# Explanatory frameworks for interaction design

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## Abstract

Explanatory design means the practice by which design solutions are evidence based. This practice has been the norm in engineering design relying, as it does on the laws of science, but much less attention has been paid to the necessity of abandoning intuitive practices in designing for the human element within technological systems. One reason for this may have been the variety of explanatory bases within psychology. There is no single psychological framework for explaining human behaviour, instead different types of problems must be solved by using very different types of explanatory frameworks and theory language. Cognitive capacity, emotions and mental contents may serve as examples of very different explanatory frameworks. Developing a theory of explanatory interaction design needs to be based on an improved understanding of the differences between explanatory frameworks.

We may have two basic stances towards design. Firstly, we may base our design on intuitions. For example, design may imitate earlier examples of working solutions with no attempt to understand the rational principles behind the construction. For many centuries architectural design, for example, has been based on well-tested traditions with no attention being paid to deeper considerations such as engineering calculations (Saariluoma 2003; Saariluoma and Maarttola in press). The outcome has not necessarily been poor, and such intuitively planned houses have been used for centuries. Nevertheless, this kind of intuitive design thinking is no longer cost efficient and it does not meet modern safety demands. This is why it has been necessary to replace intuitive tradition with a more scientific design approach (Carroll 1997; Saariluoma and Maarttola in press; Simon 1969).

Design, where design decisions are based on scientific evidence, can be called explanatory or evidence-based. The ultimate goal of scientific activity is to enable people to answer ‘why’ and ‘how’ questions. In fact, all the how-questions should be based on why-questions and vice versa. Questions such as “Why were investors unable to pick the correct numbers when reading their spreadsheet, or why did they select incorrect rows in a spreadsheet?” lead automatically to questions like “How could we improve the interaction with the spreadsheets?” These kinds of questions are typical and presuppose explanatory thinking (Hempel 1965).

In scientific explaining, one relies on scientific knowledge about the matter under scrutiny. This means that one looks for scientific laws and empirical findings, which could support the selected solutions. If such principles cannot be found, it is necessary either to make empirical analyses or to search for an alternative solution. One must have good and argued reasons for design decisions.

Explanatory design is a standard approach today when designing industrial artefacts. Historically, designers have been concerned with houses, bridges, milling machines and other engineering constructions. Hence, design ideals or rationales, i.e., the norms of design activity, have been shaped following experience collected on the basis of such design processes. Design has in very authoritative texts been seen as filling pre-defined requirements and rationales following the laws of nature (e.g. Pahl and Beitz 1989).

If we think about traditional industrial objects such as bikes, tents, shoes, power lines and even television and radio sets then the design stance has been traditionally based on the laws of nature. The user requirements for such designs are relatively simple and straightforward. It is important that a bridge stays standing and that people and cars can travel over it. There is no need to cope with complex interaction problems. Of course, engineering design is still, in the main, concerned with the laws of nature. However, new technology raises new types of problems and designers need a new range of skills to solve them.

The information and communication technological revolution has changed the human’s role in interacting with artefacts. People operating with IT-artefacts must be able to command complex information systems (Nickerson and Landauer 1997). These systems basically work with signs and symbols, which are rather arbitrarily connected to their references. Designers are encountering new problems such as, how to eliminate the risk associated with human information processing systems (Reason 1990). Interactions with different artefacts carry with them different levels of complexity. Walking up the staircase is not a difficult task but programming a computer requires that the users keeps in mind programming commands and a complex interrelated sets of symbols. In the future, these kinds of complex interactions will become increasingly more diverse. Therefore, it is essential to change our vision of design.

The revision has been ongoing for some time. Perhaps the first high-level programming languages started this movement. Instead of adapting the human mind to machines, designers started to design machines following the principles of the human mind. Programming languages such as Cobol, Fortran and Basic did not aid computing as such but they did make it easier for the human memory to interact with computers. Programming in binary made sense for the computer but the low level of discrimination and memorability had made it practically impossible for the user.

Ever since the early period, the need to take into account the human mind and the principles it follows has increased. Computers and computing devises have became consumer products, hidden computing devices with new forms of interaction are becoming more common and devices such as mobile phones presuppose an increasingly similar interaction mode with computers. Therefore, in future interaction design it will be essential to incorporate scientific information about the human mind into the design process. People need, use and buy artefacts and for these reasons alone the mind should be equally important to technology in formulating design rationales.

The increasing role of psychological and other knowledge about human mentality in interaction design makes it necessary to think more systematically about the nature of the design processes implementing knowledge about the mind. How could we best implement human knowledge into design constructions? How can we use knowledge about the principles of mentality to resolve design problems? To answer such questions we have to consider the foundations of design activities.

