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Pär-Anders Albinsson, Jens Alfredson

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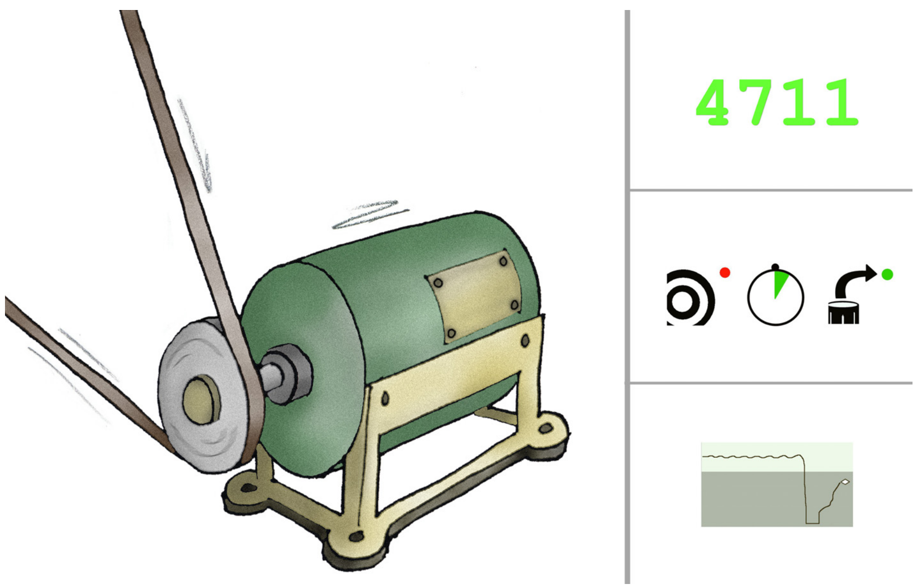

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Report title

Reflections on Practical Representation Design

Abstract (not more than 200 words)

Many systems of today show an increase in complexity. Especially large socio-technical systems are in need of methods and techniques for designing and developing efficient and usable solutions. This report takes a look at representation design—an approach to tackle inherent problems of system design. After presenting the basic theory, a practical approach for representation design is discussed. Two central issues are reflected upon in more detail in separate chapters. Firstly, the concept of frames of reference is brought up using concrete examples. Secondly, examples of the use of different forms of reference are looked upon. Two chapters discuss the concepts of searching, browsing and neighbourhoods and the relations between display design and representation design.

Keywords

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Representationsdesign i praktiken - några reflektioner

Sammanfattning (högst 200 ord)

Många system idag ökar i komplexitet. Stora system där människan är en central del är i behov av metoder och teknik för att designa och utveckla effektiva och användbara lösningar. Denna rapport tittar på representationsdesign – ett angreppssätt som försöker komma åt dessa problem. Efter en presentation av den grundläggande teorin diskuteras en praktisk ansats av representationsdesign. Två centrala delar reflekteras över i mer detalj – referensramar och referensformer. Exempel belyser innebörden av dessa begrepp. Två kapitel tar upp användandet av metaforer för navigation och sökning, samt hur displaydesign relaterar till representationsdesign.

Nyckelord

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Abstract

Many systems of today show an increase in complexity. Especially large socio-technical systems are in need of methods and techniques for designing and developing efficient and usable solutions. This report takes a look at **representation design***—an approach to tackle inherent problems of system design. After presenting the basic theory, a practical approach for representation design is discussed. Two central issues are reflected upon in more detail in separate chapters. Firstly, the concept of frames of reference is brought up using concrete examples. Secondly, examples of the use of different forms of reference are looked upon. Two chapters discuss the concepts of searching, browsing and neighbourhoods and the relations between display design and representation design.*

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1. Introduction

There is an increase in complexity of systems of today. Methods and techniques for designing and developing large socio-technical systems are increasingly important to produce efficient and usable solutions. In later years attempts have been made to address this matter, through a variety of approaches, such as user centered design, usability engineering, ecological interface design and many others.

Depending on how a situation is represented different means for interpreting and solving problems emerge. Severe consequences in distributed, safety-critical human activities often arise from problematic interaction between humans and systems. The ongoing development towards network centric warfare is one example of a process dealing with complex socio-technical systems where misunderstandings and mishaps can lead to severe consequences. Computer support systems must provide good representations of the reality and the inherent tasks to offer the efficiency improvement both regarding performance and lifecycle cost that they are indented for.

Even though the strive for being able to present certain phenomenas of the environment in a particular way has been present before, it is with the advent of advanced computer technology that the possibilities emerge. These new possibilities also give insights for the need of developing design methods suitable for coping with the grand demands of modern contexts.

The purpose of this work is to present and reflect upon an approach that considers the complex conditions of many systems of today. The approach is called *representation design* and this report will present the basic underlying theory, some illustrative examples and reflections on practical applications.

The report first introduces theoretical aspects of the basic ideas of representation design. Then follows two chapters covering the important parts *Frames of Reference* and *Forms of Reference*, presented by comparing hypothetical design solutions. A discussion about metaphors for *searching, browsing and neighborhoods* then brings up the differences between their use in reality and their representations in a medium. The relation between the term *display design and representation design* is thereafter discussed. A short conclusion completes the report.

2. Representation Design

There are several ways to define representation design. Influenced by Woods (1995) representation design could be described as the practice of designing marks in a medium to accurately portray relevant properties in the world. Stressing the importance of relations, change and higher-level properties representation design could be regarded as being about designing the relations between tokens in the presentational medium and structures and dynamics of the represented ("real world") domain.

The main effect of successful representation design is that it changes the nature of the problem:

> "*…things can make us smart, and things can make us dumb*" (Norman, 1998).

> "*… solving a problem simply means representing it so as to make the solution transparent*" (Simon, 1996).

Woods (1995) describes two challenges for successful representation design: The first considers finding the important real-world properties and real-world relations that are informative given the goals and context of the involved practitioners, and the second is the challenge of setting up the mapping between the real-world and the medium for representation in such a way that observers can extract the intended information. Cognitive task analysis (Schraagen et al., 2000) is one method of many others suited for tackling the first challenge. The gap between the two parts is a challenge in itself and has been addressed by several researchers (e.g. Potter et al., 2002).

Even though these two main challenges are parallel and iterative this paper will address the latter one, sometimes referred to as the *decoding problem* (Becker & Cleveland, 1987).

2.1. Basic Principles

How do we set about in practise to confront the decoding problem? Woods and colleagues (Woods, draft; Woods, 1995; Woods et al., 1996) present basic principles of representation design:

- **Find suitable frames of reference.** The first step is to find frames of reference that allow expression of the relevant relations between data. By using different frames of reference, different problems can be found (e.g. showing pilots' heart rates over time or spatially on a map).
- **Put data into context.** Within the frames of reference the represented data should be put into the context of related values. Provide landmarks in the frames of reference, representing significant real world circumstances (e.g. show safe/unsafe bounds or predicted value ranges for heart rates in different situations or locations).
- **Highlight significance.** When the real world object/process/etc. changes, the representation of these patterns of behaviour should support highlighting of interesting events, changes and contrasting values (e.g. heart rate drifting out of 'safe' bounds or pilots having unusual values, contrasting the others).

If the design succeeds to follow these principles properties will be emergent – they are more than the sum of the properties of the parts they are built up of.

2.2. Effects

Effects of representation design will here be brought up again in more detail. Representation design affects (Woods, 1995; Woods, draft):

- **Structure of problems**. Depending on the representation the observer will be able to see 'other sides' of the problems allowing different approaches to be used. Within information visualisation (that has a lot in common with representation design) advantages often mentioned are (e.g. Ware, 2000): that you can present data you know you need for your task, that you can present data in a way that conveys information you did not know would be important for your task, and that you can present data so problems with the underlying data itself are revealed.

