Why designers can't understand their users

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11. Cognitive structure

11.1 What is 'cognitive structure'?

The term 'structure' is a complex one. It goes under many aliases in the scientific literature, with names such as: organisation, patterns, regularity, grouping, ordering, categorisation, coherence, Gestalt and schemes. The Dutch standard dictionary 'Van Dale' (Geerts and Heestermans, 1984) defines a structure in several ways. In accordance with one of these definitions a structure is the 'the way a composed unit is built, especially applied for non-material bodies'. Structure involves the organised composition of elements, where there are restrictions on the type and nature of those elements.

For instance: When some elements in a visual field have red or green as values for the property *colour* and other elements do not have a colour, human beings will experience a structure of reds and greens. When red is repeatedly used to represent negative numbers and green to represent positive numbers, this systematic repetition of the values red and green imposes a structure consisting of negative numbers and positive numbers. When, alternatively, positive numbers are presented on the left pages and negative numbers are presented on the right, as in traditional accountancy, this systematic repetition of the *visual distance* values, left and right page, imposes the same cognitive structure (positive - negative) constructed by repeating an other visual property (*visual distance*) instead of the visual property *colour*. In both cases the property values (red or left) is repeatedly used to present the relevant information, in this case negative quantity. This structure can be used for tasks such as: find out if an invoice has been paid (find a red number), what the stock market is doing (going up; many greens or going down; many reds).

For the motor, visual, memory or cognitive human functions a structure can be defined as a property occurring repeatedly in a human function field. What this means is that a cognitive structure is an entity that represents the way in which properties of elements human cognition deals with are organised, with respect to each other, in terms of what is relevant for a task the individual performs. The elements stand out by being distinct from elements that are not relevant for performance of the particular task. Elements can be, and usually are, components of more than one structure at the same time. This ability of elements to appear in more than one structure at the same time provides considerable flexibility and subtlety to cognitive processing, but also ensures that the picture is often hard to decipher. Humans have evolved to be able to perform several tasks at the same time, simultaneously satisfying many different goals. While the human being performs a multiplicity of tasks, using several functions involving some kind of cooperation between the cognitive functions, the poor scientist often demands simple unambiguous reactions in an attempt to understand what actually happened. An element can have motor, visual, and cognitive properties, which can be compatible or incompatible with respect to the task. In some ways of performing a task an element can be used, and is a part of the task structure, whereas in other ways of the task they can be irrelevant and no part of the task structure. Often design errors are incompatibilities of structures in human fields and the task structure. What this means is that the same element, such as being coloured red or being located on the right-hand page, may be used for different purposes, especially in a designed rather than a natural world, leading to confusion of both the human and the scientist. All too often inflexible technology drives flexible users to accept one specific interface with the world, and in just the same way researchers all too often impose, on their flexible and uncomplaining subjects, the rigid and simplistic restrictions laid down by their methodologies.

In order to understand how people cope with their complex world, a multi-dimensional approach to understanding what people actually do does more justice than overly simple models. Developing the concept of multi-dimensional structure forms an essential part of such a program, as it is at this level that notions such as human functions, properties of elements and tasks can be put into their place – the notion of structure defines what 'place' means in such a context.

11.2 'Structure' in other function fields

The variable structure can be identified for all five human functions.

For the performance of human *movement* the structure of the keys on a computer keyboard are relevant. There are effects of arranging keys for entering text for human performance as research on alphabetical, qwerty, Dvorak and a velotype key arrangement has shown (Kruyff, 1983; Norman & Fisher, 1982; Noyes, 1983). The same applies to entering numbers. Number keys can be structured in a row as on the top of a qwerty keyboard. Another solution is a 3x3 structure as on a telephone keyboard. The keys are the same but the arrangement is different. A simple calculation shows that the distance to travel entering numbers is different for these two kinds of structures (see Table I). Goodman et al. (1985) showed empirically that human performance is different too.

Table I. Different motor structure, different human performance required

Mean distance between two number keys		
	Row	Block
Physical structure of the keys	1234567890	789 456 123
One finger typing:	8,5 cm	3,00 cm
Three finger typing:	3,7 cm	0,39 cm

The same applies to human perceptual structures and perceptual performance. Tullis has shown that the ways the elements in a visual field are arranged are also a relevant factor for human performance (Tullis, 1981; Tullis, 1983).

It is suggested that in language structure is relevant too. This thesis does not focus on language. No experiments investigating the effect of language properties are reported in this thesis. In language there are formalized structures, defined by 'grammar', and less formal structures, such as those underlying communicative intent and social factors. In our work we have found and solved one well-known problem by identifying a lack of language structure and consequently, bringing a language structure into the design. In computer interface design the focus today is on graphical user interface technology. Word and language structures are forgotten interface models as one can see in the whole area, where non-graphically based information and control is buried deep in the system, as in the new Mac OSX operating system. The graphical user interface obscures valuable language structures such as sentences and verb - noun combinations. In a pilot study we asked IT specialists and IT students to give a definition of the grammatically ambiguous words 'file', 'edit', 'format' and 'print'. Answers including both a verb meaning and a noun meaning were given in only 3% of all definitions (see Table II).

Table II. Definitions, noun meaning, verb meaning or both meanings given

	noun	**verb**	**both**	n	
file	84%	14%	2%	43	100%
edit	2%	93%	5%	44	100%
format	36%	60%	5%	42	100%
print	9%	91%	0%	45	100%
	32%	65%	3%	174	

Obscuring and conflating the structural differences between verbs and nouns is one of the reasons menus are so difficult to use. It is impossible for a user to select the option 'file' or 'edit' when they want to edit a file, unless they already know exactly what has to be selected. Of course, these results do not form a hard proof of the conclusion that ignoring language structures leads to bad interface design. But it remains intriguing that on the one hand verb – noun structures are relevant in almost all languages, even in formal languages such as algebra and logics, whereas on the other hand there is a master - slave communication system used by millions of people, known to be rather awkward that ignores basic language structures when they are driven by their PCs.

So far structure and human movement, perception and language have been discussed. Does having a field property structure for human memory make sense? Structure is defined as a repetition. As such, 'structure' is relevant for human memory, by definition. Design principles such as consistency, standardisation and metaphors are structures aimed at reducing load on human memory by repeating elements. This thesis does not include experiments on human *memory* and on structures for human memory. However, one memory study has been carried out for the numerical code of the destinations of the B8060. It was expected that the numerical code system to be used would generate too many errors, giving a high load on short-term memory of passengers attempting to catch a train and having to operate a ticket vending machine. For non-psychological reasons the code system was implemented. The study revealed that the (random) three digit numerical Netherlands Railways suggested cause 2.83% of the destinations selected to be wrong. This may be an ideal system for company employees, who are the only people who know such codes, but they also form the only group that, as a whole, never had to buy tickets. The structured four digit numerical code that was then suggested reduced the number of errors to 1.93% a small decrease until one realises that this may mean that about 1000 people per day request the wrong ticket, with all the consequences that may imply! The results are reported in a student's paper (Vroemen, 1987). Later the postal codes were introduced and used as the selection code, presumably helping to reduce the number of errors further. See Figure 1.

Figure 1. The numerical code for destinations on the B8060 train ticket vending machine

Aalten **7120**	Driebergen-Zeist **3970**
Abcoude **1390**	Driehuis **1985**
Akkrum **8490**	Dronrijp **9035**
Alkmaar **1800**	Druten (bus) **6650**
– Noord **1820**	Duiven **6920**
Almelo **7600**	Duivendrecht **1115**
– de Riet **7601**	
Almere CS **1310**	**E**cht **6100**
– Buiten **1300**	Ede Centrum **6710**
– Muziekwijk **1320**	Ede-Wageningen **6700**
– Parkwijk **1330**	Eibergen (bus) **7150**
Alphen a/d Rijn **2400**	Eijsden **6245**
Amersfoort **3800**	Eindhoven **5600**

The remainder of this chapter focuses on cognitive quantity, how it can serve to support performance and how an understanding of cognitive structures can help the designer to come to the aid of the user.

