Why designers can't understand their users

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Part II
The Solution:
a synthesis of psychological and design concepts

A good organization of knowledge and generalizability form some of the crucial characteristics of science and theory (Chapanis, 1988; Fleishman & Quaintance, 1984). Biology made significant progress once Linnaeus designed a systematic organization for plants. Mendeleyev's Periodic Table of the chemical elements provided a systematic organization of chemical knowledge that was based on what was known about the chemical elements and made clear what was to be expected. Using the periodic table chemists even succeeded in discovering of new chemical elements. Unfortunately it has proved difficult to discover as systematic an organisation of (applied) cognitive psychological concepts as the generally accepted ones used in biology and chemistry. Gillan and Schvaneveldt (1999) suggest that even today one of the main problems of applied cognitive psychology is that researchers miss theoretically critical variables. Of course, I do not want to miss critical variables. In fact this thesis tries to answer the question what are the critical variables for applied experimental psychology. Another reason for having a Part on psychological and design concepts is that good tools are important for any profession especially when designing a synthesis of fundamental concepts for an applied experimental psychology. Therefore I have tried to select the tools, in this case the concepts, with care.

What should the main concepts or the main structure be? Many structures for interface design theories include a 'Man' component and a 'System' component. The 'Man' component does not need further discussion at this level. For the system component several terms are used, so there might be confusion about the system concept. Initially the abbreviation *MMI* (Man-Machine-Interaction) was very common in interface design practice. When I graduated several handbooks, conferences, and journals had the abbreviation MMI in their title (International Journal of Man-Machine-Studies; Johannsen & Rijnsdorp, 1982; Margulies & Zemanek, 1982; Singleton, 1974). The use of the word 'Machine' illustrates a focus on humans working with physical machines. In the early days of ergonomics the main problem was to obtain a physical fit of the machine to the man. Today there is a shift from a human being performing a simple task using physical machines to a human being performing a complex task using a complex non-physical system. Also the system component is generally referred to as '*computer interaction'* (Gray & Altmann, 2001; Preece, 1995). In a recent publication of Smyth et al. (1996) both are very prominent. All the titles of their chapters consist of two parts. The first part specifies practice (an example, a system); the second part the more general psychological function. The title of Chapter 1 is: 'Recognising Face: Perceiving and Identifying Objects'. I select the term '*system*' because it includes machines, computers and other non-machine and non-computer like interfaces people work with, such as a train schedule visualised using a paper timetable or an electronic platform indicator.

Having a technical system and a man is not, however, sufficient. At the level of 'Man' and 'System' there is a third component that is independent of both and therefore should be included at this level. The relevance of this third component, the 'task', was well understood early on in applied science, as one can see on the focus on task analysis in this area (Grandjean, (1988); Harker & Eason, (1980); LePlat, (1981); McCormick, (1979).

4. The 'man' component

How can we specify the ‘Man’ component?

In 1985 Simes and Sirsky (1985) specified the following elements for human factors:

a) Locus of control
Locus of control is the belief or perception that an individual has control over ‘self’ in specific environments.

b) Human Information Processing and interpretation of information
Human information processing includes the capacity of human short-term and long-term memory. These are important factors determining information processing capacities.

c) Closure
Closure is the natural rhythm of a communication or interaction that meets an individual’s expectations.

d) Sensory stimulation
Sensory stimulation is information that is ‘assaulting our senses through the application of evolving technology. The main problem is over-stimulation and filtering and selecting relevant information.’

This list of elements is, at best, heterogeneous and hard to justify and I found it created a structure I found difficult to apply. It is also not very easy to specify these elements in an objective way. The elements are not independent and therefore it will be difficult to arrive at valid generalisations. ‘Closure’ for instance, might be one way to arrive at ‘locus of control’ by the user. I found it difficult to distinguish between ‘human information processing’ and ‘sensory stimulation’. Also these elements are not of the same type. ‘Locus of control’ is a product of a design, ‘human information processing’ is a human process, ‘closure’ is a property of communication actions. Taken together the structure Simes and Sirsky (1985) proposed is no more than a list of completely unrelated concepts.

At the same time Monk's (1984) 'Fundamentals of Human-Computer Interaction', has chapters on perception, learning and thinking. These elements I found easy to apply. The elements are of the same type, they all refer to psychological processes and not to products and they even map onto human biological structures. These elements can also be found in van Leyden (1989). However, van Leyden also included chapters on language (reading and speech) and human movement.