- **Overload**. Good representation design will direct cognitive actions to be more parallel, 'naturally perceptual' and less 'in the head'.
- **Attention**. By coding important properties using appropriate visual variables processing will be of more pre-attentive nature.
- **Secondary tasks**. Navigation, exploration, browsing and searching are all metaphors used widely within HCI and interface design. A bad representation design will lead users to put too much focus on navigation elements and thereby less focus on the primary tasks.

2.3. Semiotics

Knowing basic principles and effects of representation design, it is interesting to explore practical means for reaching good designs. One area to look into first is the study of signs, semiotics.

Anything that refers to or stands for something else than itself is a sign (Chandler, 2002). Peirce (in Chandler, 2002) puts it: "Nothing is a sign unless it is interpreted as a sign". Peirce and Saussure are the two main names in this area (Chandler, 2002). Saussure describes a sign in a two-part model to consist of a 'signifier' and the 'signified' – the form which the sign takes and the concept it represents. A sign cannot exist without these both parts; if one is changed it is not the same sign anymore. For Saussure both terms were 'psychological' rather than physical (thus involving the interpreter or observer or user): The *signifier* is not concerning physical form but rather an observer's psychological impression of something through his senses. Saussure's *signified* is not to be directly connected with 'an object' in the world, but a *concept* in the mind. Furthermore, according to Saussurean semioticians there is no necessary intrinsic relation between signifier and the signified; it is arbitrary. Nowadays the model tends to be more materialistically interpreted than Saussure's original ideas (Chandler, 2002).

Peirce's view is more pragmatic and concerns both the real world and the interpreter's sense of the sign. The model is triadic and comprises:

- **Representamen**. The (not necessarily physical) form of the sign.
- **Interpretant**. The sense made of the sign in the observer's mind.
- **Object**. The 'something' that the sign stands for.

A sign in the form of a *representamen* is something which stands for something in some respect or capacity to somebody. In the mind of this somebody an equivalent or perhaps more developed sign is created, the *interpretant* of the initial sign. The sign stands for its *object*, not in all respects, but on some grounds (Chandler, 2002).

The triad of Peirce is often presented using more familiar terms than the original ones. Figure 1 shows a common variant (Chandler, 2002; Fiske, 1982). Here 'sign vehicle' is the form of the sign (representamen), 'sense' is the sense made of the sign (interpretant) and 'referent' is what the sign stands for (object). The dashed line at the base indicates that there is no necessary direct relation between the sign vehicle and the referent.

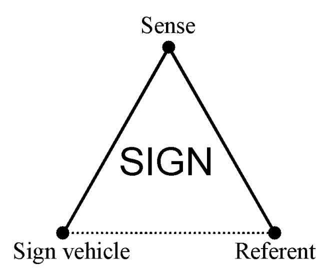

Figure 1. 'The' semiotic triangle.

Even if Saussure did not emphasize on relations between the signified (similar to the interpretant) and the signifier (similar to the representamen) his term *motivation* is used to describe the extent to which the signified determines the signifier. The more a signifier is constrained by the signified, the more motivated the sign is. Peirce went 'further' and classified three different modes of relation between the sign (meaning the representamen) and the object.

- **Symbolic**. The sign does not resemble the object in any way – forcing the relation to be learned. It is arbitrary or purely conventional (e.g. alphabetical letters, numbers).
- **Iconic**. The sign resembles or imitates the object for some senses (e.g. a moose warning traffic sign, a kid pointing and shouting "blam!").
- **Indexical**. The sign is directly connected to the object, not only by resemblance. Peirce suggests that unlike the icon, the index has a dynamical connection to the object. Examples are: a gesture showing someone how to carry out a certain action, a trail of bird footprints in the snow.

Using Saussure's term motivation a symbolic sign would be unmotivated and an iconic highly motivated. It is hard to find pure examples of these different types of signs, because there are no pure signs. A sign can be more or less of each type, depending on both point of time, observer and context. There are many different views on these issues, and trying to reach a consensus is therefore not trivial.

Another distinction sometimes made is between *digital* and *analogical* signs. Digital signs involve discrete units, such as integers and words. They tend to tell you just one thing at a time, and nothing more, though often precisely. Apparently digital signs are often symbolic (integers and words) but there are also iconic examples: a sign showing a plate with waves over it that is lit when a plate on a stove is hot. Analogical signs, however, involve graded relations between tokens on a continuum. This makes a more parallel approach possible, showing more than just a state or number. Hence something will always be lost when going from analogical to digital signs (Chandler, 2002; Woods, 1995).

The connection between semiotics and representation design is clear, and will be elaborated further.

2.4. The Symbol Mapping Principle

The two different views of how to model signs within semiotics give insight in another model (Woods, 1995) called the Symbol Mapping Principle (SMP). It has been implicitly touched upon earlier in this chapter, but now it will be related to semiotics and linked to the discussion about practical representation design.

The SMP comprises aspects of the real world objects and processes, the representations of these real world properties, and the observers 'using' these representations. 'Marks in the medium' are sign vehicles for referents in the domain, and the observers are the receivers of their interpretants. Figure 2 depicts the SMP and points at the two parts of representation design; *what* should be represented and *how* it should represent.

Much like Peirce's classification of signs, Woods (1991, 1995, draft) discusses three forms of reference:

- **Propositional**. Much like the symbolic type of signs: arbitrary or purely conventional relation to the referent.
- **Iconic**. Similar to Peirce's iconical signs: the marks in the medium *resemble* their referents.
- **Analogue**. The last form of reference is similar to the analogical signs: the *structure and behaviour* of marks in the medium are directly connected to *structure and behaviour* of the referents.

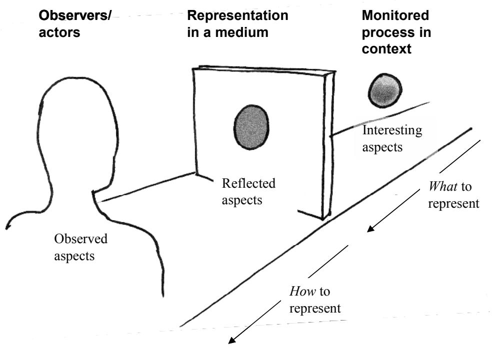

Figure 2. The Symbol Mapping Principle. Authors' interpretation from Woods (1995).

2.5. Design

Design has been described in many ways (HMI702, 2001; Howard, 2002): balance between playing and responsible critique, dialogue with the paper, switching focus between problem and solution, thinking by drawing, thinking by doing, telling stories about the future, etc. Cross (1992) presents some aspects of design:

Ill-defined problems. "Our job is to give the [client], not what he wants, but what he never dreamed he wanted; and when he gets it, he recognizes it as something he wanted all the time." (Denys Lasdun, as cited in Cross, 1992). This could be seen as if the designer acts from above providing divine solutions to simple mortals, but also – and hopefully more truly – as a view that the problem is ill-defined therefore forcing the designer to go beyond it. The solution does not 'appear' just by starting out from the problem and taking steps forward to a predestined goal, rather it is a gradual understanding of both the problem and solutions that develops during the process.

Problem structuring. That the problem cannot be solved simply by collecting and synthesising information has been observed when designers add information to the problem to reach a solution. Designers tend to try out one solution very early, and use it to explore the problem and defining the problem and solution together.

Goals and constraints. Designers study their solutions to see if they can be confirmed rather than refuted. Instead of finding what general attributes and elements should be in a solution and then work with that, they tend to stick to early solutions and determine their qualities. Goals and constraints are changed during solution generation as the understanding of the problem develops.

Solution concepts. Though the designer changes the goals and constraints during the process, the main concept for (an imagined) solution is kept for as long as possible. It can be seen as if the designer has to change the goals because the main concept is flawed, or as a learning experience for the designer, struggling with ill-defined problems.

Thinking by drawing. By drawing the designer shapes the situation according to his initial understanding of the problem and the illustrated situation feedbacks for the designer to respond to.