11.3 Why 'cognitive structure'?

11.3.1 Structure and literature

Physiological psychology characterises human neural functioning as a network process. In that network a structure originates when routes in that network are stimulated repeatedly (v. d. Heijden et al., 1989; Hebb, 1949). Psychologists who were not focussed on physiological processes have also stressed the importance of structure. Jespersen (1922), for instance stated that humans are classifying ("klassifizierendes Tier") animals (In: Hörman 1970, Jespersen, O, 1922. More recent psychologists have the same opinion. Human memory uses fixed structures (Best, 1989, Leeuwenberg, 1971, Leeuwenberg & Buffart, 1984; Wagenaar, 1989). In accordance with this theory there is more regularity in the organisation of the information after information in human memory has been changed. Psychologists who study human reasoning focus on how elements are structured. Best (1989) stated that the most striking of the features of our mental lives that cognitive psychologists agree on, is the degree of organization involved in human knowledge. Wilhelm Wundt, one of the earliest experimental psychologists, founded a school that is even called 'structuralism'. He suggested that the mind was an active agent involved in combining or, more accurately, synthesizing basic mental elements (Best, 1989). In applied cognitive sciences, the term schema is used for procedures to be followed (Wright, 1999), a term with a rich and eminent history (Bartlett, 1932; Head, 1926). Inspired by the theories of Piaget (1969) and Bruner et al. (1966), cognitive developmental psychology proposes stimulating cognitive development using classification exercises (van Eerde, 1996; Koster, 1975). In the man-computer-interaction literature, the role of structure has been stressed (Dijkstra, 1976; Sapiro, 1998).

Norman (1986) mentions the 'System Image' resulting from the actual structure that has been built. This is the embodiment of what the user will actually have to interact with, and will have been determined by the designer's and scientist's own models – distinct from the users themselves. For that concept this thesis will use the term 'interface'. What has preceded in this chapter might be difficult to understand having read it only once. This difficulty and the fact that several comments can be made on the concepts and terminology proposed by Norman, the father of this discussion, illustrates the need for such a discussion.

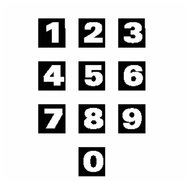
11.3.2 Structure and design

A designer has to deal with several structures. This section will describe these structures and illustrate common confusions between these structures made in design.

Human function structures
So far, this thesis has introduced cognitive quantit, and subsequently *motor, visual, language* and *memory structures.*

From the user's point of view there are motor, visual, language, memory and cognitive structures. Which structure or structures will form the basis of the interface depends on the type of activities the users needs to perform to accomplish their tasks. Goodman and Dickinson (1985) performed an experiment to establish which arrangement is better for number keys; a one row arrangement as can be found on the top of any qwerty keyboard or a 3x3 block arrangement found on calculators and telephones. See Figure 2. The answer and the design error made solving this problem is on the next page.

Figure 2. Structures for numerical keys



a block structure,

a row structure.

Which one is best?

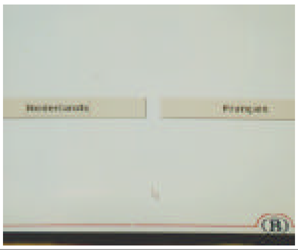
Users state that they prefer a row structure. The row structure is more compatible with the integer decimal number system in which the only difference between two numbers is, that the next one has one more. The visual appearance is compatible with the conceptual structure, a structure that is more appropriate for cognitive activities such as quantitative ordering, counting, subtracting and adding than is the 3x3 block structure. The row structure is, on the other hand, not compatible with the motor structure of our fingers having fingers, five on each hand, and having different length and keying capacities. The visual structure of the 3x3 block structure suggests that we have a ternary number system. The visual appearance is not compatible with the conceptual structure, but it forms a structure that is compatible with the three best fingers for pressing keys. As entering numbers is a motor task, compatibility with motor structures is to be preferred, because the entry is the numerical task, there is no further requirement to process the numbers in other ways that might well be better served by the row structure. This illustrates a problem with taking the simple way out for designers; asking the user and giving them what they ostensibly want. While the user should be taken into consideration with the highest priority, it is incumbent on the designer to ensure that the user is being asked the right question. Understanding structure is intended to help in posing correct questions – although all to often an adequate understanding of what question should be asked already provides an unambiguous answer, thus leading to the impression that good design is easy to do. This explains the hindsight bias of those who, knowing the answer, can easily reconstruct the question and fail to understand that only good designers can operate equally well forwards as well as backwards in their reasoning.

Technical structures

Norman (1986) mentions the 'Design Model', which is the conceptual model, held by the designer. This 'Design Model' is a human model and therefore it is more consistent, within Norman's terminology, to refer to this concept as a 'Designer's Model'. Using the terminology of this thesis the verbal label of this concept would be 'the designer's cognitive quantit of the user's 'cognitive quantit'. More words but probably less confusion.

Designers can have several models under consideration that need to be specified. Designers need to have in mind a model of the technical structure of the system. This technical structure can be the structure of the database, the technical tools or the programming method. These technical structures can be used implicitly to structure the interface, resulting in incompatibility with the cognitive quantit the user employs to perform his task. A well-known example of such a technical structure is the computer menu. This type of interface offers a very efficient technical structure blocking users to ask functions not foreseen and forcing users to understand the terminology chosen by the designer. Figure 3 compares an interface using a technical menu structure and an interface using a structure compatible with the more non-sequential, parallel way that humans are used to operate.

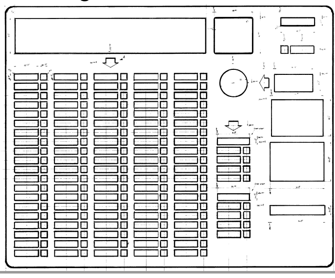
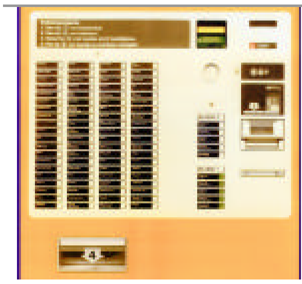
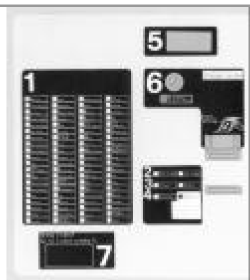
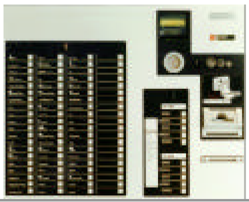
Figure 3. Interfaces for selecting language

Basis for structure:	technology,	psychology.
Type of structure:	hierarchical,	parallel.
Operation:	select language now,	change language any time, change anything any time.
Machine:	Belgium railways,	Netherlands Railways.
Picture:		

Task structures

So far there were human function structures, imposed by biological characteristics of human function involved and technical structures imposed by characteristics of design functions involved. A field of cognitive elements can be structured using the task. This should be the task for the user, of course, and not the task for the designer, which is the case in the example of figure 4.

Figure 4. Structures on the 80-destinations ticket vending machines

The designer's task is: making holes in a panel using this technical drawing: 	The task for the passenger is: to buy a ticket performing four steps.
The visual appearance of the interface presents the task for the designer: the number and size of the elements is compatible with the number and size of the holes to be sawn.	The visual appearance of the proposed interface presents the task for the passenger: the steps to be taken to buy a ticket.
	 As does the implemented redesign: 
	As does the next generation machine. 