Movement, perception, language, learning and thinking form rather stable list of elements for the human component and are identified as subjects of study in experimental psychology, as one can see in any university library having books and journals on experimental psychology. All the elements are 'functions' and consequently, of the same type. Nowadays one can allocate these functions to different physiological structures, suggesting that these components have specific characteristics and are consequently, fundamental concepts. They meet the requirements for a good cognitive structure, as we will see later in this thesis. However, doubts arise when one opens the experimental books on psychology. As Smyth et al. (1996) point out the components cannot be understood in complete isolation. In order not to complicate this thesis too much, we temporarily freeze interactions between human functions as much as possible.

Theories on the development of human cognition can differ fundamentally in the opinion on what is the cause of this development (the nature, nurture discussion), however, they agree in the phases for that development. The start is movement and the cognitive action is at the end (Piaget, 1969, Bruner, 1966, Gal'perin 1978). In the Soviet Union the human function approach was elaborated for ergonomics as the 'activity theory' (Zinchenko, 1977; Zinchenko and Gordon, 1981; van Parreren, 1972, 1981). Recently this old Russian approach has been (re-)discovered in the US (Bedney, 2001).

The conclusion is that the human component should be specified as a movement, a perception, a language, a memory and a thinking function. Language, memory and thinking are summarized as the 'mental human components'. This specification for the human component in functions might seem an obvious one, and not at all surprising, however it is rarely found in interface design theories (See chapter 13).

One can argue that emotion and drive are determinants of human performance too and should be included. Bad design certainly upsets users, as one can regularly read in newspaper reports of human aggression towards computer screens. In this thesis we do not discuss these human functions. The functions of movement and perception are attached to such easily identifiable biological structures as the human hand and the human eye. Language, memory and thinking do not have easily identifiable biological structures but the operation of these functions is based on and can be compatible with movement and perception. In addition, the biological basis of all these functions can be found in the neo-cortex. Emotional and drive functions do not have such relations with movement and perception. Also the biological basis is not the neo-cortex but limbic structures.

5. The 'interface' component

The previous chapter specified the components of the man in the synthetic approach. This specification was not a difficult one for an experimental psychologist. It is more difficult to specify the system component. The problem is that in applied cognitive psychology, and in the interface design literature, the focus is on the interface *technology*.

5.1 Interface technology approach

A very common way of structuring the Interface is to use the available interface technologies, such as, menus, form filling, command language input, voice input. This approach is used by several authors (Nielsen, 2000; Shneiderman, 1987, Willemse and Lindijer, 1993).

The advantage of the interface technological approach is that it is compatible with the obvious structure in practice - all experts involved in interface design know the interface technologies available. However, there are some experimental and theoretical disadvantages.

5.1.1 Practical and experimental problems

In the previous Part the designer's question "Where to position the 'OK'button?" was used to demonstrate the failure of the elementary approach. In the same way we will demonstrate that the interface technology approach cannot be the Solution for the application of fundamental experimental psychological knowledge. To demonstrate that the interface technology is not a fundamental variable and consequently, research focussing on the interface technology will not provide the badly needed fundamental knowledge we will analyse some experimental problems that exists in doing experiments on menus.

a) several technical input solutions

There are, at this moment, a large number of technical input solutions (keys, mouse, touch-screen, tracker ball, graphic tablet, and voice input) all requiring a different kind of human motor actions. Changing any of these variables will have an effect on the performance and reduce generalizability.

b) technical sub-solutions

Within each solution, again there are many sub-solutions. For selection of a menu option the user can enter letter keys, number keys or function keys. These keys can then be combined with an increasing number of 'dead' keys (shift, alt or control, Fn). The Emacs editor typically uses all of this together, providing extensive functionality and an enormous number of experimental conditions.

c) more technical sub-solutions

Suppose input using a particular key is selected. The number of experimental conditions is not yet fixed. There are several solutions to indicating which key to press. A print menu option can be entered in the following ways in a simple menu.

1 print;	the number of the option
p print;	a letter before the option;
print p;	a letter after the option;
print;	underscore of the letter (this now is common practice);
Print;	capitalization of the letter;
print	bold letter.