Bernstein (1988) explains some problematic views of designers' roles. The 'designer as a prettifier' has to deal with coming in late into a project and taking other's ideas and implemented solutions and getting the task to 'make it look good'. The 'designer as an executer' on the other hand has the job of taking an already decided but not yet implemented solution and execute it, thus being in the process a little longer. Both these roles are problematic since design is about going all the way from the problem (and beyond the problem) to the solutions. Bernstein continues to explain four means of getting to a solution:

- Analysis, followed by patient working out.
- Deliberately going away from the problem.
- Simultaneously considering something analogous.
- Random collision, where thoughts come into contact, either by accident or by design.

We recognize the last one from the previous aspects, which emphasize the artistic, non-deterministic parts of design. Similarly, Jones (1970) describes three views on design using the terms creativity, rationality and control:

Black box. From the viewpoint of creativity, the designer is a black box which takes the problem and explodes in all directions seeking boundaries and possible solutions.

Glass box. A rational viewpoint views the designer as a rational decision maker. Seeing the clear purposes and strategies for everything the designer does like inside a glass box. This view is close to seeing design as an automatic process.

Self-organizing system. This viewpoint sees the designer as a system that takes the actual design process in consideration and controls and evaluates the progress.

By shifting perspectives during the design process, the three views of design can be presented as in Figure 3 (HMI702, 2001). The first part of the figure shows the black box view, where the designer diverges in his/her creativity, exploring and seeking information. The middle part depicts the designer as a self-organizing system controlling the process to converge, evaluating the process and keeping good ideas and solutions. The last part shows the glass box view of the designer, where he/she in a rational way refines the design solutions and eventually reaching a final goal.

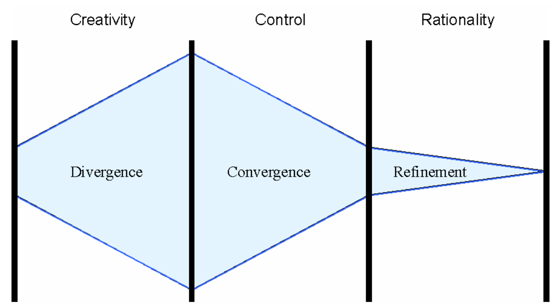

Figure 3. Strategy switching. Figure based on (HMI702, 2001).

This ‘strategy switching’ should be seen as iterative processes and not as a sequential 1-2-3 procedure.

2.6. Theory Summary

The benefits of representation design are brought out in practice. Keep the theory of representation design as a source to map findings to when designing—the basic principles, semiotics and forms of reference, and the effects of representation design. Think about the general observed methods of design; the duality of the problem and solutions, the shifting of perspectives and strategies. It is risky to regard design as a discrete process with a simple ‘problem input’ and an optimal ‘solution output’, that can be put between some other processes.

3. Frames of Reference

When describing the basic principles of representation design earlier, identifying *frames of reference* was brought up as an important step. Three different practical examples of switching frame of reference will be used to describe the concept in more detail.

3.1. Example 1 – Car Navigator

This example brings up a navigation aid for car drivers. A straightforward approach is to present a map of the relevant area to the user as well as pointing out where the user's vehicle is located on that map. Many systems exist, and with various features – route planning, time predictions, on-line updated environment status, car status etc. A generic example with a spatial frame of reference (FoR) is first presented, and then compared to a version where time is the main FoR.

3.1.1. Map as the Main FoR

If we consider that the user needs a tool to both plan a route and follow this route, a solution could look like Figure 4. The main route is shown as a dashed blue line, and since a jam (presented in reddish hue), on this route is reported to the system, the planning part of the system has to check if there are any faster alternative routes (the green one). The car where the system resides is presented as a small black blob (car).

3.1.2. Time as the Main FoR

Switching the FoR to time, a possible design is presented in Figure 5. Here the route is presented as vertical bars. The bars represent the individual roads, and their ends therefore represent crossings. The cross signs show what direction to go in the crossings, and alternative routes are presented parallel to the main route. The jam is represented as a red broken bar and the time difference to the alternative route is represented as a dashed red line (reaching out of scope for this screenshot).

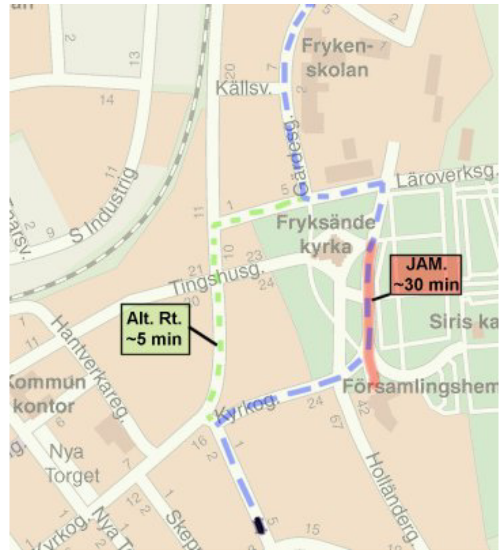

Figure 4. A map-oriented navigation system view.

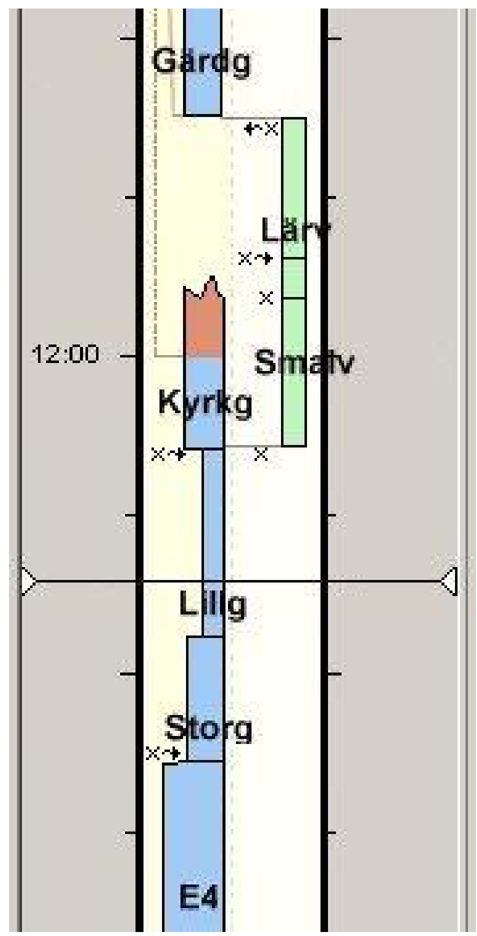

Figure 5. A time-oriented navigation system view.

The current time is shown as a thin horizontal line, and everything above that line is events in the future and below is a visible history. The timeline will slide downwards and the bars will (of course) be dynamic since the future only can be predicted.

3.1.3. Differences and Implications

The shift of FoR is quite obvious, and even if both designs are based on the same data and solve the same *main* problem (following a route), they represent the data very differently. A problem with the first design (Figure 4) is that a lot of what is presented on the screen often is of little use (e.g. roads far away and other map artefacts). Another problem is whether the map orientation should be static or dynamic (zooming, rotation etc). An advantage is that if needed it is possible to locate elements on the map (e.g. post office, restaurant, alternative routes).

The second design (Figure 5) has the obvious problem that it is concerning predefined destinations and not driving around mindlessly. A possible advantage is that it is easier to provide just the data that is concerning the actual route. Instead of having the user to map from the presented map to the world, when and where to turn, a more formal and abstract presentation (the time-based) only shows how long time it will be before an action has to be carried out.

A combination of the two designs, with good coordination possibilities could perhaps be a design to explore.

3.2. Example 2 – Time Zone Tool

When using a system where time and time zones are important, means for manually setting the zone are usually provided. One example is shown in Figure 6.