Psychological theories, such as those referred to above for memory and thinking, and practical problems, such as operating computers, hand calculators and video-recorders, suggest that humans operate in complex systems using some cognitive quantit. The next question to be answered is which types of cognitive quantit can be identified.

11.4 Which 'cognitive structures'?

Whenever there is a repetition in a field, one could say there is a structure. What structure or repetitions can be distinguished in a cognitive field? Scientists are specialists in 'navigation' in complex abstract unknown systems. They have a long tradition and well-established methods to develop a cognitive quantit of an unknown and complex conceptual structure in which they have to perform cognitive tasks. One of these traditions is the use of scales of measurement. Four values of measurement are distinguished (De Groot, 1961, Kaplan, 1964).

a) Nominal

Using a nominal scale the elements are objectively sorted into classes (De Groot, 1961). Van den Brink and Koele (1985) are more explicit and state that these classes are mutually exclusive. These authors address themselves to methods for experimental psychology and not to applied cognitive psychology. Paap (2001) has written an interesting overview of the design for menus. One of the requirements for a good menu is 'class-inclusion matching' which is defined as '… whether the target is an instance of the category specified by an option.' Meeting these requirements prevents category decisions from being faulty if there is conceptual overlap between the categories, and menu targets might belong to two or more categories. Paap (2001) does not refer explicitly to the scale concept of 'nominal' from the experimental methodology. Mandel (1997), another respected computer interface psychologist, refers to mutual exclusiveness for menus in plainer language, by stating that options very often seem very similar and yet have very different meanings. As an example he mentions simultaneously use of options such as Exit, Quit, Escape, Close, Return, Forward, Back, Enter, Accept, Up, and Down.

What search strategy can a human being apply when a structure is nominal? The advantage of a nominal structure is that the user can be sure that the entry has the information he needs. The option in the main menu of the computer program will lead to the function required. The line or the column on the trains indicator will lead the information required to select the train calling at the destination of the passenger. The disadvantage of a nominal structure is that the user has to inspect *all* group labels to find a little information. When there are only a few options in the main menu or a few trains on the trains indicator there will usually be no problem, assuming that all other design requirements are met; the structure is nominal, the labels for the options are correct and the user can understand the label. When, however, quantity increases, problems may start to appear in searching menus for options or indicators for trains.

b) Ordinal

When the elements are ordinal, the elements can be listed using some quantifiable criterion. The position for each element is objectively determined. When a cognitive quantit is ordinal, the user can inspect one arbitrary element label and decide to go stepwise up or down to find the element searched for. The user can even make a well-estimated jump in the list – although accurate estimation requires interval structures, as introduced below. Searching in one direction only is more efficient than searching for all elements of a list. Jumping is also more efficient than stepping, which requires calling at and checking all elements. Street numbers or highway exit numbers provide typical ordinal structures that can be used going either up or down. Furthermore they typically provide a rough indication of how far one has to go, information respected accurately at the interval level of measurement.

c) Interval

When the elements have an interval structure there is an equal distance between the elements. There is an arbitrary origin. The user can inspect two arbitrary elements in the list and jump quite accurately to the position for the element needed. Skipping elements in the list is possible because the user can make reasonable estimates of the distance between positions for the group inspected and the position for the element needed. Addresses in large apartment blocks can often meet the requirements of interval structure as long as all the flats are the same size. The same applies to modern housing estates, but not to the traditional Dutch town street with houses of different widths.

d) Ratio

Ratio structures have equal distance and a point 'zero' which is no longer arbitrary. When a cognitive quantit is of the type ratio then the user does not need to inspect one element in the list to locate the group needed but can directly jump to the position for the element needed after having located the whole structure. Jumping directly to the element needed is more efficient than jumping via an arbitrary group. An example of this is GPS, a system for navigation on the world globe that is discussed below.

e) Random

In practice there is a fifth value of data structure, one not mentioned by De Groot (1961) being a random structure, also called the ‘pile of bricks’ structure (Hudson & Phaf, 1981). This random structure is probably not mentioned because this way of organising information is not fruitful. In daily life and in the domain of interface design, however, information is all too often presented randomly to users and this lowest level of structuring should be taken into account. In a random structure, the elements are allocated to groups by chance. Users cannot predict in which group of the structure they will find the information they need.

With a random allocation of functions to menus the computer user will have to inspect *all* options of the menu to find the location of the function needed and hope to learn exactly what to do as there is no other way to speed up the search process. Given a random allocation of train information a passenger will have to inspect all rows and all columns of the trains indicator to find the information needed. Table III summarises values for cognitive structure.

The first experiment tests the hypothesis that using an efficient structure results in efficient performance. The second experiment describes an experimental comparison between nominal, inefficient structure for presenting passenger information on chronological trains indicators and an ordinal, efficient structure.

Table III. Values for cognitive quantity

Range for cognitive structure	Random	Nominal	Ordinal	Interval	Ratio
Pro-perty of struc-ture	mutually inclusive groups	mutually exclusive groups	directional structure of groups	equal distance between groups	point zero
Search strategy	inspect all elements of all groups	inspect all group labels only	inspect one direction of group the group label list	jump to group after inspection of one group label	directly jump to element

11.5 Experiment 1: observation of knowledge of the structure

11.5.1 Introduction

About 30 years ago public transport companies introduced electronic information panels to inform passengers about the details for their trip. Netherlands Railways in Amsterdam Central Station introduced such a panel in the eighties. The structure of the Amsterdam Central Station trains indicator has several sub-structures.

a) two main panels
There are two main panels; the left panel presents the trains going to the northwest and southwest. This includes Zaandam, Alkmaar, Hoorn, Haarlem, Schiphol Airport, Leiden, The Hague, Rotterdam and Belgium. The right panel presents the trains going to the northeast and southeast. This includes Hilversum, Amersfoort, Zwolle, Gouda, Almere, Hengelo, Utrecht, Arnhem, Nijmegen and Germany. Field trials and the scientific literature suggested that passengers do not use instructions on the top of information tables (Verhoef, 1987b, Wright, 1981).

b) the columns
The horizontal dimension of each panel presents, from left to right: departure time, final destination, platform number, train type (all stations or intercity), via (a selection of intermediate stops), and a column for remarks (delays). The final destination column was expected to be a potential problem because earlier research had already indicated that 46% of the passengers did not know the final destination of the train (Verhoef, 1984). The two groups using the horizontal structure (final destination and intermediate stops) were randomly ordered.

c) the rows
The vertical dimension of each panel presents trains in a chronological order; the first train to leave is positioned on top and the last train is on the bottom. In general, a chronological list can be regarded as an ordinal value of grouping and supports or even imposes an efficient search strategy. However, for passengers who do not know the departure time of their train, the order of the list is arbitrary and the passengers have to apply a random search strategy. For passengers who do not know the final destination of their train the vertical dimension of the chronological trains indicator is ordered randomly.

These theoretical considerations that refer to the structure of the information on the indicator led to the assumption that not all passengers recognise the structure and this might cause the serious problems already mentioned in chapter 10. An experiment was carried out to investigate this assumption.

11.5.2 Method

353 train passengers who had left Amsterdam Central Station participated in this experiment. The independent condition was a paper Amsterdam Central Station chronological trains indicator on which information on the structure was blacked out (see Figure 5). This information included the label of the columns and the content of the columns. The chronological trains indicator with structure information blacked out was the independent condition (see Figure 6). The blacked out version was presented after the passenger had used a normal (not blacked out version) for finding the departure times of five trains. The dependent variable was the answer of the passengers dealing with the structure of the indicator. The experimenter asked the following questions:

"Do you still know the difference between the left and the right panel?"

“Do you still know what kind of information was in this column?”

The experimenter pointed subsequently to the column final destinations column and the via column, which were blacked out. The answers on these questions were scored as ‘correct’ or ‘incorrect’.