## 1 The necessity of explanatory interaction design

Design is a process in which we construct plans for complex objects. It is a process of individual and group reflection during which numerous individual problem solving processes take place. In modern constructions such as houses or airplanes thousands to millions of parts must find their place and functional relations to each other (Saariluoma 1990, 2002, 2003; Saariluoma and Maarttola in press). One of the core problems is, how should human mental activity be harmonized with the available technological possibilities?

Design is thinking, deciding and solving problems (Simon 1969). Normally it is carried out by a number of designers, a project, in which individual problem solving processes are serving the whole. They are integrated by the project management. There are numerous problem-solving operations of all kinds taking place sequentially and successively. In each stage, numerous decisions must be made about what to do and how to do it. These decisions are naturally an essential component of any design process. If just one serious mistake is made then the whole process is endangered.

A very good illustration of design risks is provided by the set of tanker accidents in the sixties. Several super tankers blew up. An investigation discovered that the design of the tankers had allowed for the development of small pockets of gas in their tanks. Oil itself is not very flammable but when the tanks were empty, they had small pockets of gas, which could explode when the tanks were washed. Even a small spark caused by a nylon shirt or a nylon rope could make them explode. A minimal detail in a huge whole was incorrectly designed and the outcome was an expensive series of accidents (Perrow 1999).

One may think that this example is unnecessarily dramatic. It is very unusual for such an event to take place. However, it is good to keep the example in mind and it serves as a reminder that the PC-interface is not the only kind of modern interface in existence. Professional interfaces must be designed for complex systems such as aircrafts, paper mills, cars, nuclear power stations and tankers. In addition, much of the computation is hidden from people, whose activities may depend on it. Consequently, there is no reason to underestimate the design risks in future interaction design.

Decreasing design risks in future computing presupposes that the fundaments of all designs are sufficiently well safeguarded against possible failures. A solution to these problems is to ensure that all the design solutions have rational foundations. Instead of intuitions they must be based on the best scientific knowledge we have about the human mind. It is not sufficient to rely on intuitions and introspections, instead there must be good grounds to decide between the design problems. Problems, which may entail serious risks, in particular, must be backed by scientific information about human behaviour. All the decisions must be evidence based.

Interaction design concerns human interaction with technical environments. Naturally, explanatory design presupposes under such restrictions both an understanding of the technology and of the principles of the human mind. Psychology, sociology and other fields of human research must be integrated with the knowledge we have about the possibilities that technology has for realizing human goals and needs.

However, before such integration is possible, it is good to have a look at the structure of modern psychology. This means that we have to have a clear empirical and theoretical idea about the relevant psychological processes in designing interaction environments and activities. This kind of psychology can be called user psychology. User psychology differs from usability testing in that it focuses on relevant knowledge about the user and implements this prior to design. (Oulasvirta and Saariluoma 2004; Niemelä 2003; Saariluoma and Sajaniemi 1989, 1994)

Investigating interaction from the user’s psychological point of view it is possible to shake some dogmatic ideas about the simplicity of the mind. One might think that it opens a single and unified discourse, which can be used to investigate and resolve problems of interaction design. Instead it provides several very different platforms. Indeed, we must ask whether liking and disliking a piece of technology is a similar problem type to being able to use that piece of technology smoothly.

## 2 Explanatory frameworks

Explanatory design must be based on the idea that the right problems are associated with the right kind of scientific knowledge. There are always alternative ways of explaining human behaviour and it is not a trivial question to ask what kind of problems can be resolved on what kind of explanatory grounds. If a child has reading difficulties, it is quite possible that the difficulties are neural in origin, but this is not necessarily so. A mistaken analysis of the situation may eventually lead to a poor outcome.

Interaction design naturally has numerous dimensions. Some of them can be physiological such as stress; some such as consistency of dialog can instead be connected to mental contents. This means that it is important to look at the field systematically. If there are some problems, which can be handled by means of physiological research and arguments and others, to which physiological grounds cannot be applied, it is necessary to find a conceptual way of unifying the right problems to the right system of scientific knowledge. Such conceptual construction is called an explanatory framework.

An explanatory framework means a system in which problems and required scientific knowledge are associated with solutions (Saariluoma 2002, 2003).

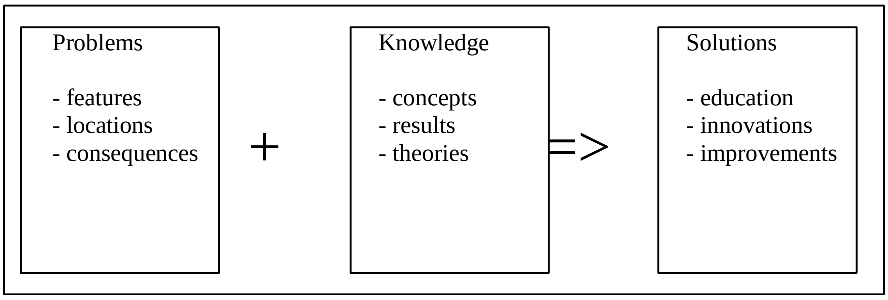

**Fig. 1.** Schematic structure of explanatory frameworks

An explanatory framework is a discourse in which one can use a unified system of scientific knowledge to explain and resolve some relevant problem.