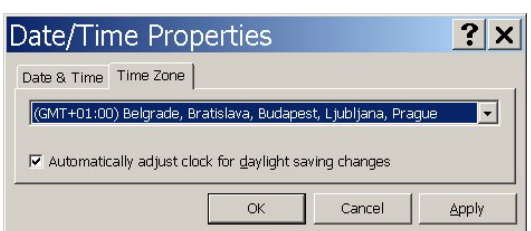

Figure 6. Time zone setting dialog based on listing all GMT time zones.

In this example the user is provided with a list of all available time zones, ordered with GMT-12:00 as first position, GMT in the middle and GMT+13:00 as last position. For each time zone, some major cities are listed.

3.2.1. Time Zones as the Main FoR

This first example's main FoR would be the actual time zones, since the cities are organized under the zones and not the other way around. You cannot type "Belgrade" to arrive at that element in the list, nor "Linköping" or any other city not in the list. Either you have to know your GMT time zone or you have to browse through the list and hope to find a city you are sure is in the same zone.

3.2.2. Map as the Main FoR

By providing a clickable world map to set the time zone, it obviously puts the map as the FoR. When the user points to where she/he is located that time zone will be highlighted to provide some feedback and acknowledgement (Figure 7).

Figure 7. Time zone setting dialog based on a world map.

3.2.3. Differences and Implications

A good thing with the first design (Figure 6) is that users knowing which GMT zone they are in will find it at once. Users not knowing the zone will have to look for cities they believe are close enough to be in the same zone.

Using a map removes the need for knowing technical parts (e.g. the GMT system at all) and the need for finding a specific city (just point on the map). But, it does demand that the users know approximately where they are, and that is dependent on former knowledge.

3.3. Example 3 – Military Order Management

A prototype has been designed, as a step in the development of a new command and control system for mechanized battalions for the Swedish Army (Fransson et al., 2000). The order management part of the prototype is basically based on a palette of various graphical elements to deploy on the map. Commanders choose some (hopefully) relevant elements (signs, arrows, areas, shapes), then put them on the map and lastly select which units to send them to.

There is no very obvious single FoR in this case. The map is one FoR, where the elements should be deployed. But in a way, the graphical elements function as a FoR as well. Since the commander has to navigate among the unstructured mass of elements some kind of implicit FoR will emerge. These graphical elements exist as a top level, a starting point for navigation, like the time zones in Figure 6.

A separate prototype was developed for order management (and unit representation) where the FoR had been changed (Grafisk Orderhantering, 2002; Albinsson & Fransson, in press). Instead, of starting out with symbols and other graphical elements, the military unit and its available orders were set in focus and thus defaulting to most probably relevant graphical element.

3.3.1. Units and Orders as FoR

In Figure 8 a screenshot of the "new" order management system is shown. In the leftmost button list available units are presented. The topmost represents own unit and below are subordinate units. By pressing one of the subordinate units, a new button list will appear, showing what possible orders that can be given to that unit. Choosing an order provides the commander with a regulation-based graphical element to deploy, while rubber-banded to the selected unit. The commander can modify this default element as well as give some extra options in a dialog before sending it.

Following this procedure to give orders, the units and their orders are the main FoR more explicitly than are they in the old prototype.

3.3.2. Differences and Implications

A problem with the old prototype was navigating among and browsing for graphical elements, as well as a lack of structure in the way the orders looked as such. Positive aspects could be the freedom of drawing and putting stuff on the map as you like.

The new system has the advantage that the orders will be structured and consistent and hopefully faster in deployment since one does not have to search for graphical elements that fit the task. A possible drawback would be if commanders experience limitation when restricted to deploy according to regulations.

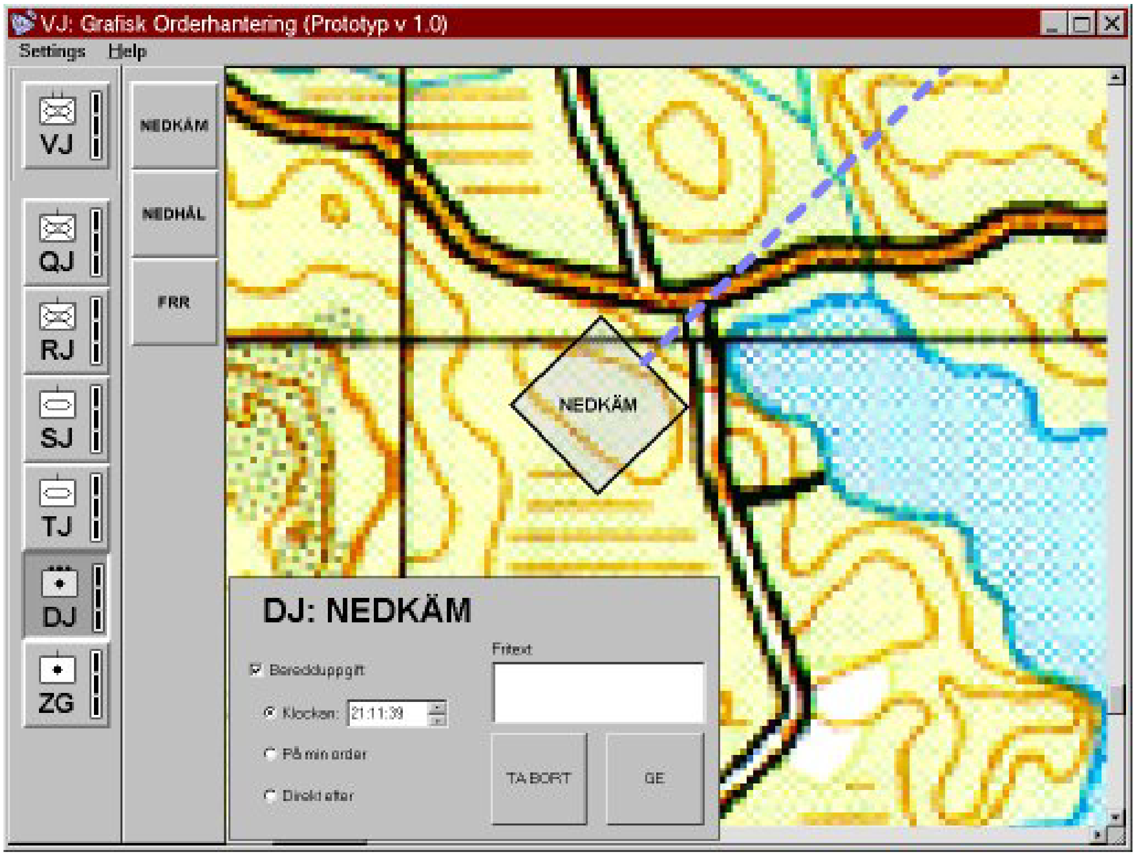

Figure 8. Screenshot from the alternative order management prototype where units and tasks provide a FoR.

4. Forms of Reference

Earlier we discussed how representations could have different forms of reference. Below, it will be exemplified by switching icons with text, numbers with words etc.

4.1. Example 1 – Traffic Signs

Icons, or any kinds of signs are widely used *everywhere* in the world. What happens if we take some iconic signs and transform them into propositional ones using text?

Many of the traffic signs in Sweden contain elements of iconic form of reference. Representations depict generic roads, vehicles, houses, animals, obstacles etc. Often the traffic signs include parts that are more of a symbolic nature, like arrows and other shapes. Some examples are shown in Figure 9. These are all common Swedish traffic signs (Vägar & Trafik, 2002).

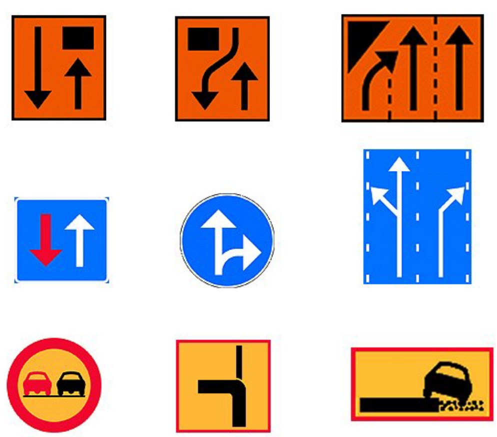

Figure 9. Some Swedish traffic signs.

