. Paper 5, however, is addressed to a somewhat different audience than the other papers. Here, we have attempted to catch the attention of interaction designers and human-computer interaction specialists. The intended audience is also reflected in the choice of publication media: Paper 1 is accepted by "Theoretical Issues in Ergonomics Science", paper 2 is accepted by "Cognition, Technology and Work", paper 3 is submitted to "Transportation Research Part F: Traffic Psychology and Behaviour", paper 4 is accepted for the "Proceedings of the Nordic Ergonomics Society's 34th Annual Congress on Humans in a Complex Environment ", and paper 5 is accepted for the "Proceedings of NordDesign 2002 – Visions and Values in Engineering Design".

Because the intended audience differs somewhat from paper to paper, the terminology, abstraction level, and precision also differ between papers. In general, it has been my aim to stay at a level which is comprehensible for a large audience with different backgrounds (e.g. product design engineering, the information sciences, psychology, anthropology, philosophy and all those in between).

3. Results

Because the results of the papers in this thesis are different in kind (according to the above discussion), I will describe them chronologically rather than as a whole.

3.1. Paper 1

Paper 1 argues that an important aspect was lost during the transition from hard-wired control rooms to full graphical interfaces (GUI). Even though the work environment has become much more tidy (one or a few generic screens that can convey all information imaginable), it also introduces a "keyhole effect" (Woods, 1997). The keyhole effect refers to the fact that a full GUI forces the operator to view information sequentially, in which only a small portion (or "keyhole") can be viewed at any time.

The digitalisation and processing of data is a powerful tool in that information can be represented in just about any way. At the same time (as argued in paper 1), this capability might be a devil in disguise. Because there is nothing in the computer medium that constrains the relationship between what is represented and its representation, it is the job of designers to constrain this relation in a fashion compatible with the basic cognitive functioning of the operator. The status of the representations depends on whether one chooses a disembodied- or embodied mind approach to the description of cognitive functioning. Within the human factors tradition, it has been common to use the classical information processing approach. The stick-man description of this approach goes as follows (in order to avoid presenting *my* stick-man, I quote from Gordon's (1997) "Theories of Visual Perception"):

"In any momentary visual fixation of the world, the relationship between distal and proximal stimuli is likely to be imperfect: retinal images shrink as objects of fixed size move away from us; a table shows only three legs; tilted rectangles yield trapezoidal retinal images. We see things that are not physically present when we complete gaps in patterns or see illusory contours. Colour resides not in objects but in our heads. The sensation of a tickle does not resemble the objects which induced it. In other words, sensory inputs are commonly too impoverished or too degraded to specify aspects of the world….Because sensory inputs (or sensations) are not rich enough to mediate perception, the perceiver must add to them. The elaboration of sensory data involves inferential processes utilizing memory, habit, set and so on. Survival pressures require that inferential processes deliver "correct" solutions most of the time – we successfully go beyond the sensory evidence – but sometimes inferences fail and we experience illusions or other "errors" of perception….The essence of the constructivist paradigm therefore is that perception of stimulus information before the final perceptual response is attained; sensory inputs must be represented as images, schemata, models." (p.183).

This empiricist approach inevitably leads to a focus on the mental mechanisms for the interpretation of the proximal stimuli. Hence, in this perspective, the focus lies not on the real world physical representation, but rather on the processing of internal mental representations. Within the ecological approach (Gibson, 1979), there is no dualistic view of the perceiver, which separates the perceptual experience from the objective world. Rather, the information in the world gives rise to invariant patterns that can be detected. I argue further; given that the ecological approach is sound, one should not focus (as is often done in the Human Factors

literature) on reaction times, information flow, processing bottlenecks, memory stores, signal detection etc. Rather, one should focus on the invariant relations between the perceiver and the perceived, which gives rise to meaning. In this perspective, it is the physical representations that should be attended to, not the internal mental mechanisms for the interpretation of those representations. Thus, the issue of design of representations of computerised systems should focus on artificially recreating the perceptual invariants to which people have become sensitive through evolution.

What may these representations look like? In paper 1 I have focused on the centrality of the perception of continuous flow of time and spatial extension, the experienced magnitude of sensory information, as well as the ecological scaling to the human perceptual apparatus. According to these aspects, the most common forms of representation in computerised systems (such as e.g. numeric, graphical, haptic etc.) were evaluated and mapped. A case study from the field of electric power control was also presented, which served as an example on how the task of augmenting the ecology of computerised systems might be pursued in a practical setting.