This kind of framework allows the application of correct information to resolve definite problems. Both the problems and the frameworks vary. Nevertheless, there are not too many frameworks in psychology and this is why they allow the systematization of design planning. It is possible to evaluate in advance what type of explanatory framework must be used to resolve different kinds of problems.

To make the notion of explanatory framework more precise it is possible to eventually reduce the main explanatory frameworks down to two. They are biological and content-based explanations. These two cannot be eliminated or reduced. Capacity explanation, for example, can be reduced to biological systems (cf. Saariluoma 1990, 1995). However, it would be very unpractical to use only two explanatory grounds to discuss all problems. This is why it is better to use a more versatile system of language-games in psychological explaining.

Indeed, it is best to see explanatory frameworks as language-games (cf. Wittgenstein 1953). This means that there is a set of problems, which can be solved by means of capacity language. Its concepts and meanings are relatively accurate and unified. However, the language makes sense only in capacity-based explanatory contexts. Capacity language is meaningless when we talk about problems typical to content-based problems (Saariluoma 1997).

Some of the most important explanatory frameworks shall now be described. These are not the only possible explanatory frameworks, but they enable us to cope with many typical interaction problems. These frameworks are capacity, emotions, and mental contents. One could also discuss physiological and personality or social group-based explanations, but the frameworks presented here are certainly sufficient to demonstrate the nature of explanatory interaction design.

## 3 Capacity

Human performance is limited in several senses. People can only perceive a limited spectrum of physical energy and only hear around 10-20 000 HZ frequencies of sound. The visual angle is around 180 degrees but the sharpest information pick up is within one to three degrees (e.g. Goldstein 1996). Depending on the circumstances one can make only limited background-foreground discriminations and the systems of discriminative cues may vary substantially.

Somewhat different types of limitations are met in attention. Attention is a system, which selects the target or figure out of the background (Pashler 1998; Styles 1997). There are always millions of possible ways to segment perceptual reality and often numerous different messages reach our ears. Attention selects those messages, which are important. In this way, it allows the human mind to focus on important things.

The capacity of selection is normally one unit at a time (Broadbent 1958). It is possible to switch attention from one target to another relatively swiftly and thus follow two or more competing messages at a time (Pashler 1998). However, this kind of performance has its costs and is very risky. Consequently, it is argued that the capacity of human attention is around one unit (Broadbent 1958; Norman 1969).

There are several mechanisms, which allow people to circumvent the immediate attentional limits under certain conditions. Task switching, which was described above is one such mechanism. (Pashler 1998). Another important mechanism is automatisation (Shiffrin 1988; Underwood and Everatt 1996). If people repeatedly carry out the same task in similar circumstances the speed and efficiency began to improve. The activities require less cognitive load and they are basically effortless. Often the performance is not conscious. For these reasons, it is possible to carry out automatic tasks simultaneously with a more controlled main task. In fact, our performance is normally composed of a mixture of automatic and controlled parts. However, the existence of automatisation does not change the fact that human attentional capacity is limited. It only allows us to circumvent the limits.

Attention can ultimately be seen as a process of information collection. During the attentive process, target information is defined, and after that it is perceptually completed. Any target object has numerous dimensions such as location, form, color, kind, close environment, movement, size etc. An attention task presupposes that at least one of the required dimensions is open or unfamiliar to the attending person and that there exists at least one criterion on which the target or targets can be discriminated from the background objects. Attentional learning naturally means that people get information, which helps them either to segregate the target from the background or to identify it or to predict its location. This kind of holistic interpretation of attention can be called apperceptive attention.

An additional form of capacity limitation is working memory. We cannot hold more than four to seven independent units in our minds at the same time (Atkinson and Shiffrin 1968). This seriously limits, for example, human thought processes (Anderson et al. 1984; Covan 2000; Johnson-Laird 1983). It is not possible to build up a very complex representation of new items and this is why something is easily forgotten.

It has also been very well demonstrated that working memory has subsystems and that the capacity of these subsystems is also limited (Baddeley 1986; Baddeley and Hitch 1974; Logie 1995). Visuo-spatial and auditory subsystems cannot carry out two simultaneous tasks effectively in same modality. Though the systems are to some degree safeguarded against interference inference caused by secondary tasks on the other module, within module interference is a serious problem.