4.1.1. Replacing Icons with Text

If we try to take these traffic signs and switch the images to text, we could get a result like in Figure 10. At a first glance they might seem much harder to grasp than the ones in Figure 9, but how much of that is because of previous experience? In USA traffic signs are often based on text and not images (Manual of Traffic Signs, 2001), and people there might feel the other way around when confronted with a similar switch.

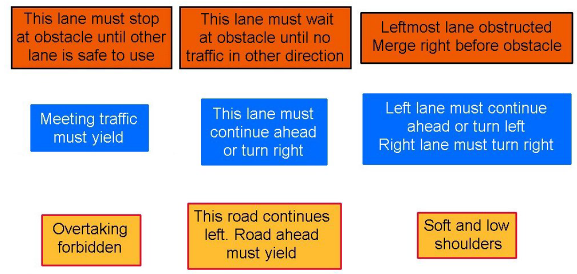

Figure 10. The resulting signs when changing the icons to words (interpreted by the authors).

4.1.2. Differences and Implications

Text can be easy to understand if you know the language. However, it does not (to the same extent) allow the user to have her own opinion about the situation. The words (not chosen by the user) are already there – in black and white. The user either understands the words and their meaning and probably quite fast (in this traffic sign example), else if she does not get it, it will be hard to get any further. An icon can be seen as more blunt, allowing the user to put own "words" to it and what it means.[1] If the user already has seen it and understood it, it will be fast to "get the information" again. If it is a new icon for the user, it will take some time to understand it, depending on the "quality" of the icon, the context (including culture) and of course the user (in the worst case it will never make any sense and then you are out). In the text mode on the other hand, it might not make any significant difference if you have seen it before – you will have to read it again. However, if it is just a few words, you might recognize it as a symbol.

The word 'read' above is interesting since in semiotics 'read' is used for all kind of signs, not just combination of letters (Fiske,

[1] It seems to be the other way around when it comes to books (text) and movies (images), since you often feel that the elements in the movie were not like you had imagined them from the book. Elements in a movie tend to be of analogical reference though – rather than iconic or symbolic.

1982) This means we always have to 'read' the sign again even if it is iconic. Maybe it is equivalent to fewer and fuzzier letters than in a natural language representation, and thereby faster? Ware (2000) states: "In contrast with the dynamic, temporally ordered nature of language, relatively large sections of static pictures and diagrams can be understood in parallel. […]"

This act of 'reading' is (indirectly) proposed to be fundamentally different for text and images (Ware, 2000), placing information from text in a verbal system and information of images in a different nonverbal system. These systems can be strongly interlinked though.

Furthermore, in the examples of traffic signs, text explains in few words what we should do, but images can tell us more than that. They can give us a picture of what could happen if choosing different actions. In Figure 9 the representation of obstacles looks quite massive to smash into, whereas the corresponding text in Figure 10 just says "obstacle". The last example in Figure 9, also gives a hint what will happen if we drive too close to the side of the road. It looks a little dangerous; the soft gravel may cause the car to be pulled off the road. The text version (Figure 10), on the other hand, reads "Soft shoulders" and it is up to the driver to think about the consequences (or not).

When could text work better than graphics? When it comes to complex and rare situations, a representation without text could be quite full of signs and potentially hard to grasp. Could it be that the fuzzy 'letters' get too hard to put together, and the strict natural language letters then come out better?

Ware (2000) has collected examples from various research results and some short summary points where text works better than images are for: detailed procedural logic, abstract concepts, and conditional information.

When it comes to pure symbolical signs, you really have to know what they mean, and therefore such traffic signs are few, often important and widely used (e.g. Figure 11). Because of their commonness and importance, for most people they act in an iconical way.

Goonetilleke (2001) sums up some problems concerning icon design: Designs are limited by implementation constraints and sometimes restricted by already existing icons in the system. Problems are imminent when there is a lack of direct mapping between real objects and system objects. Serious problems arise when similar metaphors are used in different contexts.

Lastly, the combination of text and images are often more effective than either in isolation (Ware, 2000) even if some research suggests that text should not be used in icons, because text could be confusing (see Goonetilleke (2001) for various examples).

Figure 11. Symbolic traffic signs.

4.2. Example 2 – Speedometer

The driver of a vehicle often wants to know the current speed. Driving on a normal road or street, that information is needed to perform according to rules and regulations. Most often the speed is represented as a needle's position on a circular scale, marked with numbers at an interval. Other examples include straight horizontal scales (e.g. Volvo 140) or strictly numerical, showing only the current speed as a single value.

These days, automatic speed limit information is on the way. What happens if the numbers and 'change in numbers' are replaced with words considering this speed limit information? To represent something strictly by numbers or words would usually mean that propositional forms of reference are used.

4.2.1. Replacing Numbers with Words

A quite ordinary speedometer is shown in Figure 12 (Scooters, 2002). If the current speed limit is known a possible textual solution would be to inform (in words) whether the driver is going too fast or not. Figure 13 shows an example where the vehicle is travelling in a speed well below the limit and therefore informs: "Well below speed limit". The *frame* of reference is then mainly the speed limits instead of as before the speed scale.

What happens when the numbers are replaced with words is that the dynamic properties of time are less stressed. With words we can express a state in a detailed manner, but to describe the dynamics of speed we need a lot of words. We are used to use numbers as a representation of speed, and that helps our understanding. Furthermore, seeing the needle move in the graphical/numerical version gives a direct insight of acceleration and deceleration. Without worrying about the relevance for the driver, an attempt to add that information to the textual version is presented in Figure 14. By adding the words "but increasing" the driver can now see that the speed is increasing, but still well below the limit.

The original speedometer in Figure 12 chooses to present 70 km/h and above in a different colour (red) indicating that it is perhaps quite fast and that the driver should notice that. Using the current speed limit information a similar coding could be used in the text-based speedometer (see Figure 15-Figure 17). Potentially dangerous/illegal circumstances are presented in the alternative colour (red).

To complete the combinations of possible textual presentations in this example, these are the words:

```
([Well] below | Within) | ([Some-
what | well] above) speed limit
[, (and | but) (increasing | de-
creasing) [gently | heavily]]
```

What are the differences between these two examples and what can be said generally about numbers and words in representations?

Figure 12. Speedometer from a scooter.

Figure 13. Text-based version of a speedometer.

Figure 14. Text-based speedometer showing change in speed as well.

Figure 15. The driver is accelerating heavily.

Figure 16. The driver is really stepping on it.

Figure 17. The driver slows down.

4.2.2. Differences and Implications

First, this example is special since it is both graphical (the needle etc) and numerical. Another example would be a comparison to a strictly numerical version of the speedometer (a propositional/digital form of reference instead of an analogue one). Furthermore, since the situation is neither very complex nor has many variables involved, the change in representation is not that stunning.

An obvious difference when changing to words, is that a range of numbers will have to map to the same words – the numbers are continuous, but the set of words discrete (in this example). This implies some kind of loss of exactness, and a loss of analogue feedback. Furthermore, the explicit frame of reference of the original version is removed when using words. Instead a vague and mainly implicit frame of reference is formed by the presented sentences, which makes 'putting data into context' hard.

Another difference is that to put (meaningful) words to ('objective') numbers, it is required to know – when designing – what different numbers mean. The words will not be the users' own words, as discussed earlier about the traffic signs. Hence, if we do not know how the numbers might change, how they relate or what they imply, putting words to them is tough.

Is exactness always needed? Is exactness sometimes useless or *bad*? Can a range of numbers sometimes say less than a set of words? A system presenting many continuous numbers in complex cooperation would perhaps benefit of an abstraction to a textual representation (see Figure 18 and Figure 19 for a totally imaginary system).