3.2. Paper 2

Whereas the Powerdesk case study in paper 1 is merely an interaction concept, the CSSD – system presented in paper 2 is a full-fledged functional energy management system (EMS) interface. This shows how some of the ideas put forth in paper 1 can be implemented in real operational environment. While being more realistic than the Powerdesk-case in terms of technical and practical implementation, it is at the same time less extreme. The CSSD work has mainly focused on increasing the ecology of representations within the frame of a full GUI system, as opposed to the Powerdesk, in which no such constraints were present.

In the past decades, much work has been done on nuclear power control rooms. However, very little work has been done on the regulation of electrical power flow. The representations most commonly found within EMS interfaces are numerically presented, e.g. in single-line diagrams for visualising single aspects of the system state, such as line flows, reactive power-flow, voltage situation etc. The aim of the CSSD – system was to provide the operator with higher level-information (fig. 1). This information is represented by perceptual invariants that the operator can get attuned to, given the opportunity to work with the system over time.
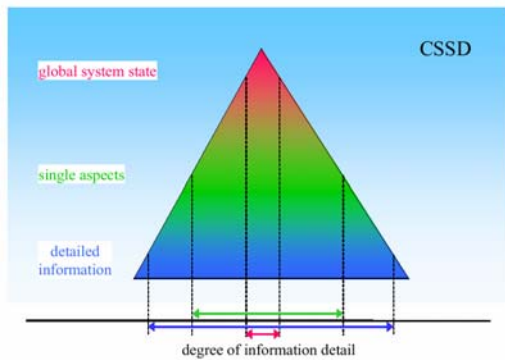
Fig. 1 The hierarchical approach

The CSSD – system utilises some of the insights derived at in paper 1, e.g. that a continuous representation of system state, combined with processes represented by spatial changes, increases the ecology of the representation. Hence, the CSSD – system supports the operators' decision making process in the operational setting. Fig. 1 shows a normal load as opposed to a serious overload condition.
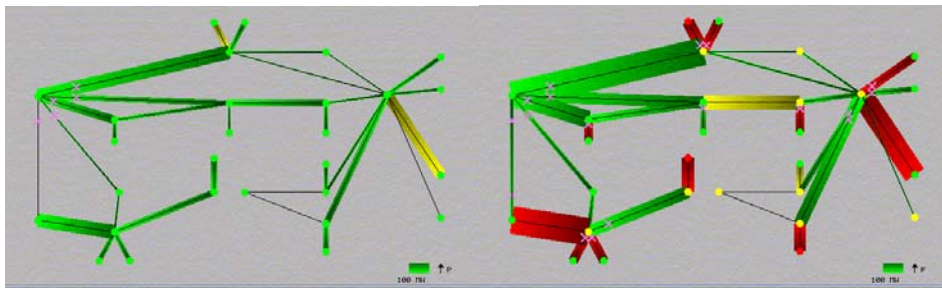
Fig 2 Representations of normal and overload power flow

3.3. Paper 3

In order to operationalise the ideas derived at in papers 1 and 2, it was decided to move from the context of complex sociotechnical systems, in which experimental control is very hard to achieve, to interface design of in-vehicle information systems, which can be subject to experimentation. The hypothesis of paper 3 was that, in a within-subjects design, in a driving simulator environment (fig. 3), a speech-based interface would outperform a traditional mobile phone interface (WAP). The effect should be observable both in terms of subjective workload (as measured by NASA-TLX), as well as in objective measures of driving performance. On the one hand, this hypothesis is rather conservative, in that it does not

maximise the full potential of the ecological interface design suggested in paper 1. On the other hand, the experiment is applied, in that is evaluates interfaces, which are currently available in the commercial market.

According to the hypothesis, it was found that in many respects, the speech-based interface outperformed the graphical interface (WAP). This effect was found on several dimensions. In direct comparison between the two, the handheld interface revealed a significantly higher workload than the speech-based interface on time pressure and effort. The mental workload category showed tendencies (not statistically significant), in favour of the speech-based interface. The WAP-interface gave a significantly higher score on total workload in relation to the test-drive condition, whereas there were no such difference between the speech based interface and the test-drive condition. In relation to baseline, both interfaces had a higher total workload score. The WAP-interface had lower p values than the speech-based interface did.