There are cognitive mechanisms, which enable people to chunk information (Covan 2000; Miller 1956). Miller’s (1956) famous limit concerned the number of chunks of information but made no comment on the size of the chunks. It is possible to have huge chunks of information (Ericsson and Kintsch 1995). Blindfolded chess players keep in their minds thousands of piece locations and taxi drivers know the street maps of huge cities off by heart. (Kalakoski and Saariluoma 2001; Saariluoma 1991; Saariluoma and Kalakoski 1997, 1998). It is also well-known that people store information in long-term working memory, where it suffers far less interference from secondary tasks.

Nevertheless, working memory is a serious limitation to human information processing capacity and it can be empirically demonstrated that working memory really limits design thinking (Anderson et al. 1984; Kavakli and Gero 2003). The limits of this system can all too easily be surpassed and this may cause severe performance risks. Therefore, it is necessary to avoid all too demanding interaction tasks and design interfaces so that the problems can be avoided.

These examples are not the only capacity limits in the human mind, but they do give a good idea of what capacity-based explaining can mean. It is necessary to ensure that interaction with an interface does not surpass the available capacity. This is difficult because it is possible that even external conditions such as noise, interruptions or additional tasks may cause people to accidentally surpass the limits. In these cases the risk of errors naturally rises and this is why interaction should always ensure some redundancy.

Explaining by capacity is sensible, when it is possible to show that the environment is too complex for the thinking limits of human information processing system. The key sign for capacity problems are errors caused by complexity. Naturally, the main way of reacting is to reduce the complexity. This can be done either by redesigning the interface or by improving the skills of the personnel.

## 4 Capacity and interaction

Forgetting a currently active navigation route or an important command in constructing command lines are typical examples of the problems which capacity may cause interaction design. Many lapses of attention and memory can be avoided if the designers understand the importance of limited capacity. It is distressing for a cognitive engineer to observe that a person wishing to purchase a ticket has to push tens of keys to get a machine to print one ticket. This can be found even in stations with only one or two main destinations. Such a system is difficult to learn to use and leads to wasted time and frustration.

The psychological notion of capacity must be transformed into a design plan. Answers to “why”-questions must be changed into “how”-questions. Psychological knowledge must be applied to understanding design problems. This is the very core idea of explanatory design. It may be useful at this point to present some illustrative examples. Image quality in screens and other displays is important, because it affects readability and communicability. Luminance, contrast, flicker, colors and character design are essentially design attributes, which are ultimately based on human perceptual capacity, discrimination threshold and attentional discrimination phenomena (e.g. Snyder 1988). This family of problems has recently received much attention, as web-page design has become an important theme (cf. Nielsen 1993; Nielsen and Tahir 2002).

Another perspective to capacity is provided by memory. Early studies on programmers illustrated that working memory capacity is an important interaction problem (Anderson et al. 1984, Broadbent 1975). Similarly it has been shown that designers have substantial problems with working memory limits (Kavakli and Gero 2003). The immediate memory capacity problems can also be seen in visual information chunking. The form of display presentation is essential for good recall and navigation. Saariluoma and Sajaniemi (1989, 1991) demonstrated that spreadsheet-users utilize the visible forms of numeric information to learn and remember the systems of cell reference of the non-visible functions and calculations. Finally, it can also be shown that people use mental images in making interaction easier.

## 5 Emotions

Emotions provide us with a clearly different system of explanatory grounds compared to those of capacity. Emotions, for example, have contents so that it is possible to talk about positive and negative emotions, for example, while capacity is minimally emotion-based. We can fill our working memory with any imaginable emotional contents as long as the load caused by the representation does not exceed its limits. It does not really make much difference whether our working memory stores likes or dislikes, though, of course, this difference is essential from the point of view of emotions. For this reason, one cannot really effectively explain issues of emotional contents on the grounds of cognitive capacity (Saariluoma 1997, 2002).

There is very little doubt about the importance of emotions in interaction design (Norman 2004). It is an emotional issue whether one likes an interface and a specific interaction model. User acceptance and marketing dimensions such as branding are essentially very emotional issues. This is why, one cannot disregard knowledge about emotions, when discussing future interaction design.

It is not possible here to consider all aspects of human emotions. Less interesting and important themes such as the length of emotional states or their strength must be neglected here. Instead, attention shall be paid to the contents of emotions. Emotions are activated by a cognitive analysis of the situation (Power and Dalgleish 1997). This can be called appraisal. It is an essential process in investigating the activation of emotional states. Our emotions are reactions to prevailing situations and before we know what a situation is we have to be able to make a cognitive analysis of it. We do not know whether there is a dangerous animal around, unless we have noticed it (Lazarus 1999, Power and Dalgleish 1997). It is also possible to influence emotions by influencing cognitions (e.g. Beck 1976).