Imagine that the numbers relate in a complex way, and that all numbers have different 'normal value ranges'. Both designs have propositional forms of reference. But the frames of reference (though vague) are different. In the first one, the frame of reference is pressure (in Pa) and temperature (in °C) while the latter is a set of categorical states (dependent on same data).

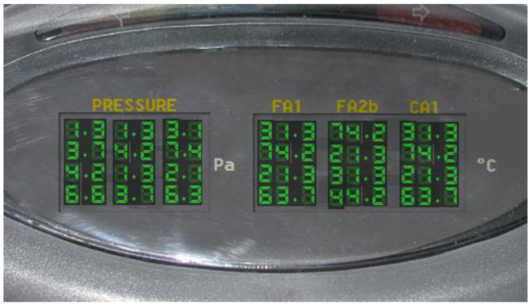

Figure 18. Numerical representation design of a complex process.

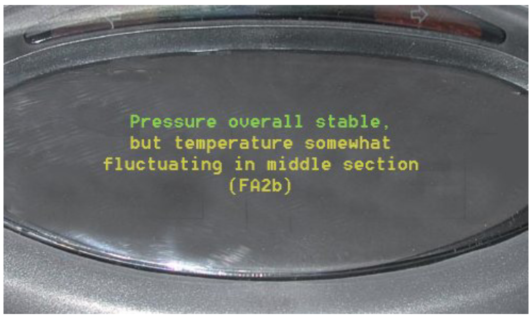

Figure 19. Textual representation design of a complex process.

4.3. Example 3 – Pattern Words

Pattern words are words that describe trend or change (or no change). The change can concern a single value, but also more complex situations where many values change, dependently or independently.

4.3.1. The Words

In Table 1 some pattern words are exemplified to give a starting point for further discussions.

Table 1. Pattern words

Increasing	Overall	Mostly
Decreasing	Mutual	Somewhat
Fluctuating	Separate	Gently
Deviating	Independent	Heavily
Degenerating	Dependent	Significantly
Getting worse	Coordinated	Insignificantly
Getting better	Structured	Temporarily
Drifting	Stable	Dangerously
Recovering	Out of bounds	Repeatedly
Breaking down	Within bounds	Relatively
Stabilizing	Safe	Anomalously
Violating	Unsafe	Normally
Approaching	Optimal	Accurately

4.3.2. Replacing Words with Graphics

How could graphical presentations of some of these words look like? Below, some words are picked as an example.

Recovering + temporary + out of safe bounds

If we want to present the fact that "the process is and has been temporary out of safe bounds but is now recovering" a strictly graphical and hypothetical example is depicted in Figure 20. To see that it is out of safe bounds, there is a distinction (the lightness) between safe and unsafe ranges. That the process is recovering is shown by the recent changes in value towards safe bounds. The 'temporariness' of this event is also shown in the history of recent values.

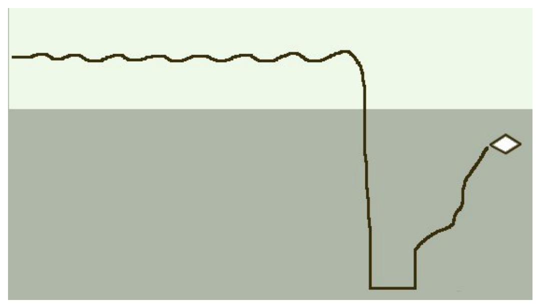

Figure 20. Process temporary out of safe bounds but recovering.

This representation is of an analogue form of reference. Is it possible to provide a useful solution using other graphical forms of reference? Considering each of the topical pattern words, we try to construct signs (icons or symbols) that convey the information (see Figure 21).

Figure 21. Signs representing 'out of bounds', 'temporary' and 'recovering'.

Finding good metaphors for the pattern words is hard, as is constructing clear and simple signs using these metaphors. The signs in this example are mainly of iconic form of reference – they try to look similar to what they represent. Try to figure out some better iconic solutions, there is some white space to the right.

4.3.3. Differences and Implications

Graphical designs that should represent pattern words in a useful manner have to consider all implicit parts of the complex words. Using an analogue form of reference is a good way to start. We need to identify relevant frame(s) of reference, relevant landmarks in those frames, and a good indicator to move around in the frames (Woods, 1995).

When trying to use other forms of reference when representing the pattern words the solutions tend to be far from easy to grasp. Even though better icons can be designed than in the previous example, there are a lot of pattern words out there, and those words are already vague compared to a good design using analogue form of reference.

5. Searching, Browsing and Neighbourhoods

This section reflects upon commonly used metaphors in virtual applications. First, metaphors in general will be discussed and thereafter some examples will be presented.

5.1. Metaphors

"Searching", "browsing", and "neighbourhoods" are metaphors that often are used for virtual applications. Neale and Carroll (1997) state:

> *"'Space' metaphors can help users understand information structures even if no specific visual presentation of a particular space is used. Commands and concepts found on most world-wide web browsers reflect this approach (e.g., back, forward, go to, jump, home page, path, address and others)."*

The metaphors, thereby, may help us organising the abstract information in the virtual domain, so that we can form functional mental models. If it is true that spatial metaphors can complement the visual presentation even if no visual presentation of space is used, it is probably also true that it can complement the visual presentation if it is present. However, the interaction between the spatial metaphor and the spatial visual presentation is not obvious. In what manner does the visual presentation have to harmonise with the metaphor? Is it better if they complement each other, or should they be "redundant", in some sense? And how do we accomplish that?

Löwgren (1993) explains:

> *"Metaphors actually say too much and too little at the same time. They say too much because they can activate too much background knowledge in the user's mind... ...At the same time, metaphors of this type say too little because they do not help the user find the services that are particular to the computer system."*

How explicit and detailed should the metaphors be? Perhaps, the technical "evolution" will bring us useful metaphors after a long period of elaborating with a variety of suggestions. Hopefully, we can speed up that process using our knowledge of humans and computer systems for development of visual presentations and for creating new metaphors.

5.2. Examples

Within representation design, concepts like searching, browsing and neighbourhoods are important; both their original use in the real world and their representations in a medium. Any case of representation design will come to a point where such concepts will be addressed and therefore it is of value to look upon them and try to relate them to each other, and how their relations differ between real world and media.

When trying to understand and define searching and browsing it is soon discovered that there is a need to consider some other concepts, namely: exploring and navigating. The starting point of this hunt for understanding will be formal definitions from dictionaries (HyperDictionary, 2002). Beginning with searching, these are some of the explanations.

Searching:

- To look over or through, for the purpose of finding something; to examine; to explore.
- To inquire after; to look for; to seek.
- To examine or explore by feeling with an instrument; to probe.
- To examine; to try; to put to the test.
- Exploring thoroughly; scrutinizing; penetrating; trying.
- The activity of looking thoroughly in order to find something or someone.

Some common elements in these definitions are the 'carefulness', the structured procedures, and that there is a well-known task or goal.

Browsing:

- Reading superficially or at random
- Look around casually and randomly, as through files and directories on a computer
- Shop around; not necessarily buying

Even if there are some similarities with some of the definitions of searching, the main differences are the lack of organisation and the lack of an explicit task or goal. The definitions are quite familiar and possible to separate.

Exploring:

- To seek for or after; to strive to attain by search; to look wisely and carefully for.
- To search through or into; to penetrate or range over for discovery; to examine thoroughly; as, to explore new countries or seas; to explore the depths of science.
- Explorer: someone who travels into little known regions (especially for some scientific purpose)

As in searching there is an obvious 'carefulness' involved but the difference is that the surroundings are unknown and therefore the goals are not as clear. Lastly we look at navigating.

Navigating:

- The guidance of ships or airplanes from place to place.
- Finding your way around.

The old 'real world' meaning of this word is about sailing boats on the oceans but a more general meaning is as in orienting. It seems more goal-driven than does exploring, whereas the 'carefulness' is more on a same level – to navigate a ship is for sure something 'structured'.