As for the behavioural dimensions, differences were found between the WAP-interface and baseline, and between the speech-based interface and baseline for average speed (but not for lateral positioning). There was no difference in average speed or standard deviation between the two conditions per se.

The results also indicated that controlled experiments, in a realistic and high-power driving simulator, provide a sufficient level of ecological validity in order to make generalisations to normal driving. This finding was supported by the fact that no differences in workload were found between the subjects perception of workload of normal driving and the experimental baseline.
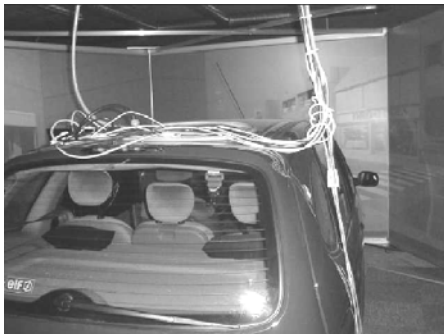

Fig. 3 Picture of the simulator

3.4. Paper 4

The experimental set-up reported in paper 4 is fairly similar to the one reported in paper 3. However, the hypothesis of this experiment is much less conservative than that of paper 3, in that a Tangible Car Display (TCD) (fig. 4) was developed with the aim of maximising the ecology of the interface. Because we expected a much larger effect (due to the maximisation of ecology) compared to the former experiment, fewer subjects participated in that study. Due to greater experimental sensitivity of subjective data compared to objective data observed in the experimental manipulation of paper 3, only subjective mental workload and subjective pleasing of the interface was sampled in the experiment reported in paper 4.

Fig. 4 Picture of the TCD

There was a difference between a traditional GUI-based Personal Digital Assistant (PDA) and the TCD on the physical load dimension of the NASA-TLX, but not for the overall NASA-TLX score. However, there was a difference on the overall score between GUI and the perceived workload of normal driving. No difference was found between TCD and the perceived workload of normal driving. The subscales physical load, time pressure, effort, and perception of performance, contributed significantly to the added workload of using the GUI interface.

Additionally, subjects evaluated the TCD interface as being safer to use in traffic, more likely to be purchased, as well as being more natural in the in-vehicle environment, than the GUI interface.

3.5. Paper 5

During the development of the TCD system, we were bothered by the traditional use of the terms Solid User Interface (SUI), Graphical User Interface (GUI), and Tangible User Interface (TUI). There seemed to be no apparent match between the definition of what constitutes ecology in paper 1, and the most frequently used terms, which imply a certain use of the interface. Through a series of examples of different user interfaces imaginable for a hammering device, we showed that a) there are interfaces that give rise to very different user experiences, which refer to the *same* category within the SUI-GUI-TUI taxonomy (fig. 5), and b) that there are interfaces which belong to the same category within the SUI-GUI-TUI taxonomy, that give rise to very *different* user experiences. It was argued that the reason for the apparent discrepancies between user experience and interface category, was that the SUI-GUI-TUI taxonomy refers to *properties of the interface*, rather than to properties of the human-machine system.
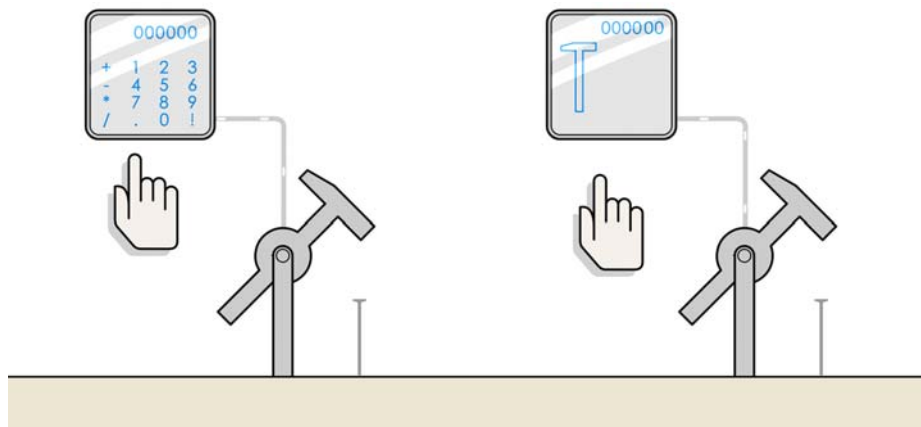
Fig. 5 Two SUI's with different interaction experiences