A detailed description of the method for this experiment can be found in Annex 1 ‘Design indicator experiments‘.

Figure 5. The experimental chronological trains indicator

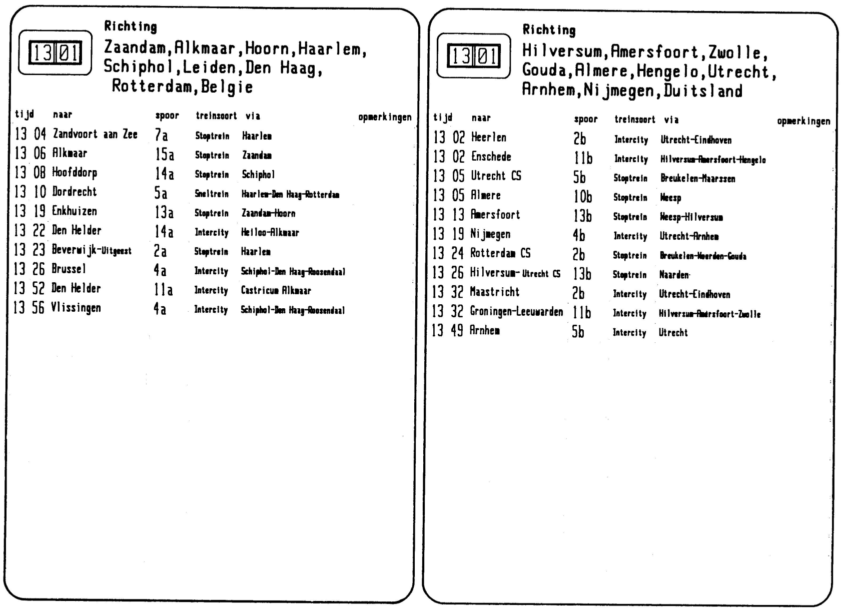
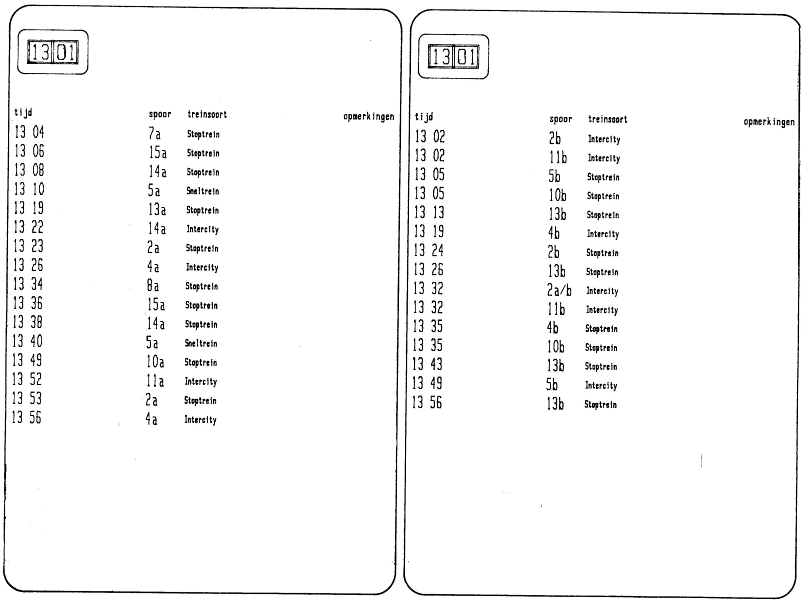


Figure 6. The experimental chronological trains indicator, structure blacked out



11.5.3 Results

353 passengers answered the questions on structure. The difference between the left and the right panel was only recalled by 15%. 'Final destination' was given as the answer by just 11% of the passengers when the experimenter pointed to that column. The last question, where the experimenter pointed to the 'via' column was correctly answered by 47%. Six percent gave a correct answer to all three questions on structure.
Table V summarises the results.

11.5.4 Discussion

Before interpreting the results, a few considerations should be made. As far as passenger experience is concerned, the question "What is the difference between the left and the right panel?" was answered after the passenger had used the panels five times. Therefore one might argue that 15% of the passengers recalling the difference between the two indicators is rather low. It suggests that they did not even notice, let alone use, the 'two panel structure' despite its obvious status in the explanation here.

The same rationale accounts for the column for the group trains, i.e. 'final destination'. The number of correct answers for that question was 11%. This percentage is not a strong indication for the efficiency of the column final destination.

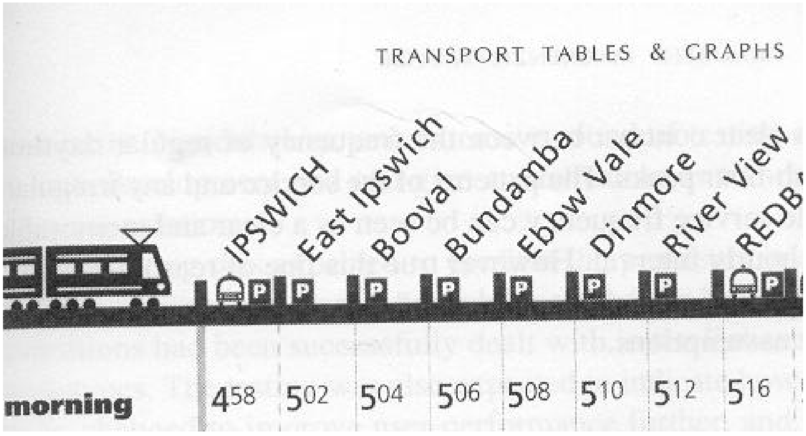
It should be noted that noticing and using the column for final destination does not guarantee correct performance. There are more findings suggesting that the column final destination is a randomly ordered, at least for some of the passengers. Earlier studies (Verhoef, 1984) had already indicated that 46% of the passengers did not know the final destination of the train. It should be noted in passing that included in this 46% are 9% who thought they knew the final destination but in fact mentioned the wrong destination. These data suggest that final destination is not an appropriate basis for the structure of passenger information and a moment's reflection supports this analysis – why does anyone other than the driver and the conductor need to know the specific nature of the final station before they turn round? This is a good example of making sure that the designer asks the *right* question of the user before designing an interface.

Table V. Percentage correct answers for questions on the structure of the chronological trains indicator

Structure recalled	Performance
difference between left and right panel	15% correct.
Contents of the column 'final destination'	11% correct.
Contents of the column 'via'	47% correct.
n	353

These experimental findings concerning the structure of the indicator board supported the assumption that the passengers did not know the structure, even after having used it several times. The failure rates suggested that there was definite room for improvement. The next section describes the development of a new structure and an experimental comparison of the structures.

Figure 7. Enhanced numeric prototype for a train service



11.6 Experiment 2: comparison of structure

11.6.1 Introduction

How should you structure information? A conceptual structure should, of course, be logical, though several 'logics' are possible. For instance, there are several ways to structure information about the departure time of trains, and many of these are used in practice in different countries. On British railway stations, the information is arranged by destination and the destinations are listed alphabetically. In Germany, the destination information is presented in chronological order. Netherlands Railways categorise trains that go in the same direction, but combine different destinations in chronological order. Often international trains are marked distinctly from national ones, e.g., using red rather than black letters in the information presented to passengers.