Today, most menus have many options, having several options starting with the same letter. There are several solutions to solve this problem.

d) visual appearances

The visual appearance of a menu can be different depending on the use of colour, alignment, words, icons and combinations of these. Furthermore menus can be pop-up or pull down.

e) verbal appearances

As the visual appearance, the verbal presentation of a menu has several solutions too. There are synonyms. The use of synonyms increases the *number property of the language field*. Having a higher value for this property can have dramatic effects on human performance (Landauer 1995). For 'customisation' of the operation of a software application the user might have to select one of the following terms: 'configuration', 'modifier', 'normal', 'option', 'personal', 'set up', 'selves service centre'

, and ‘settings’. Not having all four letter entries[1] for the residence town of the Netherlands government will increase search time for that town 14 times (2 seconds for non-synonym names and 38 seconds for the residence) and 16% of the subjects are unable to find the residence (Verhoef, 2000). In menus one cannot include all synonyms. There also are several syntactical variations (print, to print, to printer, make print, send to printer).

f) conceptual appearances
The conceptual variations of a menu include the number of options (breadth and depth) and the order of the options. Common ways to order options in a menu are: alphabetical, frequency of use, random, recency of use and combinations of the previous.

g) interactions
Unfortunately for the advocates of the technology approach it is even worse. Above several main variables were mentioned. There might be interactions between those variables mentioned too. These possible interactions increase the number of alternative explanation for any experimental result rather dramatically.

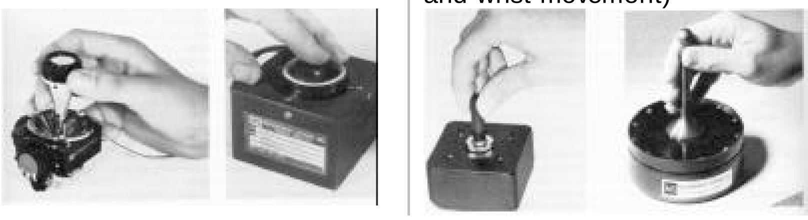
The number of variations and combinations of variables to control in an experimental design, with the interface technology as an independent variable, is rather large. Of course, one can select some combinations of these variables as they appear in given products and compare human performance using experimental psychological methodology. In that way one can obtain tables that very useful for consumers who have to select one from several products. But consumers are not scientists nor are they professional designers. One can wonder if there really was a need for all the studies investigating menus over several decades to arrive at the conclusion of, Paap (2001) “ …it is difficult to rank the … alternatives [for pointing an option in a menu] because there is too much variability in performance between alternatives of the same type.” However no generalizable knowledge can be sought for or acquired with the application of such an interface technological approach, means that each successive evaluation has to proceed from scratch.

[1] In Dutch, The Hague has two verbal labels that each can be put under two different entries:
d Den Haag
h Den Haag
s ‘s Gravenhage
g ‘s Gravenhage

Another disadvantage of accepting research questions from non-psychologists to solve a psychological problem is that one all too easily *misses the right psychological solution*. Buxton (1986) showed that asking “What is better, a tracking ball or a joystick?” is the wrong question. Technology is irrelevant and human motor activities are relevant, so the right question is “What is better input using finger muscles (operating a tracking ball or a joystick) or input using finger and wrist movements (operating a tracking ball or a joystick)?”. See Figure 1.

Figure 1. Technology and muscular moments

two technologies, *one* type of muscular movements (finger movements)	*one* technology, *two* types of muscular movements (finger movements and wrist movement)



Accepting research questions from non-psychologists to solve psychological problems is accepting that design is in command. This might be the wrong organisational structure as Norman (1990) strongly argues. Design should not ask questions but elaborate requirements specified by psychologists.

5.1.2 Theoretical problems

So far, practical and empirical considerations suggest that the interface technological approach is a dead end for scientists and professionals. There are some theoretical considerations too.

The technologies cannot be mapped directly onto human functions as specified in the previous chapter. This lack of any clear correspondence with psychological reality is like building theories without taking account of gravity. It opens the door for amateurs to build psychological castles in the air, supported by nothing other than reasonable assumptions and indisputable logic, but without any reference to the facts in the case that may have had to be gathered by many detailed fundamental empirical studies where expectations have been found to be unconfirmed.

Scientists and professional designers should have knowledge, for instance about human functions. Using that knowledge they should be able to evaluate a given interface technology in the same way physics can evaluate a revolutionary craft that is said to be able to fly. Doing such a principled analysis, before any experiment is considered, would immediately provide the opportunity to raise some fundamental doubts on the user 'worthiness' of the interface that is proposed to communicate with the user efficiently. For instance, how can one be so sure that an arbitrary and hierarchical structure, such as a standard menu structure, is appropriate for use by a human biological structure that does not working hierarchically but more 'chaotically' and using a neural network structure. Perhaps a more fluid structure, such as hyperlinks, is more appropriate. The issue here is that neither has an *a priori* claim to correctness as The Structure for interface design. An experienced interface design professional should be very cautious when an interface technology is presented that offers so many advantages for technology. When using menus, for instance, there is no risk of having users asking functions that are missing in the application. Another advantage for technology is that it is not the application but the user who has a problem when there is confusion on the verbal label of a function (Verhoef, 2001d).