Emotional contents can be divided into two components. Firstly, there emotional valence. Emotions normally exist in positive vs. negative pairs. Typical examples could be relief and angst, joy and sorrow or trust and mistrust. Valence is naturally very important, because we avoid unpleasant emotions and pursue pleasant ones.

A more complicated explanatory ground is provided by emotional theme. The theme is the characteristic, which separates different emotions from each other. Joy is different from grief and consequently they have different theme. It is necessary to understand the nature of important emotions in order to be able to use emotions in interaction design. Depending on the type of interaction, we might pursue very different emotional themes. In computer gaming, for example, fear and excitement might be very important but in computer programming these themes might be more harmful than useful.

Investigating emotions and using emotional explanations in interaction design is important for a number of reasons. Perhaps, the most important is the close connection of emotions to motives and the role of emotions in determining the importance of issues to oneself. Emotions are important in motivation for the reason that emotions convey information about our needs (Franken 2000). If we are hungry then we feel uncomfortable. Naturally, these connections have an important role in motivating our immediate actions.

Finally, emotions are always important when we evaluate the importance of objects, issues, people or events. Emotions tell us what is important. This is why the emotional dimensions of interfaces are so important. Unless designers are able to effectively cope with emotions, the risks of design errors and failures increases.

## 6 Emotions and design

Many people still remember an old advert in which a Chaplin-like figure interacted with computers. This was in the early days of computers when most users were novices. Chaplin who is a symbol of fumbling yet prevailing was a very insightful choice of symbol for novice PC users. The advert referred to difficulties, positive humor and solving problems. In this advert emotions were notably important.

Our example is close to one of the major negative emotions in practical interaction design. This is user-frustration. Interfaces which are too complex or which have slow interaction speeds easily lead to user-frustration (Preece et al. 2002). The main reason to call attention to user frustration is to illustrate that emotional design is a practical necessity. Emotions have a role in interaction design whether we want them to or not.

A typical example of applying the psychology of emotions to interaction design is to analyze, how the acceptability of products correlates with personality traits. This information can then be applied to the interface and usability design (Jacoby et al. 1998). A somewhat more complex example of emotion and personality based interaction design is the so called “brand personality” (e.g. Aaker 1997). It has been noticed that a brand may enable consumers to express their personalities, i.e., emotional patterns. Consequently, products can be designed for certain types of personalities (see e.g. Iacocca 1984, for the design of Ford Mustang).

In practical design, it is possible for example, to show consumer products to people and to investigate how their emotional or personality traits explain their relations to some definable features (Bruseberg and Macdonagh-Philip 2001). This kind of activity can be called emotion or personality profiling. It can be used, for example, to find justifications for design solutions.

These examples illustrate very well the nature of emotional design. In a holistic sense it is very closely associated with personality and product communication. Marketing and design are essential in creating emotional atmosphere around a product. It is meant to provide feelings for users. The closer these feelings are to the user’s emotional value system and personality, the better.

## 7 Apperception and mental contents

Despite their fundamental role in human action emotions have their limits as an explanatory framework. They cannot really represent important cognitive contents. We can cognitively categorize our environment in a much more detailed manner than we can emotionally categorize our environment. There is no substantial emotional difference, for example, between keyboards and screens. This is why we have to investigate mental contents in representations.

When the topic is the interface, it seems natural to assume that perceptual information is highly important. Indeed, it is important, but it is hardly the core process in constructing mental representations (Saariluoma 1990, 1995, 2001). We have numerous important non-perceivable content elements in mental representations. We talk, for example, about possible and impossible, files and storage, past and future, infinite and eternal. We also talk about laws, standards and regulations. In general, such things are non-perceivable and we cannot, even in principle, have their representations on our retina. For these reasons, it is important to draw a distinction between perception and apperception.

Apperceiving means “seeing something as something”. This means the ability to give a meaning to an object instead of just perceiving the object. We can listen to an unfamiliar language without understanding a word. This means that we hear what is said but we do not understand it. Understanding is one kind of apperceptive process. Similarly, apperceptive processes are, for example, comprehending or apprehending. The key characteristic of apperception is that it constructs both conscious and subconscious parts of mental representations (Saariluoma 1990, 1992, 2001, 2003; Saariluoma and Kalakoski 1997, 1998). This is why the concept of apperception, which has been widely used over the last four hundred years is very helpful in the discussion about the construction of mental representations (Kant 1787/1985; Leibniz 1704; Stout 1890; Wundt 1913).