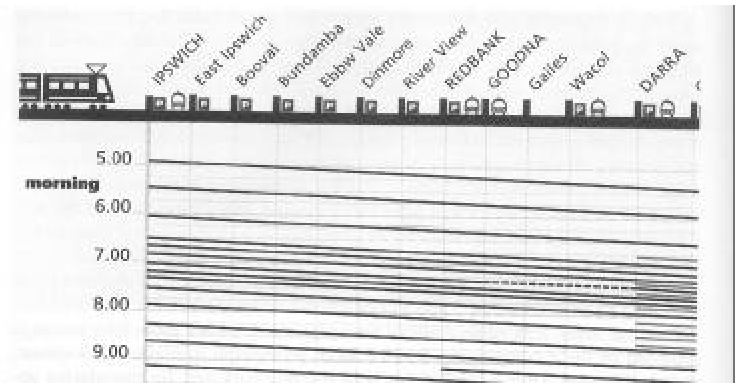
General cognitive psychology (e.g., Best, 1989) does not offer information that can be used to select the best structure for information on chronological trains indicators. Even Neisser (1976) goes no further than stating that what is perceived should fit in the schemata of the user. Such statements, whilst evidently true, do not provide much in the way of empirically or theoretically well-founded bases for designers to use.

The applied psychological literature is, however, more specific. MacKenzie-Taylor (1999) studied the presentation of timetable data. She compared three designs empirically.

- Standard - the existing alphanumerical Queensland Rail timetable.
- Enhanced numeric - the alphanumeric prototype timetable (See Figure 7. The standard and the enhanced differed in a graphical way. Both timetables presented arrival and departure information in a numeric fashion.
- Timelines, a linear graphic timetable in which the numeric timing points are replaced with linear representations with time on the x-axis and destinations in geographical order on the y-axis (See Figure 9).

Although this study was very extensive, going back to 1786, it does not relate how information on trains indicators should be structured.

Figure 9. Timelines prototype



Joshi (1996) also investigated the presentation of railway timetables and concluded that a graphical presentation was better than the table Indian Railways had used for 50 years. But here again, both timetables had the same conceptual structure; time on one axis and position on the other axis.

Adams et al. (1984) report a study that provides specific and useful information for designing indicators. They stated that destination on a signpost should be arranged by directions. For instance, all left side directions on the left of an indicator and all right side directions on the right on the indicator so that compatibility between the location of the destination and the direction in which to go is enhanced. The Amsterdam Central Station chronological trains indicator had two directional structures. The left panel presented the trains for the northwest and the southwest whereas the right panel presented the northeast and the south-east. In addition, on each line there was one train that is a specific direction. The reason for selecting a directional structure is that this leads to a distinct lay out (Adams et al., 1984). The drawback of this theory is that distinctness is often difficult to specify and they are in conflict with the next rather strong theories and findings.
Wright (1988) stated that signposts at elevators should not arrange information by direction (floor) but by destination. Research carried out by Spijkers et al. (1985) supports this theory. They also investigated the structure of information on signposts. Users performed better when the information was arranged in accordance with information already available to them; for example, known categories such as the alphabet. Spijkers et al. (1985) hypothesised that semantic categories of destinations on a signpost perform better than a random listing of destinations. The reason is that semantic categories enable the user to skip whole categories. For the same reasons they hypothesised that alphabetical lists would perform better than random lists. Structure often provides users with information about what they do *not* need to know, enabling them to concentrate on their real problems for which they seek a solution.

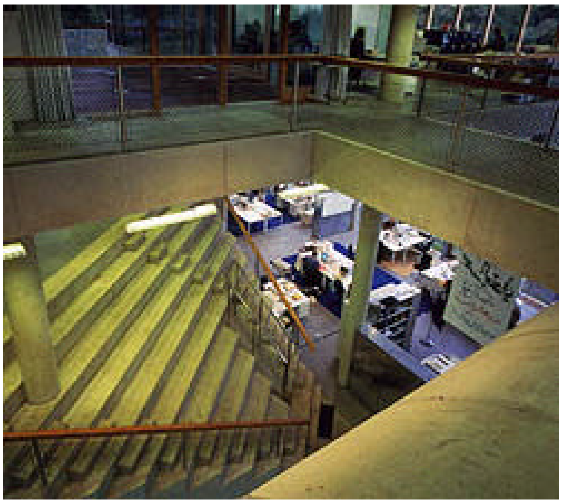
Spijkers et al. (1985) found that the best way to structure destinations is indeed alphabetically. Table VI summarises their findings. This table also defines the experimental conditions of Spijkers et al. in the values for structures presented in section '11.4 Which 'cognitive structures'?' of this Chapter. Comparing their experimental conditions is difficult because some experimental conditions included several values for structures. The extreme scores are for the single value of categorisations (random and alphabetical) and can be interpreted straightforwardly. So the conclusion is that a random structure is less efficient than an ordinal (alphabetical) structure.

Table VI. Way-finding performance and values for cognitive quantity

Structure	Correct	Values
random	49%	not nominal
random+categoric	79%	not nominal+nominal
direction +alphab.	62%	not nominal +ordinal
direction+categoric+alphab.	76%	not nominal+nominal+ordinal
categoric+alphab.	87%	nominal +ordinal
alphab.	91%	+ordinal
not investigated		interval
not investigated		ratio

Interval and ratio values were not investigated by Spijkers et al. Is their investigation still incomplete or is the typology of structures redundant when applied to structures for public information systems? Figure 10 shows a part of 'Villa VPRO', of the VPRO, an artistic Dutch broadcast company, whose broadcasting building is best characterised as a labyrinth (Zwaap, 1997). Having no system of corridors, no regular stairwells, no clear identifiable floor order, and even no rooms, the villa gives the impression of a physical chaos. It would seem to be a hard job to signpost such a building in a traditional way, i.e. using floor and room numbers. The designer solved this problem effectively by assigning a three dimensional number system to pillars. Theoretically this ratio system enables all those visitors who can count and can read numbers to find any

Figure 10. Interior of Villa VPRO



location effectively. The existence of a ratio sign posting in the Villa VPRO does not prove that a ratio structure is more effective than an interval, ordinal, nominal or random structure for way-finding. However, it is interesting to see that the designer solved this difficult problem consistently with the theory presented here. In addition, when empirically the opposite might be proven, it will be difficult to convince chess players, sailors and explorers that they are better off not using their traditional ratio navigation systems.

How can we translate these finding to chronological trains indicators? The Amsterdam Central Station chronological trains indicator presents trains (one on each line). This is a rather common way of presenting train travel information in stations in, for instance, Belgium, England, Germany, Italy, Luxemburg, Sweden, Switzerland and Tsechoslowakia. Figures 11 and 12 show two examples. The British Rail indicator in London Paddington in Figure 11 looks quite different from most other European railways. However, closer inspection learns that it has the same structure as the ones in Figure 13 and 12, the only difference is a reversed x and y-axis.