5.2 Properties approach

It was concluded that for a scientific approach the 'interface' component of the MMI should not be specified as the interface technology. But if not, then how should the Interface component be specified?

Perceptual psychology has been very successful in supporting ergonomics by specifying human performance on identification tasks e.g. reading and attention tasks. It proved to be possible to specify properties of interfaces that can be related to physiological structures at one hand and at the other hand can be found in any interface. The effect of visual properties as *size*, *luminance* and *form*[2] are well known in ergonomics and have been established in guidelines for readability and presented in a conspicuous manner (Grandjean, 1988, Leopold et al., 1983, Schuffel et al., 1989). This interface property approach has proven to be both fundamental and applicable: The approaches bridge the gap between fundamental psychological findings and practical design. Designers can predict human performance of the technical interface options they have, without having to do comparative or evaluative research studies.

The interface properties approach might form a better way to structure psychological information for design than having a structure based on interface technology. Therefore this approach, successful for perceptual physiological properties, is applied and tested in this thesis for non-physiological properties. In the next sections concepts and terminology for this elaboration are defined.

5.2.1 Properties of the element of an interface

When the interface is a machine, like a ticket vending machine, it is not possible to specify one single visual or motor property. The interface has to be broken down somehow. In the literature several terms are used at this level, such as ‘highlighting’, ‘coding’, ‘object’, and ‘element’.

One term that is proposed as a distinct candidate for further specification of the interface is ‘*highlighting*’ is used by several authors (Fisher, Coury, Gengs & Duffy, 1989; Fisher, & Kay, 1989). Boxing, flashing and reverse video are examples of ‘highlighting’. The term ‘highlighting’ has some disadvantages for the use as a fundamental concept. It is strongly related to perceptual properties and is not appropriate for non-visual perceptual properties nor for cognitive properties. In addition, it does not indicate a property but a *value* of a property for presenting information in a presented in a conspicuous manner. Properties and their linked values should not be confused. Another disadvantage of the term ‘highlighting’ for a property is that values are confused. ‘High’ is a particular value of the property ‘highlighting’. These disadvantages do not apply for the term ‘element’. This confusion of elements or properties and their values is one that has been discussed and solved by the technologies, in this case computer programming languages, where one can distinguish between a type of variable, its identity and its value. The data types *string*, *real* or

[2] Interface properties that are a part of the solution, are printed in italic in this thesis.

integer can be the type of a variable such as X or Y or even string and they can have values such as 1.414 or 27 or 'string of letters'. The confusion in interface design identified here comes partly from failures to make such distinctions in advance. The sloppy use of words can easily create confusion when distinctions are not rigorously controlled, so we can not tell if we are referring to the type, the variable or the value when we use the word 'string' unless we have been clear in advance.

A second candidate used by several authors is the term '*coding*' (Carterette & Friedman, 1978; Christ, 1975; Hudson, 1984, 1985; Leeuwenberg, 1971). In most cases 'code' is used for the property of colour. One also could use code for form, luminance and flashing. 'Colour coding', for instance, means how is colour used, which meaning is attributed to a particular colour. As such the term 'coding' is used by those authors as a compound rather than as a simple concept. The term 'coding' implies three elements: (1) a property, (2) a value of that property and (3) the meaning of that value. On a basic level one needs to use primitive terms and concepts that do not consist of several elements. When using the terminology 'properties of elements', that kind of confusion does not exist.

The third candidate is '*object*'. This term is used for instance by Eriksen, (1953); Jenkins, & Cole, (1982) and Smyth et al. (1996). The disadvantages applicable to the terms 'highlighting' and 'coding' do not apply for the term 'object'. However, the term 'object' is rather concrete and harder to apply to non-physical, abstract systems, than is the term '*element*'. Even Norman (1986) used a rather physical definition of the system part by using the term 'physical structure'. At the same time, Charlton (1988) noticed that it is difficult for ergonomists to focus on non-physical systems. The medico-mechanical tradition is still strong in the discipline.

It can be concluded that the best verbal label for the interface component is the term 'element'. An interface is a combination of elements having particular psychological properties. Combinations like motor element, perceptual element, language element, memory element, thinking/ cognitive element might not always sound like perfect English, but this may be advantageous use of jargon to identify new concepts and unusual combinations for which everyday language proves to fall short. The definition of 'element' as 'something a human function performs an activity with' is clear. The term is general and can easily by used for any human function. Humans can perform motor, visual, language, memory and cognitive activities with elements. The term is specific and can easily be used to more specify complex concepts like ‘highlighting’ and ‘coding’.