Working with apperception is content-based by nature. This means that apperception research works to answer problems, which can be explained by mental contents (Saariluoma 2003). Obviously, mental content is a rational ground to explain human behavior. If I ask somebody, why he or she is going in that direction and he or she answers, because I can buy a computer there, then there is nothing strange in explaining his or her behavior on the grounds of mental content.

Of course, the above example is not very exiting, but there are much more important phenomena, in which the content-based approach is relevant. It can be shown, for example, that mental representations have a property, which can be termed functionality. This means that all elements in representations make sense or are senseful (Saariluoma 1990; Saariluoma and Maarttola in press). Functionality means that there is always a reason why any element is incorporated into a representation. In the computer, we have a keyboard to input information and a screen to provide visual output. We use graphical interfaces, to decrease memory load. Similarly, all human constructions are knit together by networks of reason and this is why they make sense. Naturally, such schema of functions or functional reasons is a content-element in mental representations.

The phenomenon of sensefulness has many consequences in interaction design. Firstly, the elements of interfaces and human actions normally make sense. We know why we use buttons or why we use a command language in constructing an interaction. We should also know why people in a shopping centre move as they do to provide themselves with effective e-computing services. A presupposition for understanding what people think and do, is the analysis and opening of the hidden functional schemata (Saariluoma 1990; Saariluoma and Maarttola in press).

Secondly, these rules are important in investigating the phenomena of consistency and coherence (Saariluoma and Maarttola in press). If we use blue to visualize high temperatures, we certainly are in contradiction with cultural conventions. If we print install on the screen, when the machine is actually removing programs, we violate the norms of semantic coherence. All questions of this kind type implicate sensefulness and an investigation into mental contents.

Mental contents again provide a new type of explanatory framework for interaction design (Saariluoma 2003). We cannot reduce these concepts and discourses into capacity nor can we effectively express typical capacity phenomena in terms of mental contents. Naturally, the phenomenon of functional schemata is one of the many types of mental contents, which may have an explanatory value.

The example should be sufficient to illustrate that one can build around mental contents an explanatory framework. There are psychologically relevant phenomena, which can best be explained in terms of mental contents. They are determined content phenomena on which one can ground content-based explaining. This is common in clinical psychology, but it is increasingly more evident in many phenomena related to thinking, for example, presupposed content-based thinking. It is important to develop this discourse because it provides new possibilities for explanatory interaction design in future.

## 8 Applying apperception – experience design

Designing the interaction contents is naturally one of the most important aspects of design. It is all too easy to make concept-explainable errors. Missing one’s way in the jungle of cultural differences is a typical example of such errors. Illustrations, which look nice in Finland such as those of forests and lakes may nevertheless give a very different message in United States and signify a country’s underdevelopment rather than its dynamism. As more firms increasingly operate via the WWW, these relatively common problems take on an important role.

Visual design is another practical example. At first glance, visualization, for example, may be a pictorial and perceptual issue, but this is an oversimplification. Visualization is important because it improves conceptual communication (Brown et al. 1995; Tufte 1983, 1990, 1997). This is evident when the issues, which are visualized, are very often non-perceivable. The temperatures in different parts of an engine or the issues of population distributions, for example, are not genuinely perceptual issues. Visualization makes them understandable, but this does not mean that visualization would not be perceptual they are apperception related problems rather than perceptual.

Interfaces for machine and architectural design may serve as an additional example of apperception and thinking related problems. In them, thought models and other content-based explanatory concepts are important (Saariluoma 1990, 2003; Wills and Sanders 2000). In designing professional software, content-based concepts are vital, but there are numerous standard problems as well which can be resolved by applying such theoretical devices as apperception and content-based research (Saariluoma and Maarttola in press).

## 9 Creativity and explanatory design

One may naturally think that explanatory design scheme bounds creativity. It seems to be going against free innovation to think that one must base one's ideas on an explanatory schema. This is a misunderstanding in two senses. Firstly, it neglects the necessity of basing design on a scientific understanding of the world and secondly, it entails a simplified view of creativity.

Free creativity cannot neglect the laws of nature and the mind. This is why it is important to ground one's ideas in scientific knowledge. It entails the least risks and makes it possible to construct the intended solutions in real life. This is why explanatory creativity is so important.

Another misunderstanding concerning creativity is also very common. Creativity is very often seen as free-associating. Brainstorming and tests such as "uses" are typical examples of the divergent notion of creativity (Guilford 1950; Stern-berg). However, empirical research has shown that creativity seldom works in its divergent form (Weisberg 1986, 1993). This is why Saariluoma (1997) wanted to establish a convergent form of creativity called foundational analysis.

In foundational analysis, people concentrate on analyzing explicit and implicit assumptions of the existent objects and work to restructure them. The idea is to found an unfound intuitive, i.e., implicit, or explicit, theoretical presupposition, which is not valid and by means of replacing the weakness with another, improved one. Creativity in this sense is analytic thinking rather than free-associating.