Figure 11. Chronological trains indicators in London Paddington

Figure 12. Chronological trains indicators in Paris, Gare du Nord

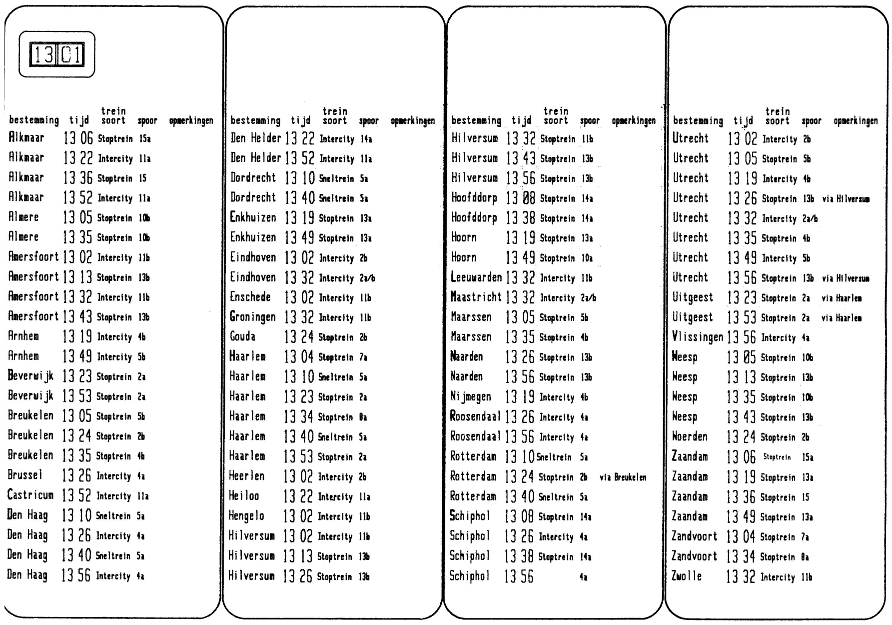
The identification for a train is its final destination. As discussed in section '11.5.4 Discussion', final destination is not a reliable source of information. Passengers might not know the final destination of their train. Even when passengers do know the correct final destination of the train, this information in not conclusive because there are still several trains that will arrive at that destination. Finally, the chronological departure order presented on the Amsterdam chronological trains indicator is not compatible with the arrival order of the trains presented. The train leaving first might be the last to arrive because of a lower speed, a detour or more intermediate stops. It is supposed that structuring travel information using the final train destination is a random structure for passengers.

Theoretically the categories of the Amsterdam Central Station chronological trains indicator for passengers are not mutually exclusive and are consequently, randomly ordered. Theoretically an indicator having an ordinal structure, or at least a nominal structure, should be better than an indicator having a completely random structure. To be more specific: an alphabetical list of destinations (ordinal structure) is better than a chronological trains indicator (a random structure). This hypothesis was investigated in the following experiment.

11.6.2 Method

304 train passengers who had left Amsterdam Central Station participated in this experiment. The independent variable was the value of indicator. The chronological trains indicator represented the random cognitive quantit and the alphabetical destinations indicator represented the ordinal structure. Randomly the passengers were assigned to either the random cognitive quantit or to the ordinal cognitive quantit group. All passengers got two indicators, a chronological trains indicator and an alphabetical destinations indicator. The order of presentations was random. The independent variable was the number of correct answers and the time needed to give that answer. The scoring is the same as described in Chapter 11. A detailed description of the procedure for this experiment can be found in Annex 1 ‘Design indicator experiments‘.

Figure 13. The experimental alphabetical destinations indicator



13 01

bestemming	tijd	trein soort	spoor	opmerkingen
Alkmaar	13 06	Stoptrein	15a	
Alkmaar	13 22	Intercity	11a	
Alkmaar	13 36	Stoptrein	15	
Alkmaar	13 52	Intercity	11a	
Almere	13 05	Stoptrein	10b	
Almere	13 35	Stoptrein	10b	
Amersfoort	13 02	Intercity	11b	
Amersfoort	13 13	Stoptrein	13b	
Amersfoort	13 32	Intercity	11b	
Amersfoort	13 43	Stoptrein	13b	
Arnhem	13 19	Intercity	4b	
Arnhem	13 49	Intercity	5b	
Beverwijk	13 23	Stoptrein	2a	
Beverwijk	13 53	Stoptrein	2a	
Breukelen	13 05	Stoptrein	5b	
Breukelen	13 24	Stoptrein	2b	
Breukelen	13 35	Stoptrein	4b	
Brussel	13 26	Intercity	4a	
Castricum	13 52	Intercity	11a	
Den Haag	13 10	Sneltrein	5a	
Den Haag	13 26	Intercity	4a	
Den Haag	13 40	Sneltrein	5a	
Den Haag	13 56	Intercity	4a	
Den Helder	13 22	Intercity	14a	
Den Helder	13 52	Intercity	11a	
Dordrecht	13 10	Sneltrein	5a	
Dordrecht	13 40	Sneltrein	5a	
Enkhuizen	13 19	Stoptrein	13a	
Enkhuizen	13 49	Stoptrein	13a	
Eindhoven	13 02	Intercity	2b	
Eindhoven	13 32	Intercity	2a/b	
Enschede	13 02	Intercity	11b	
Groningen	13 32	Intercity	11b	
Gouda	13 24	Stoptrein	2b	
Haarlem	13 04	Stoptrein	7a	
Haarlem	13 10	Sneltrein	5a	
Haarlem	13 23	Stoptrein	2a	
Haarlem	13 34	Stoptrein	8a	
Haarlem	13 40	Sneltrein	5a	
Haarlem	13 53	Stoptrein	2a	
Heerlen	13 02	Intercity	2b	
Heiloo	13 22	Intercity	11a	
Hengelo	13 02	Intercity	11b	
Hilversum	13 02	Intercity	11b	
Hilversum	13 13	Stoptrein	13b	
Hilversum	13 26	Stoptrein	13b	
Hilversum	13 32	Stoptrein	11b	
Hilversum	13 43	Stoptrein	13b	
Hilversum	13 56	Stoptrein	13b	
Hoofddorp	13 08	Stoptrein	14a	
Hoofddorp	13 38	Stoptrein	14a	
Hoorn	13 19	Stoptrein	13a	
Hoorn	13 49	Stoptrein	10a	
Leeuwarden	13 32	Intercity	11b	
Maastricht	13 32	Intercity	2a/b	
Maarssen	13 05	Stoptrein	5b	
Maarssen	13 35	Stoptrein	4b	
Naarden	13 26	Stoptrein	13b	
Naarden	13 56	Stoptrein	13b	
Nijmegen	13 19	Intercity	4b	
Roosendaal	13 26	Intercity	4a	
Roosendaal	13 56	Intercity	4a	
Rotterdam	13 10	Sneltrein	5a	
Rotterdam	13 24	Stoptrein	2b	via Breukelen
Rotterdam	13 40	Sneltrein	5a	
Schiphol	13 08	Stoptrein	14a	
Schiphol	13 26	Intercity	4a	
Schiphol	13 38	Stoptrein	14a	
Schiphol	13 56		4a	
Utrecht	13 02	Intercity	2b	
Utrecht	13 05	Stoptrein	5b	
Utrecht	13 19	Intercity	4b	
Utrecht	13 26	Stoptrein	13b	via Hilversum
Utrecht	13 32	Intercity	2a/b	
Utrecht	13 35	Stoptrein	4b	
Utrecht	13 49	Intercity	5b	
Utrecht	13 56	Stoptrein	13b	via Hilversum
Uitgeest	13 23	Stoptrein	2a	via Haarlem
Uitgeest	13 53	Stoptrein	2a	via Haarlem
Vlissingen	13 56	Intercity	4a	
Weesp	13 05	Stoptrein	10b	
Weesp	13 13	Stoptrein	13b	
Weesp	13 35	Stoptrein	10b	
Weesp	13 43	Stoptrein	13b	
Woerden	13 24	Stoptrein	2b	
Zaandam	13 06	Stoptrein	15a	
Zaandam	13 19	Stoptrein	13a	
Zaandam	13 36	Stoptrein	15	
Zaandam	13 49	Stoptrein	13a	
Zandvoort	13 04	Stoptrein	7a	
Zandvoort	13 34	Stoptrein	8a	
Zwolle	13 32	Intercity	11b	

11.6.3 Results

The mean score for the alphabetical indicator was 0.97 and 0.92 for the chronological indicator (T-test, t=4.36, df=1185, p<0.001). This might be expected since the task was a somewhat easy search task. Errors that were made were predominantly visual confusions, for instance:

- Haarlem instead of Heerlen
- 23 instead of 32
- 05 instead of 50

A much more marked difference appeared in the selection of sub-optimal trains: 3% for the alphabetical but 14% for the chronological indicator. The mean search time for the chronological indicator took 7 seconds and the alphabetical indicator 4 seconds, per train found (Anova f=15.2, p<.001). This is nearly twice as long for the chronological indicator.