The psychological properties of elements are well defined by physiological psychology. Perceptual elements, for instance, have the properties form, size, luminance, colour and flash. Using these properties the visual appearance of that element is completely specified. With such a description it is possible to make an identical visual copy of that element.

5.2.2 The value of properties of elements

Perceptual psychology has been rather successful at studying the visual properties of elements. Knowledge about visual properties such as *size*, *luminance* and *colour* has proved to be very useful for the design for interfaces. It became possible for properties of elements to specify requirements for design that can be expressed in physical measurable units that are reliably related to human performance. It also became possible to relate this measurement to human performance. Well known are thresholds for *size*, *luminance*, *colour* and *flash* below which text becomes illegible. Designers need that kind of exact specifications of values of properties in order to be able to design (Meister, 1989).

There are several verbal labels to indicate the value of a property. Some of these labels are confusing. In Dutch, the property *size* is indicated with a word also indicating a particular value of size (‘grootte’ in English ‘bigness’). The same applies to the property *distance*. In applied psychological literature concepts as ‘proximity’ (Barnett, 1986; Woodward, 1972) and ‘eccentricity’ are used (Cole, & Hughes, 1984; Engel, 1974) to indicate the property whereas these words also refer to a particular value of that property. A final example is the Dutch word ‘helder(heid)’, referring to a property (*luminance*) and to a high value of that property. When luminance is low, this usually is not indicated by some form of the word ‘helder’ (e.g. ‘onhelder’) but by an other word ‘donker’ (dark) which word form does not suggest that the word refers to one end of a single continuous scale. Terminology for applied experimental psychology should not confuse the concepts ‘element’, ‘property’ and ‘value’ of that property.

Scales with the values of a property should at least be nominal and, if possible, quantitative having a begin, an end and positions in between. Within a scale there are values relevant for human performance, e.g. thresholds. For properties of motor and perceptual elements scales these thresholds are well known. For instance, the *psychophysiological thresholds* indicating at which physiological value 95% of the users are able to notice a minimal value of a property. The reading threshold for character *size* is 200 times character size and the visibility threshold for luminance is 100 cd/m2. A value of a property can be too low or too high. Characters being too large can become unreadable; luminance being too high can damage the retina. Physiological threshold are measured under optimised conditions in a laboratory.

In the real world the conditions encountered can be less favourable. Therefore, in practice one should use thresholds that are more conservative. These kinds of thresholds are referred to as *thresholds for practice*.

Table I presents an example of visual properties of an element and the values of that properties that should specify a visual element completely.

Having discussed the elements, their properties and their values one can now place the components discussed so far, into an orthogonal table having ordinal scales on each axis (See table I). This table shows several interesting questions.

- The table suggests that the property ‘visual form’ can be specified in a normal or ordinal scale, as it is tried in the table above. One of the questions one can pose is: “Is this correct?”
- Form is a visual property of an element. If form is a property then there are several values for that property corresponding to several levels of human performance. Which are those values? Table I below suggests an ordinal scale starting with characters, as the simplest forms, and ending with integrated displays as the most complex forms. “Is this a useable scale for form?”
- The last question is: “Why is this kind of experimental psychological information not summarised in some such way in human factors and ergonomics books?”.

Table I. Visual properties and thresholds of elements of an interface

System properties	**Visibility** Below physiological threshold	Above lower physiological threshold	Below upper physiological threshold	Above upper physiological threshold	Max. number of values in an interface
form		characters letters numbers words text	analogue pictogram icons graphics pictures	pie diagrams integrated displays	70
size	2°	200 times character size	500 times character size	170°	5
luminance	10 cd/m2 dark	100 cd/m^2	1000 cd/m^2	pain dazzle	3
colour	ultraviolet x-rays cosmic rays	blue	red	radio infrared	5
change	once in a life time?	2 hertz	6 hertz	90 hertz	2
luminance contrast	no sight	1:3	1:10	dazzle	2

5.2.3 The field properties of an interface

Having specified all the properties of an element of an interface is not sufficient for design practice and for the determination of human performance.

a) for design practice
A complete description of all properties of the elements of an interface is insufficient for a designer. Complete information on all properties of individual elements does not inform the designer where to position those elements in a two- (x, y) or three-dimensional (x, y, z) interface that has to be designed. More is necessary for any fully adequate description of what appears and when.

b) for human performance
Knowing all motor and visual properties of a key is insufficient to predict the time needed to press this key and the number of errors made when pressing that key. Performance also depends on the number of keys to press (pressing only one key or pressing the same key several times, Van Nes, 1976), the position for the key to press (close to the previous key or at a large distance) and the arrangement of the keys (number keys in a row or number keys in a 3x3 arrangement, Goodman et al. 1985).