In order to account for the phenomenological aspect of interaction, a set of so-called Ecological Interaction Properties (EIP) that constitutes a direct-indirect continuum were developed. The direct-indirect continuum is based on the embodied-mind perspective of Lakoff and Johnson (1999), which indicates that recurrent patterns of human bodily movement, manipulation of objects, and perceptual interaction, forms so-called image schemata (or perceptual gestalts). These schemata can be figuratively developed and extended as a structure around which meaning is organised at more abstract levels of cognition. This figurative extension and elaboration typically takes the form of metaphorical

projection from the realm of physical bodily interactions onto so-called rational processes, such as the reflection and the drawing of inferences from premises.

"Direct" then, refers to perception-action cycles (Turvey, 1977a), whereas "indirect" refers to slow, serial, explicit mental reasoning based on internal mental models. As the term "direct-indirect continuum" refers to, there are *degrees* of directness or indirectness.

Furthermore, it was shown that the discrepancies between user experience and interface category unaccounted for by the SUI-GUI-TUI taxonomy were perfectly accounted for within the EIP-framework.

4. Discussion

Throughout this thesis, I have theoretically and experimentally, as well as through practical product development, attempted to show that there are very important factors regarding human-machine systems that are not accounted for by the information processing approach to human cognition.

In my view, the most important contributions of this thesis can be found in papers 1 and 5. I view papers 2, 3 and 4 as an effort to validate the general approach through practical product development and experimental set-ups.

The main contribution of papers 1 and 5 is the pinpointing of the ecological properties of representations in computerised system (or as in the case of paper 1, the *lack* of such properties). A careful reading of papers 1 and 5 will reveal that there are considerable differences between them in results. This is mainly due to the fact that paper 1 discusses systems that represent ongoing processes (electrical, nuclear, or petrochemical), and focus very little on the interaction between the operator and the system. A typical example of such a system is the National Operator Control Room at Statnett. Here, there is actually no direct input given from the operator to the system – all interventions are performed indirectly via phone calls to lower-level control rooms. The operators are simply monitoring an ongoing process.

Paper 5 however, additionally considers products with which one interacts (where there are no processes running at the back of the system). In this situation, there are even more ecological properties at play than described in paper 1. The reason is the introduction of the input/output aspect, which in particular gives rise to problems of directness. Even though the prototypical example of paper 1 (Statnett control room) and paper 5 (in-vehicle information systems) puts very different demands upon the design process, the properties arrived at in paper 1 might nevertheless represent a special case of the EIP-framework arrived at in paper 5.

4.1. Conclusions on the EIP-framework

Whereas we are optimistic concerning the EIP-framework, we acknowledge the fact that it is in an early phase. The framework is somewhat validated by the theoretical arguments put forth, by the appropriateness of the framework to account for the differences between interfaces that are not accounted for by the SUI-GUI-TUI taxonomy, and to some extent, by the various experiments, particularly the one described in paper 4.

The framework needs to be more anchored theoretically. Additionally, we need to show that the framework can account for important differences in interfaces in general, not merely the examples presented in paper 5. Finally, and most importantly, the framework needs to be validated experimentally by way of type 1 experiments (i.e. highly controlled laboratory experiments).

Hence, the EIP-framework should be considered a point of departure for scientific endeavour, rather than a ready-made package for use in interaction design projects.

4.2. EIP – necessary but not sufficient

During the last phase of work on this thesis I realised that we might have carried out reductionism, which is the very approach we have attempted to avoid. In our defence, it should be said that it is a very different form of reductionism from the traditional one. The interaction properties we propose refer to phenomenological aspects of interaction, and not to properties belonging to the interface per se (such as the TUI-SUI-GUI taxonomy), or to properties belonging solely to the operator as such (e.g. the cognitive approach).

Nevertheless, I cannot overemphasise the qualifications regarding the EIP-framework discussed in paper 5. An interaction designer cannot design interfaces out of interaction properties any more than a painter can make paintings out of gestalt principles. Hence, the interaction properties are a means to an end rather than the end in and of itself.