5.3. Relations

The words 'carefulness', 'structure', and 'goal' have been used when describing the topical words. By using them as a frame of reference we can represent the topical words *relation* spatially as in Figure 22.

Exploring and browsing have the 'unknowness' or that they are data-driven in common but the difference that browsing is more 'random' or unstructured. For this interpretation of the dictionary's definitions navigating and searching end up in the same quadrant: structured and goal-driven.

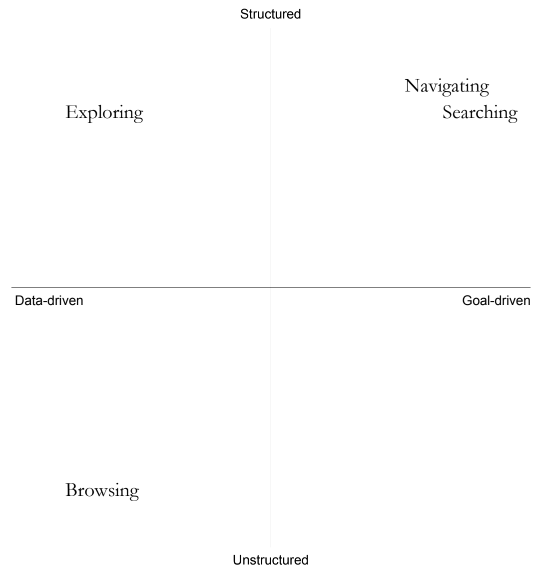

Figure 22. One possible way to relate searching, browsing, exploring and navigating to each other.

Another approach is to arrange the concepts hierarchically in some way. A speculative approach is to use the words in a useful context: An adventurer sailing the seas, could be said to 'explore the world'. To do this the adventurer has to navigate the ship, making navigation a part of exploration. To navigate he has to search for stars, the moon, etc, making searching a part of navigation. Now and then the adventurer browses the horizon for unforeseen landmarks (or pirates), making browsing a part of navigation as well. Figure 23 depicts these relations.

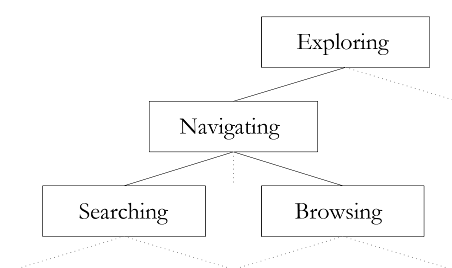

Figure 23. Hierarchical relations.

5.4. Other Points of View

The literature presents a variety of complementary views on this subject. One example is Spence's work about navigation (Spence, 1999). Spence brings up the difference of "getting lost" in the old time's navigation, in the physical world, and in these days, often in the virtual world. Spence proposes a framework for navigation that comprises formulation of a browsing strategy, conducting the browsing and then interpreting the content according to mental models.

Furthermore, navigation is defined as to be concerned with learning about a space, whereas searching concerns the use of that space. That is different to what we discussed earlier, when searching and navigation ended up quite near. However, it is more consistent to the earlier presented definition of *exploring* which considered the "unknown space" to be learned. Also, there is a whole area of research about *exploratory learning* firmly connecting exploration and learning (Rieman, 2002).

When navigating you can learn more about the fine art of navigation, but when you learn things from the space you are travelling through, is that not exploratory learning rather than learning explicitly thanks to the act of navigation?

Furthermore, Spence (1999) places navigation as a component of searching, defining navigation as a self-contained activity that can be accessed when searching. An example using this definition is easy to find: You are searching for an item and you need to navigate to find it.

Spence (1999) defines browsing as the registration of content or a somewhat high-level answer to "what's there?" There may be no specific target that is sought, but there may be "weights" of importance for certain types of content. One example is a quick look at a reference list of an unknown paper to see whether you recognize some interesting ones and then get an idea of the possible value for your own work. Spence calls this weighted browsing, and contrasts it with opportunistic browsing, having no weights to begin with. That browsing often is considered random or unstructured is unfortunate according to Spence, seeing unstructured browsing as just one browsing strategy among many others. Spence exemplifies different browsing strategies that we neatly can fit in each quadrant of earlier presented frame of reference (Figure 22). The dimensions used in his categorization are *cognitive – perceptual* and *planned – opportunistic* (see page 930 and Figure 12 in Spence (1999)).

Höök et al. (1998) look at navigation as an activity divided into four different parts:

1. orienting oneself in the environment,
2. choosing the correct route,
3. monitoring this route, and
4. recognising that the destination has been reached.

Exploration is considered to be a special case when the destination is unknown.

Dahlbäck (1998) identifies that navigation often is defined either concerning geographical space only or hypermedia spaces only (and seems sceptical to Spence's definition). The similarities and differences between these spaces give grounds for a definition. He presents some conclusions about navigation: "The navigator is an active agent. […] There is a movement through a space, and this movement is monitored and adapted during the process. There is a goal for the process, and once the goal is reached the process is finished."

To connect searching and browsing to the discussion again, Jul and Furnas (1997) describe searching and browsing as two tasks that can be carried out using two tactics, querying and navigation:

- **Searching**. The task of looking for a known target.
- **Browsing**. The task of looking to see what is available in the world.
- **Querying**. Submitting a description of the object sought to a search engine, which will return relevant content or information.
- **Navigation**. Moving oneself sequentially around an environment, deciding at each step where to go.

Using this definition, one can search either by query or navigation and also browse using these two tactics. One example is when feeding search engines with offhand queries; you are browsing the site by querying.

Persson (1999) brings up the problem of 'getting lost' while navigating (or exploring, or browsing, or searching) hypermedia. In the 'real world' there are a lot of concrete landmarks to aid us (e.g. anything out there!), but in hypermedia, landmarks tend to be more abstract and non-natural. To provide more, and more natural landmarks, Persson presents the "Agneta & Frida system", which combines virtual navigation and *narrative* into a joint mode. In short, the system consists of interactive characters sitting on your computer desktop watching what you are doing like sitting in a cinema. They comment on what they see, and what you do, and thereby providing landmarks for the user navigating.

5.5. Neighbourhood

A neighbourhood is defined as (HyperDictionary, 2002):

- The quality or condition of being a neighbour; the state of being or dwelling near; proximity.
- A place near; vicinity; adjoining district; a region the inhabitants of which may be counted as neighbours.
- The inhabitants who live in the vicinity of each other.
- A surrounding or nearby region.
- People living near one another.
- The approximate amount of something (usually used prepositionally as in `in the region of').

All these explanations are about objects being close to each other: If a number of objects are within a certain range from each other, they are in the same neighbourhood. Using some of our different definitions of searching, browsing, exploring and navigating we discuss how they relate to neighbourhood.

Searching. Since you know the target (the goal), the objects around that target (the neighbourhood) are not as important (initial definition). Using the definition of Jul and Furnas (1997) though, searching by navigation will most certainly consider the neighbour objects of the target.

Browsing. If you do not know what you are looking for, you will have to consider objects in the neighbourhood to guide yourself (initial definition). Browsing by navigation (Jul and Furnas, 1997) will be continuously dependant on the neighbourhoods, while browsing by querying will dip into them more discretely and implicitly. In some sense, you already have to know what neighbourhoods are down there. Spence's weighted browsing and opportunistic browsing will both use the space (neighbourhoods) thoroughly.

Exploring. Using the definition depicted in Figure 23: You do not know the space and its object, meaning that you build your understanding about neighbourhoods while exploring. For navigation, you know the space and objects, to a higher degree, and use them and their neighbourhoods for your process. You can explore a neighbourhood and then navigate through it (as iterative processes).

Navigating. As Dahlbäck (1998) suggested, there is for sure movement involved in some way when navigating. Therefore there is a natural connection to neighbourhoods and as we said before: you can navigate through a neighbourhood.