Of course the reconstructed ideas need not be small. In classic philosophy, for example, the very explanatory principle was always reconstructed. The principle of all explanation such as water or fire was replaced by some other principle (Zeller 1899). This means that there is no limit to the ideas, which can be reconstructed, if the reconstruction can be justified.

Naturally, explanatory design is a notion, which effectively serves convergent creativity. By means of analyzing the arguments and reasons used to justify some design solution, it is possible to find problems and argumentatively resolve them. For example, the graphic interface replaced the symbolic because it provided better memory support for beginners. The true grounds were psychological and they also proved to be correct.

## 10 Conclusions

In this paper, I have outlined some principles for explanatory interaction design. By this kind of design I mean that design decisions are based on various explanatory frameworks. In the ideal of explanatory design, one must look for solutions, which can be explained on the ground of scientific knowledge and from the explanatory point of view the more well argued the design decisions the better the design.

Instead of a unified psychological argumentation, we have different frameworks, which can be used to solve very different types of design questions.

Three examples, capacity, emotions and mental contents have been discussed in this pa-per. These frameworks are not exhaustive but they do enable the point regarding explanatory design to be made clearly. Our scientific languages are limited in their power of expression. There is no possible way to use capacity based argumentation in solving content-originated problems. We can fill our attention or working memory with information of any contents, as long as the capacity is not limited (Saariluoma 1997, 2003). This is why it is impossible to use capacity explanations to solve problems of mental contents. Nor can capacity language help us with essentially emotional problems. Limited working memory capacity does not have much value when we work to understand why clients do not feel that an interface is emotionally intriguing.

Putting these two main lines together the paper has outlined a metascientific framework for future interaction design. It should be based on natural scientific and human knowledge, design decisions should be based on explanations and explanations should be grounded on suitable explanatory frameworks.

## References

Aaker JL (1997) Dimensions of brand personality. J Journal of marketing research 34:347-357

Anderson JR, Farrell R, Sauers R (1984) Learning to program lisp. Cog Sci 8:87-129

Atkinson R, Shiffrin R (1968) Human memory: A proposed system. In: Spence KW, Spence JT (eds) The Psychology of Learning and Motivation, vol 2. Academic Press, New York, pp 89-195

Beck A (1976) Cognitive therapy of emotional disorders. Penguin Books, Harmondsworth

Baddeley AD (1986) Working memory. Oxford University Press, Oxford

Baddeley AD, Hitch G (1974) Working memory. In: Bower G (ed) The Psychology of Learning and Motivation, vol. 8. Academic Press, New York, pp 47-89

Broadbent D (1958) Perception and Communication. Pergamon Press, London

Broadbent D (1975) The magic number seven after twenty years. In: Kennedy R, Wilkes A (eds) Studies in Long Term Memory. Wiley, New York, pp 253-287

Brown, JR, Earnshaw, R, Jern, M, Vince, J (1995) Visualization. Wiley, New York.

Bruseberg A, Macdonagh-Philip D (2001) New product development by eliciting user experience and aspirations. J International Journal of Human-Computer Studies 55:435-452

Carroll JM (1997) Human computer interaction: psychology as science of design. Annual Review of Psychology 48:61-83

Covan N (2000) The magical number four in short term memory: A reconsideration of mental storage capacity. J Behavioural and Brain Sciences 24:87-185

Ericsson KA, Kintsch W (1995) Long-term working memory. J Psychological Review 102:211-245

Goldstein B (1996) Sensation and perception. Brooks & Cole, Belmont, CA

Guilford JP (1950) Creativity. J American Psychologist 5:444-454

Hempel C (1965) Aspects of scientific explanation and other essays in the philosophy of science. Free Press, New York

Iacocca L (1984) Autoelämänkerta. [car autobiography, in Finnish]. WSOY, Porvoo

Jacoby J, Johar G, Morrin M (1998) Consumer behaviour. J Annual Review of Psychology 49:319-344

Johnson-Laird P (1983) Mental models: Towards a Cognitive Science of Language, Inference, and Consciousness. Mass, Harvard University Press, Cambridge

Kalakoski V, Saariluoma P (2001) Taxi drivers’ exceptional memory for street names. J Memory & Cognition 29:634-638

Kant I (1787/1985) Kritik der Reinen Vernunft. Philip Reclam, Stuttgart

Kavakli M, Gero JS (2003) Strategic knowledge differences between an expert and a novice designer. In: Lindeman U (ed) Human behaviour in design: Individuals, teams, tools. Springer, Berlin

Lazarus RS (1999) Stress and emotion – a new synthesis. Free association books, London

Leibniz G (1704) New essays on human understanding. Cambridge University Press, Cambridge