The most important qualification made in paper 5 (which is related to the general discussion of paper 3) regards *activity* (although important qualifications are also being made with respect to task/operator and technology). The basic unit of analysis of a human-machine system is the activity-level, and not the system-representation level. It is the analysis of activity that constrains the ecology of the interface, not the other way around. Hence, the designer cannot determine up front whether all aspects of a given interface will benefit from a maximisation of the interaction properties described in paper 5. Paper 3 provides a very good example of this fact. After merely observing the experimental trials, it became obvious that the interface lacked support of compensatory variables, particularly workload-management. Given the limited space of the interface, it is much more important that the interface is highly direct regarding aspects important for workload management, than, say, to have a main on/off button which has a high degree of directness.

Interestingly, the case study presented in paper 1 also revealed a similar utilisation of the EIP-framework. Activity analysis of day-to-day operation of the Nordic power grid network, revealed that (similar to the example above) one of the major deficits of the interface is its lack of flexibility in order for the operators to manage their workload; that is, to be able to distribute workload more evenly over a period of time. Hence, we focused particularly on the issue of high ecology of the interface., To make tangible representations of all possible windows within the system would, for example, be a complete waste of time.

4.3. Further work

The first steps to an ecology of human-machine systems presented in this thesis could (or for the sake of future human-machine systems *should*) be followed by continued work in several directions:

1) *The experimental approach*. As mentioned above, the EIP-framework arrived at in paper 5 paves the way for controlled experimentation. In particular, it would be interesting to

experimentally manipulate each of the interaction properties. Exactly how far one can push each property towards the indirectness end, before a breakdown in performance is detected, is a central question.

2) *The practitioner approach*. This approach should aim to refine the framework arrived at in this thesis in order to develop practical tools for interaction designers. In this process, it would be important to carry out applied design projects, which shows that the approach can make a difference in commercial products.

3) *The theoretical approach*. This thesis leaves much unsaid about the Techno-Totemism discussed in the preface. Given that the main assumptions presented in this thesis is valid, and that the embodied-mind approach and the ecological approach in general are also valid, then one should study not only how Techno-Totemism has shaped the technological systems we surround ourselves with, but also how it has shaped the way we study people. Is it at all possible that the same underlying mechanism that has contributed to the technology centred product development so frequently seen today, also have contributed to shape both the tools and theories used in the contemporary social sciences for the description of man? If such a conclusion were to be made, it would display a great paradox indeed.

4.4. Conclusions: Mind Design

There are at least two apparent meanings of the title "Mind Design". The first is that engineers should be explicitly aware of cognitive functioning when designing technical systems or products. When I teach the issues addressed in this thesis to engineers, they are always surprised when they discover that they actually *have* an implicit theory of human mental functioning. The fact that they do possess such a theory is a rather trivial point. It is as trivial, really, as to say that a designer of a hat has a theory of the size of a head. The first step is to make their theory explicit to them, and step two is to put their theory under close scrutiny.

The second meaning of the title refers to the fact that when studying human cognition, one should acknowledge the fact that, when viewed as a distributed enterprise, a lot of cognitive processing occurs outside the skull of the operator. Not only does cognition shape reality – reality also shapes cognition. Bradd Shore (1996) argued that one should have culture in mind when studying cognitive systems. I would like to add that one needs to have external artefacts

or "Design" in Mind. Although I use the term "design" in a narrow fashion in this thesis, many of the points made could be extended to cover design in a broader context (e.g. product design engineering, architecture, civil engineering, design of public spaces, branding and identity design). To make these extensions might be as important as the three other areas mentioned as important steps towards a general theory of design ecology.

5. References

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List of papers:

1. Hoff, T. Comments on the Ecology of Representations in Computerised Systems. *Theoretical Issues in Ergonomics Science.* Submitted

2. Hoff, T. & Hauser, A. (In press). Applying the Ecological Approach to Interface Design on Energy Management Systems: Developing a Compact System State Display (CSSD). *Cognition, Technology and Work.*

3. Bjørkli, C.A., Hoff, T., Jenssen, G.D, Øritsland, T.A. & Ulleberg, P. (In press). On Representations of In-Vehicle Information Systems – Effects of Handheld vs. Speech Based Interfaces. *Transportation Research Part F*: Traffic Psychology and Behaviour. In Press.

4. Hoff, T., Alsaker, M. & Bjørkli, C.A. (2002). Effects of Tangible User Interfaces (TUI) in
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5. Hoff, T., Øritsland, T.A. & Bjørkli, C.A. (2002). Ecological Interaction Properties. *Proceedings of NordDesign 2002.*