5.6. Summary

Only by looking at a few attempts to define the topical words, we see that quite different results have been reached, sometimes the opposite to each other. It is hard to regard one definition as to be the 'right' one; rather one should assimilate the underlying discussion to draw one's own conclusions.

6. Display and Representation Design

Is there a difference between display design and representation design? The question has at least three answers: "Yes", "no", and perhaps also "it depends". Below all three answers will be tried out under the corresponding headline. Hopefully the reader will increase his/her understanding of the question, and perhaps even find the answer that best fits that subjective understanding.

Yes

"Is there a difference between display design and representation design?" Yes, there is a difference. The only reason for that the question is raised, in the first place, is that you in both cases often use a display as a medium for your representation. The similarity between display design and representational design ends there. The difference is mainly that display design is about designing displays, and representation design is about designing representations. There is a fundamental difference in the two activities, and the underlying philosophies. The fundamental differences in the activities result in fundamental different results. Focusing on the display, during display design, risk leading to less focus on the representation and on the overall context. Using the term "representation design" instead of the term "display design" represents more than a swift of terms; it represents a shift of paradigm in human factors. Woods (1995) gives the following:

> *"Terms such as representation, cognition, problem solving, and support for cognitive work will be seen over and over again in the company of ideas that relate to perception, especially for this forum – ecological perception. This juxtaposition is not the result of momentary fashion; rather, it is indicative of a paradigm shift that has been underway for some time in human factors and human-machine systems…*"

Not only does representation design regard the representation and the context, but also the user. It is in the interaction with the user that the representation finds its meaning

No

"Is there a difference between display design and representation design?" No, there is no difference, what so ever. The reason to why no difference exists is that it is the same activities that are referred to in both cases. There is only one reality, and if we chose to describe it in one fashion or another, does not change the reality itself. Different names for the same phenomenon do not change the phenomenon itself. We could not distinguish the two from each other by any objective measure. We could not point at a device and state that this was made of 38% display design, and 62% representation design, and at the same time keep our research dignity! An animation is an animation, and it exists. If it exists because of a process called "display design", or because of a process called "representation design", or perhaps because of some other term referring to the same process of creating it, does effect neither the actual animation, nor the process that created it. Focusing too much on the terms of the process, instead of the process itself, may lead to that the process gets out of focus. Although the terms "display design" and "representation design" were not the terms in focus, Flach (1992) states:

> *"There seems to be a clear consensus that graphical interfaces provide an opportunity to integrate data from complex processes in a way that can greatly enhance the problem solving ability of human operators in the future. However, this consensus is masked by a proliferation of terms to express this position in the basic and applied research literatures (e.g., 'integrality', 'configurality', 'proximity-compatibility', 'visual momentum', 'direct manipulation', and 'ecological interfaces'). While the subtle nuances that distinguish among these terms are of academic interest, designers have great concern for the general principles that might be gleaned from across the subtle distinctions."*

It Depends

"Is there a difference between display design and representation design?" It depends. It depends on several things.

Firstly, it depends on who gives the answer. Some persons state that there is a difference. Then there is a difference according to them. It might be that some other persons do not regard the different terms to be different. The theoretical concepts of display design and representation design are themselves representations. They are themselves representations of phenomenon in the real world, "displayed" as theoretical concepts, and "observed" by a human. Who that observer is, who the user of the terms is, is one criteria for determining if the representation is optimal, that is, it depends on the person.

Secondly, it depends on what you regard as a difference. The difference could be of qualitative nature, that is, the terms describe different aspects of the underlying reality. The difference could also be quantitative, that is the terms could be more or less synonyms, with a slight variance in strength. In this case the difference may be more or less significant. That is, it depends what you regard as a difference.

Lastly, the very occurrence of the two expressions implies that they need to be distinguished from each other. If there had not been a need for distinguishing between the two terms anybody had settled with one. That is, it depends on the need of terms, such as the terms display design and representation design.

6.1. Models

Seeing the terms as essentially the same, differing only in consideration of a specific context can result in a model depicted in Figure 24. Here we see display design as an instance of a more general representation design. Other possible contexts could be traffic signs, advertising, movies etc.

Another view, where representation design can be interpreted to concern more general aspects and theories (e.g. the symbol mapping principle) leaving the physical, visual issues to be covered in display design, could be modelled like in Figure 25. The representation design could then be seen as a separate process providing results to be used in the display design process (e.g. the representation design indicating a certain frame of reference and certain landmarks and forms of reference to be preferable, giving grounds for the display design). What about the other way around: representation designing under the constraints of a display design?

Finally, another possible interpretation linked to the "it depends" view, is that representation design and display design do differ to what they comprise, but that the differences are vague and hard to pinpoint. Sometimes during the design, the focus lies on representation theory while sometimes closer to the solution and display issues. Figure 26 tries to depict this behaviour.

The presented interpretations of representation and display design need not to be disjoint. A combination of them all might be more "true" than any single one alone.

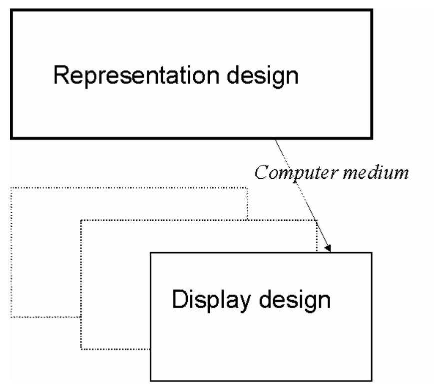

Figure 24. Display design as representation design in computer medium.

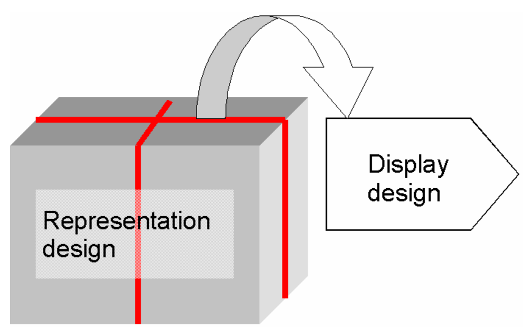

Figure 25. Display design using results from representation design.

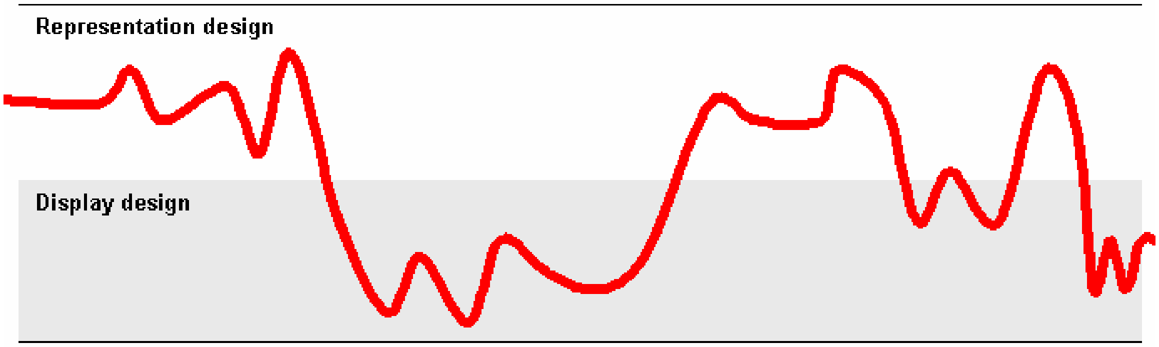

Figure 26. Design with different focus over time.

7. Conclusions

When developing complex socio-technical systems, such as advanced command and control support systems, it is important to carefully consider how important aspects in reality are represented in the system. A bad representation can make it hard or impossible to solve important problems, whereas a good representation can make the solution transparent.

This report presented and discussed an existing approach (among others) that aims to aid the process of designing good representations—*representation design*. It confronts two main challenges: *what* to represent and *how* to represent it. The report focused on the latter challenge and examples showed how the principles of the approach can guide different steps in the design process in a straightforward manner.

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