The mean delay that the passengers would have experienced if they had really taken the train they selected was, when using the chronological trains indicator, four times greater than when using the alphabetical destinations indicator: 3.6 minutes to 0.9 minutes. This shows an even greater difference between the different types of presentation.

'Junction' stations give more problems than do other stations and, with these, the chronological trains indicator performs much more poorly than does the alphabetic alphabetical destinations indicator. The cause of these problems is that the train schedules of junction stations are complicated. These kinds of station can often be reached by both 'all stations trains' and 'express trains'; they can be reached directly or by a detour; and several trains for this kind of station maybe leaving at almost the same time.

After having searched for five departure times on a chronological trains indicator and five on an alphabetical destinations indicator, the passengers compared indicators (see table VII). These subjective scores were 6.1 for the chronological trains indicator and 8.2 for the alphabetical destinations indicator (score 1 was poorest, score 10 was best).

Table VII. Performance of passengers for using timetables having several values for cognitive quantit

	Value of structure	
	random trains chronologically	**ordinal** destinations alphabetically
Correct selections	0.92	0.97
sd	0.275	0.171
n	715	735
Mean delay	3.6 min.	0.9 min.
Mean search time	7 sec.	4 sec.
Passenger evaluation (min=0, max=10)	6,1	8,2

It can be concluded that passengers perform better on all categories measured with an alphabetic list of destinations (an ordinal list) that with a chronological list of trains (random list).

11.6.4 Discussion

Before interpreting the results, a few considerations should be made.
First, there are some differences between passengers searching for their train in a station hall and passengers in this experiment searching for trains mentioned by the experimenter. In real situations, passengers will only look for one train, whereas for this investigation passengers were asked to search for the departure times of five trains. This extra practice might have caused a slight advantage for the experimental situation.
Secondly, there were several differences between the experimental task conditions and the task in real practice. In the experiment every station was asked for an equal number of times; in reality main line junction stations cause more problems than line stations because such junction stations have more route options (Intercity or all stations trains, trains having a detour route). In addition, more passengers travel to junction stations than to line stations. Only trains and destinations considered were those that:

- were inland only (an exception was made for Brussels because many trains are more or less an inland train);
- were presented on the indicator;
- would leave within one off-peak hour;
- would depart in accordance with schedule.

These differences will cause better over-all performance in the experimental situation than in real practice. Experimental results confirm this hypothesis for number of correct trains, mean delay and search time. In the field Experiment 1: observation of performance, carried out with the real indicator in the station hall of Amsterdam CS, described in chapter 10, the figures are: 62% correct, with potential delays of 6 minutes and an average search time of 20 seconds. In the experiment carried out in the train with indicators presented on paper the figures for the trains indicator are: 92% correct, delay 3.6 minutes and a mean search time of 7 seconds.
Finally, it should be noted that, as far as passenger experience is concerned, the chronological trains indicator had already been in use for several months, and 43% of the passengers who participated in this investigation had been looking at this chronological trains indicator some minutes before they did the experiment. An alphabetical destinations indicator had probably never been seen before. This extra practice might have caused a slight advantage for the chronological trains indicator.

The interpretation of the results of this experiment can be straightforward. All measurements carried out in the experiment indicated that an alphabetical destinations indicator performs better than does a chronological one. These results are consistent with the data from Spijkers et al. (1985) discussed in the section '11.6.1, the Introduction, and an experiment described in the section 11.7.2. On a more general level it can be concluded that human search performance is better when the information has an ordinal structure than when the information has a random structure. The suggestion is that a higher value for structure means better human performance.

When cognitive psychology suggests an unusual and more user efficient design the following types of disadvantages are often mentioned.
A cognitive disadvantage of a destinations indicator is that passengers are not familiar with the suggested design and structure, in this case a destinations indicator/ structure. Most dynamic public transport indicators have a trains (or airplanes) structure and other information are destination structured too (platform indicators, timetable posters and books). However …

- The experiments showed clearly that this was not correct.
- System separation between the destinations indicator and train indicator structured systems is rather large and consequently, will have a low effect, if any at all. Experimental data support this theoretical conclusion. Only 6% of the subjects were able to answer all three questions on structure correctly. The questions were asked immediately after the subjects had used the structure five times. When there is negative interference because there are inconsistent systems, performance on the design presented as the second one should be lower than the design presented first. Second presentation performed equal or better than the design presented first.
- Destinations indicators will perform worse than trains indicator because passengers are not familiar with the structure. The structure is destinations ordered alphabetically. It is unlikely that the passengers do not know either the alphabet or their destination.
- The answer to the question why Railway companies, nevertheless, install inefficient trains indicators rather than efficient destinations indicators, has already been given in section 11.3.2. Trains indicators present the task structure of the Railways (driving trains). Destinations indicator presents the task for the passenger (selecting a destination).

In 2002 Netherlands Railways were to have installed a destinations indicator in Schiphol Station. See Figure 14.

Figure 14. The destinations indicator Netherlands Railways intended to install in Schiphol in 2002

11.7 Generalisation of knowledge

11.7.1 Interface technology generalisation 1: train indicator

The indicators in the experiments show several trains. On stations there also are indicators showing information on only one train. Figure 15 presents two examples. Before reading further it is worthwhile to examine the structure of these two, twin train indicators found in the London Underground.

The left structure, the usual one, is a geographical one. The right structure, hard to find on any stations all over the world is an alphabetical one. Which one is better?
MacKenzie-Taylor (1999) carried out an extensive investigation on presenting this kind of information. This investigation was described in an earlier section. It was expected that timelines would be better than

alphanumeric timetables. However, using timelines 72% of the respondents could still not specify the departure times with an accuracy better than five minutes. The Solution presented in this thesis suggests an explanation for not finding any improvement. The designs used were different regarding the presentation (alphanumeric tables versus a graphical table). *Visual form* of the elements, in this case alphanumerical and graphical, is not the fundamental property in this task, but is secondary. Cognitive quantit might be more relevant. All her conditions were two-dimensional tables with time on one axis and stations on the other axis. Figure 15 shows that there are at least two cognitive structures for presenting route information to passengers. Neither the theory presented by MacKenzie-Taylor (1999) nor her experimental results provide an answer on the question, which one of the figure below is better for passengers.

Figure 15. Two cognitive quantits *for information of one line*

The Solution presented in this thesis suggests an answer. Both structures are nominal, assuming there are not stations having the same name. The geographical structure is an ordinal structure for designers, train drivers, passengers familiar with the line and passengers in the train. For none of these groups is the indicator intended – they already know where they are going. The alphabetical, and rather uncommon structure, makes sense to passengers standing on a platform who are unfamiliar with the underground system and in need of useable information, such as foreign tourists.

11.7.2 Interface technology generalisation 2: timetable books

Weitenberg (1998) recently studied the cognitive quantit of passenger information for paper timetables. She came to the conclusion that ordinal structures are better than random ones in designing a paper train timetable book. She compared two paper timetables, one with a list of destinations (see Figure 17) and one with a structure based on train lines, as the current timetable book of Netherlands Railways (see Figure 16). She concluded that an alphabetical list of destinations is better than a chronological list of train lines. A structure based on destinations increased search time 1.5 times, at least for those passengers who could actually find their train (n=19). Most passengers (56.1%) were not able to find their train using a chronological train lines structure as compare to an alphabetical list of destinations. For the alphabetical list of destinations this failing percentage was only 1.8% (n=19).