In the literature these kinds of properties are referred to as 'Gestalt laws' and 'emergent properties'. The intention is to describe what it is that makes the difference between an unorganised collection of components and something that has an individual identity at a higher level. Chairs, ladders and bicycles support functions that are not readily available to their individual components and not easily inferable unless the components are located in some 'correct' order. This correctness of combination, itself forming a single entity at some 'higher' level, is what these concepts attempt to cover. What is the best verbal label to indicate the type of property discussed in this section?

a) Gestalt
Well known of course, in this context, is the term *Gestalt* (Foley & Moray, 1987). I will not use the term Gestalt in this context. The term generally is not translated and this might well indicate that as an underlying concept it is difficult to describe and that confusion is possible. A German-Dutch dictionary (Stoks, 1988) defines the German word

‘Gestalt’ ‘gedaante’, ‘figuur’ and ‘vorm’. There might be confusion with the psychological visual concept ‘form’ describing a particular characteristic of an element and the psychological visual concept of structure, describing the arrangement of several visual elements.

b) emergent properties
Another suggested verbal label to indicate holistic properties of interfaces comes from system ergonomics. Within ergonomics ‘system ergonomics’ explicitly focuses on the total picture of a design and distinguishes *emergent properties* (Meister, 1989). These are properties that are meaningful only in terms of the whole, not in terms of its components. Unfortunately no definition of that concept is given only an example. A bicycle as dispersed parts has no power to move a human. Put together as a bicycle, the function of transportation or movement has ‘emerged’. A ladder has to be put together in the right way, otherwise it will never carry a person towards their higher goal.

c) field properties
This thesis will use the term *‘field properties’* where others might use ‘Gestalt’ or ‘emergent’ properties. The term ‘field’ is compatible to the term ‘element’. The term ‘Gestalt’ nor the term ‘emergent’ have such an obvious congruent term. The term ‘field’ can easily be combined with the previous defined concept of the interface properties approach ‘element’ resulting in ‘field of elements’. This is perfect English and makes sense for psychologists and designers. The concept ‘field of elements’ can easily be used for all human functions discussed (the motor field, the perceptual field and the mental fields).

Field properties have the following characteristics.

- The property exists only when there are more elements in a field (e.g. more buttons to press). The field property is not an element property, of course.
- The property exists in a field of human performance (i.e. motor field, perceptual field, language field, and memory field of cognitive field.
- Changes in the property will change human performance. This change in human performance cannot be attributed to other factors.

5.2.4 Which field properties of the interface

Listing properties of elements is not very difficult. Experimental psychologists have investigated properties of motor and visual elements extensively in the laboratory and in practice. Mapping properties of elements onto psycho-physiological structures and corresponding physical properties for the designer to select is easy today.

Listing field properties is more difficult. Analysing human motor performance is more easily carried out than analysing perceptual and mental performances. In section 5.1 it was mentioned that research identified the following determinants of keying performance: the number of keys to press, the distance between the keys to press and the way the keys are arranged on the keyboard. This thesis will elaborate: the field properties *quantity*, *distance* and *structure*. Other candidates for the list of field properties are, for instance, '*time*' and '*contrast*'.

5.2.4.1 The field property *quantity*

The first field property discussed is *quantity*. This field property simply refers to the number of elements relevant for the performance of a task using a human function. Instances are the number of keys on the keyboard, the number of visual information on a screen, the amount of information to recall and the number of concepts to deal with solving a problem.

Chapter 10 evaluates the field property *cognitive quantity* theoretically and empirically in more detail.

5.2.4.2 The field property *distance*

The next field property suggested in this thesis is *distance*. This field property indicates how far an element is from the focus of the user. For motor distance, the distance is how far to travel with the fingers to the next key and for visual distance the distance is how far the information is presented from the fixation point.

Chapter 9 evaluates the field property *visual distance* theoretically and empirically in more detail.

5.2.4.3 The field property *structure*

The last field property elaborated in this thesis is '*structure*'. This field property indicates how the elements in a field are arranged. For entering numbers using keys a line structure, as on the top of a qwerty keyboard, is an other way of arranging number keys than a block arrangement, as the number keys of a telephone are arranged.
Chapter 11 discusses the field property *cognitive structure* in more detail.

5.2.5 'Man' and 'Interface'

Having discussed human functions and the properties of the interface we now can put the components discussed so far in an orthogonal table having ordinal scales on each axis (See Table II). This table summarizes the solution and offers a framework for organizing applied cognitive psychological knowledge.