Logie R (1995) Visuo-spatial working memory. Erlbaum, Hove

Miller GE (1956) The magical number seven plus or minus two: Some limits on our capacity for processing information. J Psychological Review 63:81-97

Nickerson RS, Landauer TK (1997) Human-computer interaction: Backgrounds and Issues. In: Helander M, Ladauer TK, Pradhu PV (eds) Handbook of human-computer interaction. Elsevier, Amsterdam

Nielsen J (1993) Usability engineering. Academic press, New York

Nielsen J, Tahir M (2002) Kotisivun suunittelu [Homepage usability: 50 websites demonstrated] [In Finnish] Edita, Helsinki

Niemelä M (2003) Visual search in graphic interfaces: A user psychological approach. Jyväskylä studies in computing 34. Jyväskylä University Printing House, Jyväskylä

Norman D (1969) Memory and attention. Wiley, Oxford

Norman D (2004) Emotional design. Basic Books, New York

Oulasvirta A, Saariluoma P (2004) Long-term working memory and interrupting messages in human-computer interaction. J Behaviour & Information Technology 23:53-64

Pahl G, Beitz W (1989) Konstruktionslehre. (in Finnish). MET, Porvoo

Pashler H (1998) The psychology of attention. MIT-press, Cambridge Mass

Perrow C (1999) Normal accidents: Living with high-risk technologies. Princeton University Press, Princeton

Power M, Dalgleish T (1997) Cognition and emotion. From order to disorder. Hove, Psychology Press

Preece J, Rogers Y, Sharp H (2002) Interaction design. Wiley, New York

Reason J (1990) Human error. Cambridge University Press, Cambridge

Saariluoma P (1990) Apperception and restructuring in chess players' problem solving. In: Gilhooly KJ, Keane MTG, Logie RH, Erdos G (eds) Lines of thought: reflections on the psychology of thinking. Wiley, London, pp 41-57

Saariluoma P (1991) Aspects of skilled imagery in blindfold chess. J Acta Psychologica 77:65-89

Saariluoma P (1992) Error in chess: Apperception restructuring view. J Psychol Res 54:17-26

Saariluoma P (1995) Chess players' thinking. Routledge, London

Saariluoma P (1997) Foundational analysis: presuppositions in experimental psychology. Routledge, London

Saariluoma P (2001) Chess and content oriented psychology of thinking. J Psihologica 22:143-164
Saariluoma P (2002) Thinking in work life: from errors to opportunities. (in Finnish). WSOY, Porvoo
Saariluoma P (2003) Apperception, content-based psychology and design. In: Lindeman U (ed) Human behavior in design. Springer, Berlin
Saariluoma P, Kalakoski V (1997) Skilled imagery and long-term working memory. J American Journal of Psychology 110:177-201
Saariluoma P, Kalakoski P (1998) Apperception and imagery in blindfold chess. J Memory 6:67-90
Saariluoma P, Maarttola I (in press) Stumbling blocks in novice architectural design. J Journal of Architectural and Planning Research
Saariluoma P, Sajaniemi J (1989) Visual information chunking in spreadsheet calculation. J International Journal of Man-Machine Studies 30:475-488
Saariluoma P, Sajaniemi J (1991) Extracting implicit tree structures in spreadsheet calculation. Ergonomics: Special Issue: Cognitive Ergonimics, 34:1027-1046
Saariluoma P, Sajaniemi J (1994) Trasforming verbal descriptions into mathematical formulas in spreadsheet calculations. J International Journal of Human-Computer Stud-ies 421:915-948
Shiffrin RM (1988) Attention. In: Atkinson RC, Herrnstein RJ, Lindzey G, Luce RD (eds) Stevens' Handbook of Experimental Psychology, vol 2: Learning and Cognition. Wiley, New York, pp 731-811
Simon HA (1969) The sciences of artificial. MIT-Press, Cambridge, Mass
Stout GF (1890) Analytical psychology. MacMillan, London
Styles E (1997) The psychology of attention. Psychology Press, Hove
Tufte ER (1983) The visual display of quantitative information. Graphics Press, Cheshire
Tufte ER (1990) Envisioning information. Graphics Press, Cheshire
Tufte ER (1997) Visual explanation. Graphics Press, Cheshire
Underwood G, Everatt J (1996) Automatic and controlled information processing: The role of attention in processing novelty. In: Neuman O, Sanders AF (eds) Handbook of perception and action 3. Attention. Academic press, London
Wills F, Sanders D (2000) Cognitive therapy: transforming the image. Sage, London
Wittgenstein L (1953) Philosophical investigations. Basil Blackwell, Oxford
Wundt W (1913) Grundriss der Psychologie. Kröner, Stuttgart