Figure 17. The experimental train timetable of Weitenberg

1 Amsterdam - Leiden Centraal

via Haarlem

Amsterdam CS		*03*	*11*		*21*	*33*	*41*
- Sloterdijk		*09*	*17*		*26*	*39*	*47*
Haarlem		*20*	*26*		*35*	*50*	*56*
Haarlem	*08*		*28*	*38*			*58*
Heemstede-Aerdenhout	*13*		*33*	*43*			*03*
Voorhout	*23*		|	*53*			|
Leiden Centraal	*29*		*47*	*59*			*17*
Leiden Centraal	*34*		*48*	*04*			*18*
Den Haag CS	*48*		|	*18*			|
Den Haag HS			*58*				*28*
Rotterdam CS			*16*				*49*
Dordrecht			*42*				*13*

Figure 16. The experimental destination timetable of Weitenberg

Amsterdam CS

Aalten *19, 49 min over overstap Arnhem*
Abcoude *12, 22 min over rechtstreeks Breukelen*
Akkrum *36 min over rechtstreeks Leeuwarden*
Alkmaar *22, 52 min over rechtstreeks Den Helder*
- Noord *22, 52 min over rechtstreeks Den Helder*
Almelo *6 min over rechtstreeks Enschede*
Almere CS *17 min over rechtstreeks Lelystad*
- Muziekwijk *24 min over rechtstreeks Lelystad*
- Parkwijk *24 min over rechtstreeks Lelystad*
Alphen a/d Rijn *0, 7, 30, 37 min over overstap Leiden*
Amersfoort *6, 36 min over rechtstreeks*
Anna Paulowna *22, 52 min over rechtstreeks Den Helder*
Apeldoorn *6 min over rechtstreeks Enschede*
Appingedam *36 min over overstap Groningen*
Arkel *3, 19, 33, 49 min over overstap Utrecht*
Arnemuiden *0, 30 min over overstap Roosendaal*
Arnhem *19, 49 min over rechtstreeks Nijmegen*
Assen *36 min over rechtstreeks Groningen*

11.7.3 Domain generalisation: computer program menus

So far the conclusions regarding the values for structure have only been applied to single dimensional structures for travel information on sign-posts and train schedules. However, the theory does not impose this restriction. At this moment, using this theory, a design is elaborated for a more complex system than signposts and train schedules. A program has been started to establish how to improve human computer interfacing.

Figure 18. A random list, the Word main menu

The first step in this wider program was to establish the value of structure for the interface. Figure 18 shows the menu interface for such a complex system, the Word main menu. The cognitive quantit used is a hierarchical one, commonly indicated as a menu. We will restrict ourselves to one dimension of that structure, the main menu. Suppose a user wants to 'Edit a file', 'View tools for editing a file' or 'Help on viewing tools for editing a file'? The only way to find information on those questions is 'trial and error'. Theoretically the main structure of the menu has a random structure; the options are not even mutually exclusive. In common language it is chaotic and, theoretically, problems with navigation are to be expected. The same analysis can be made for the Windows start menu, Excel's main menu etc. The conclusions are the same too. An unreported study confirmed this hypothesis and showed that even expert computer users only selected the correct option for 40% of simple word processing tasks (63 observations).

The next step is to design a structure that is not random but nominal or, if possible ordinal. Cooper (1995) developed such a structure for menus (see Figure 20). In his main menu there are three options: 'Program', 'Document' and 'Element of documents' (e.g., a word, sentence, character, Chapter, footer). 'Program' is very general; it includes commands that are applicable for more or less all documents. 'Document' is more specific; it includes commands applicable for one document only. With the quantitative variable 'level of specification' as criterion for allocating word processor commands to main menu options, it is an ordinal structure.

Figure 20. An ordinal computer main menu, the Cooper menu

Elements of doc.	**Document**	**Program**

Its ordinal structure becomes even stronger when it is extended on the left or on the right side (see Figure 20). The ordinal structure can easily be extended to the left with an option 'Programs', referring to the operating system level. To the right 'Element of documents' can be specified in 'Elements of document' including words, sentences and lines, and in 'Element of document', including the lowest not further expandable elements. For a word processor a lowest level element would be a letter, for a picture program a pixel and in a spreadsheet the lowest level would be a cell or a number. Consequently, with the Cooper main menu it should be more easily to find commands than with the Word main menu.

Figure 19. An extended ordinal computer main menu, the Cooper menu

Element of doc.	**Elements of doc.**	**Document**	**Program**	**Programs**

I found, in a study with 105 observations, that the nominal menus such as the Cooper main menu, scored better (54% correct answers) than chaotic menus such as and the Word main menu (40% correct answers) (see Table VIII). In view of the fact that most subjects were experienced computer users, of whom several were familiar with the menus standards used for the Word Main menu and that no explanation at all was given for the nominal menus, the results are promising. Most errors made were caused by the ambiguous Word terminology had to be used in order not to change two fundamental variables at the same time (cognitive structure, the focus of this experiment and language number and structure that had to be the same for all conditions).

Table VIII. Number of correct selections for chaotic menus and nominal menus

Chaotic menus	correct	n
Word main menu	12%	18
Word submenu	48%	23
total	**32%**	**41**
Nominal menus		
Cooper main menu	67%	21
Verb noun menu	59%	16
Verb noun menu	41%	27
total	**54%**	**64**

11.8 Conclusion

A theoretical analysis including physiological, cognitive and developmental psychology suggests that cognitive quantit is a fundamental property of a field with cognitive elements, even if that structure is essentially non-existent, as in the random 'pile of bricks' structures that are to be found in real applications such as Windows menus.

Several experiments reported in this chapter support this suggestion, and the suggestion that structure can be beneficial for users. The experiments showed that changing the cognitive quantit of an interface affects human performance. With nominal structures humans perform better than with chaotic structures. The structures commonly used with the type of interface investigated and in the domains analysed are of the chaotic types, for instance the trains indicators of stations in Amsterdam (2002[1]), Antwerp, (1992), Brussels (1987), Edinburgh (1986), Frankfurt, (1987), London Kings Cross (1986), London Liverpool Street (1986), London Paddington (1988), Milan (1985), Munich, (1988), Paris Gare du Nord (2002), Paris Gare Montparnasse (1986), Prague (1988), Rotterdam (2002), Stockholm (1986), Stuttgart (1987), The Hague (2002) and

[1] This number refers to the year the of observation and the photograph was made.

Zurich (1987). In research focussing on the domain of travel information the concept of cognitive quantit was, nevertheless, not identified by Adams et al. (1984), Joshi (1996), or MacKenzie-Taylor (1999). Cognitive quantit was implicitly or explicitly identified by Spijkers et al. (1985), Weitenberg (1998), Wright (1988) and Zwaap (1997).

MacKenzie-Taylor (1999) focussed on the presentation of information for one train. Her experiments did not answer the question what is the best way to present the information nor was it possible to answer the question: "Which of the two route strips in figure 15 is best?" The experiments carried out for this thesis focussed on the presentation of information for several trains. Nevertheless the Solution presented in this thesis suggested that a fundamental variable was missing in the experiments of MacKenzie-Taylor and suggested an answer to the route strip question of Figure 15. These suggestions might indicate that the Solution is also domain and interface independent.

The experiment of Weitenberg (1998) provides information on how interface independent the conclusion is. She did an experiment in the domain of travel information, not with an electronic but with a paper timetable. The conclusion of her study was that the timetable having a train direction cognitive quantit is far less efficient than a timetable where the cognitive quantit is based on destinations, but of the passengers and not of the trains.

A theoretical analysis and experimental data from a pilot study suggests that the concept of cognitive quantit is domain independent too. The analysis suggests that computer menus mostly used in the computer operation domain (for instance Microsoft and Apple applications) are chaotic and consequently, will lead to navigation problems. This conclusion does not contradict an as yet unreported study and everyday experience. The conclusion of that study predicts better navigational performance on interfaces having cognitive quantities of the types interval or ratio. This prediction is correct for navigation at sea, in the air, in space and in chemistry. In all these domains navigation performance of users is higher than in the domain of personal computer operation.