Table II. Suggested components of applied cognitive psychology

System component	**Human component**					
		Perception functions		Mental functions		
	Movement function	Visual function	Auditory function	Language function	Memory function	Thinking function
Element properties of the interface	size weight	size form luminance colour change	volume			
Field properties of the interface	quantity distance structure	quantity distance structure	quantity distance structure	quantity distance structure	quantity distance structure	quantity distance structure

6. The 'task' component

Initially psychology did not focus on the task. Human beings were seen as ‘black boxes’ having inputs and outputs. Only these were studied and not the drives and the aims for the outputs. For experimental psychology there was no need to analyse the experimental tasks extensively because the tasks the subjects have to perform, generally are rather simple. Although Miller (1967) stressed the importance of task analysis this subject was not prominent in ergonomics. Techniques to analyse tasks, such as PAQ, de AET and USES did not include questions regarding the tasks to perform (Verhoef, 1991). As mentioned in the introduction of this Part Grandjean’s (1988) book, there has been a recognition that tasks were important, but little progress made in what to do about them, certainly when it comes to finding ways of describing tasks that can help in designing tools that will help people to perform those tasks.

There is a strong need to consider the task when the activities required to accomplish the task are complex, there are several ways to perform the task and when the activities are invisible which is the case when mental activities are involved. Also there is a need to analyse the task, to understand just how a subject performs the task (Card et al., 1983; Newell and Simon, 1972). The aim of the task always has been a prominent element in Soviet ergonomics (Miller, 1967; Zinchenko and Gordon, 1981) and European soul mates (Volpert, 1974; LePlat, 1981). These scholars do not define a human being as a black box but rather as a being performing activities to accomplish an aim. The aim of humans is also recognised as relevant in research on cognitive psychology (Card et al., 1983, Newell and Simon, 1972) and human error (Brown and Groeger, 1990). It is concluded from these theories that the task should be included in applied cognitive psychology.

Designs are explicitly made to realise aims such as, fast, errorless and accurate human performance, safety, costs reduction and comfort for the operator. Therefore it can be concluded that, from a practical point of view, goals or the aim of human activities should be included in applied cognitive psychology too.

For an experimental psychologist it is not difficult to specify the human component. Specification of the system component is more difficult and several solutions are available (these are the interface technology and the interface properties approaches). It is even more difficult to define and specify the third component, the task. Singleton (1974), for instance, concluded that there are at least twenty-four definitions of tasks and task related concepts. Patrick (1980) concluded that these kinds of definitions are often vague and even mutually exclusive. Fortunately, in this thesis the focus is on easily identifiable tasks such as: buying a ticket in a ticket vending machine and finding a train in a time-table. These are simple tasks and no thorough task analysis is required. The interpretation of measured human performance will not obscure the discussion on the focus of this thesis, the man and the system component.

7. Testing the Solution

The previous chapters of this Part have described the concepts for synthesis I have used for several years now. For my own practice these concepts were successful. For instance, I have been able to understand why graphical user interfaces, and especially the Windows interface, is so difficult to use. Using the basic concepts I was able to specify a computer interface that does take account of the way humans perceive, talk, remember and think. Another result of using these basic concepts is a two days seminar for DOS based interface on the application of experimental psychological knowledge about human functions. When DOS was out of fashion and Graphical User Interfaces and Windows came in, I deleted DOS examples and could easily allocate Graphical User Interface topics to fundamental concepts (See table III below). The interface technology changed but these underlying concepts remained the same. In hindsight it should have seemed surprising that a change in interface philosophy that was heralded as radical (Gates, 1995) led to no real difference at all. Today a version of the seminar is running successfully, in which Windows examples are deleted and Web examples are inserted. The specific examples of good and bad experimental psychological interface may have changed, the fundamental theory, structure and design requirements again remain the same. When another new interface technology becomes the mode, I now feel quite confident that I only need to delete some old examples and insert new ones.

In my practice there is no need to make the concepts used more explicit and to evaluate the concepts as is common in science. For a scientific foundation however there is a need for explicitation and evaluation. This chapter discusses how to evaluate the components and their relation.

Table III. Allocation of practical software topics to the solution
Solution concepts in bold, practical topics not in bold.

System component: properties of:	Human component: human functions movement	perception	language	memory	thinking
elements	**Size** Size of (screen) buttons.	**Size**			
elements	**Form**	**Form** Text or icons? What is a graphical user interface?			
elements	**Resi stance**	**Luminance** When to use bold?			
elements	**Texture**	**Colour** When to use which colour?			
elements		**Changes** When to use change?			
fields with elements	**Quantity** How to design for few keys to enter?	**Quantity** How to design quiet screens?	**Quantity**	**Quantity** Design for progress indicators and 'are you sure' interfaces.	**Quantity** Mental load.
fields with elements	**Distance** Entry with keys or selection by pointing. How to reduce RSI?	**Di stance** Where to position information ?	**Distance** How to design for clear language?	**Distance** Why help cannot help. Help that helps.	**Distance** Understan ding complex concepts.
fields with elements	**Structure** Keys in a row or keys in a block.	**Structure** How to design efficient screen lay out and tables?	**Structure**	**Structure** **C**onsisten-cy and standards.	**Structure** Navigation in (complex) systems, menus, hierarchies .

7.1 Theoretical evaluation

Personal practice and experience is not sufficient to make a synthesis scientific. At best this leads to a degree of face validity that, while useful, does not provide any proof that solutions and methods are correct. The synthetic concepts have to be made explicit and available to test. The concepts used have to be defined and one has to explain why that concept is relevant. Part III of this thesis provides this theoretical evaluation.

7.2 Empirical test using students

A typical scientific test, to evaluate a synthetic interface design model as presented in this thesis would be the following: One group of design students is taught to use the synthetic model and other groups do not get such an education, just a general standard introduction to interfaces, typically by having various features pointed out to them or their own experience. After training all groups, the subjects perform design work and their designs are independently evaluated. If the designs of the synthetic model group are better than the designs of the other groups, then the synthetic model improves design and may start to describe the design truth. Gillan and Schvaneveldt (1999) refer to this kind of research and conclude that user interface designers with training create more usable designs than designers who have not had such training.

I do not test the synthetic concepts testing empirical performance of designers. There are several reasons.
One can wonder if such a scientific approach for this question is useful and applicable at all. This dissertation presents just one solution, other sets can probably be specified equally well. There are several ways to educate experimental psychologists. When those other educations are not included, differences in effect might be caused by the education instead of the contents thought. One always can say: “What if the students were educated in another way?”. ‘The other way’ can refer to another psychological content or to an other educational form. On top of the orthogonal variables psychological content and educational form, one has to include control groups to control for the effects of pre- and post-test. Campbell & Stanley (1963) state that for a scientifically sound comparison, an education would be needed for five different groups in order to control all effects of pre- and post-tests.

7.3 Practical test by comparing designs

Although ‘in action’, I did not want to become unreflective and intuitive (Schön, 1983) but reflective and explicit, as an experimental psychologist should be. This means that there should be a practical test comparing designs. Operationalization of a theory in an interface design is not mentioned by Gillan and Schvaneveldt (1999) as a method, but there is little difference. So far there are no problems. However the focus of western psychology is observation, mostly of *existing* educational materials and interfaces. Van Parreren (1972, 1981) introduced me to the Soviet approach in which psychologist do not focus on observations but on construction. Two methodological problems emerged. The first problem is that ‘construction’ implies more than observation and the application of existing knowledge. One has to be specific about the movement, perception, language, memory and thinking of users because all of these are reflected in the interface at the same time. One has to make trade-offs between perception (red is difficult to read) and understanding (red is interpreted as danger); presenting all the options on a ticket machine simultaneously simplifies and increases the task of the customer because people both want to know what their options are and also do not wish to have to search when there is a clear logic in the sequence of choices to be made. Another example is the choice of character size: smaller letters mean that readability decreases, but understanding of the information can increase because the designer has more options available for arranging the information. The only way to apply cognitive science in an interface is a synthetic approach, in contrast to the analytic approach of the fundamental scientist who is interested in the behaviour of single elements, typically controlling out the possible interactions of multiple components. This ‘engineering’ psychology nevertheless has considerable opportunities for feedback to theory. For instance, it can show the need for certain concepts. Engineering revealed a second intriguing methodological problem. When educational materials or interfaces have been designed using cognitive psychology, does it make sense to compare them in the traditional empirical way? Chapter 14 will return to this question.

This thesis cannot set the rules for science, of course. Therefore some of the interfaces based on the Solution are evaluated in the traditional experimental psychological manner. In all cases designs that are not consistent with the synthetic Solution are compared with designs that are consistent. The comparison includes a theoretical evaluation and a traditional empirical evaluation.

7.4 How the synthetic model will be tested

Testing all concepts and all their relations is not possible within the context of a dissertation but a few critical ones can be tested. If two interfaces differ in only one fundamental concept and human performance with those two interfaces differs too, than the experimental results support the conclusion that there is a fundamental difference.