In Part I, ‘Method’, it was concluded that in a scientific context, a property approach to interface design is to be preferred above an interface technology approach. The interface technology approach is driven by the specifications of the object that are needed for technological realisation. Assumptions about what potential users can and cannot do are often implicit. It is technology that drives the psychologists to answer questions to solve technological problems, thereby placing the cart firmly well in front of the horse. The technology changes rather rapidly over time and, therefore, the human being has to change accordingly. The human being, at the other hand is much less variable. Biological changes in a species take several thousands of years.

The rather invariable human has to change and the rather flexible and changing technology becomes the fixed part of the design equation in the technology drive approach. In the property approach this situation can be turned around. The human being is given as fixed and it is the technology that has to adapt. Psychology is leading and can ask technological questions, not to solve technological problems but rather if they do not understand psychological specifications. In terms of experimental design this can be viewed as a reversal of the roles of dependent and independent variables. In plain language it is like swapping master and slave.

The proposal is that changing what can be changed easily is more effective than trying to change what is hard to change, especially when changing is no option. The proposal is that the interface element properties approach will lead to better scientific and practical results than will the interface technology approach. This part presents several experimental tests of this hypothesis.
We selected four interface element properties of increasing complexity to test this hypothesis, starting with two visual properties of interface elements. To get used to the approach we start with visual size, a visual property that is easy to comprehend. The next property used to perform the test is visual distance. Two subsequent chapters test cognitive properties: cognitive number and cognitive structure. This order of properties is chosen from the point of view of the development of the argument, with visual size as the simplest property and cognitive structure as the most complex. In practice a designer should, of course, operate in the reverse order, starting with the task and the structure of the system and subsequently filling in the details such as visual form and size at the last moment.

In the theoretical sections of each chapter we describe why the property is relevant for the human component and the system component. The specific nature of the property under study is distilled out of an analysis of what is usually a wide range of overlapping but not always inclusive concepts. This may appear to be a linguistic game, attempting to find the best definition, but it is a well-understood methodology in linguistic philosophy that attempts to find the term that is most compatible with the underlying concept, while examining the many words used. For instance, the term visual distance is finally used here to cover the concepts that are also used such as: closeness in space, eccentricity, optimum viewing area, peripheral vision, proximity, proximity and spatial separation. This process searches for the best level of description for a phenomenon that is to be labelled and that provides for generalization. Another reason for playing this linguistic game is that words are the tools for building theories. Professionals and scientists need perfect tools, as any professional does, especially when they are working at the frontier of knowledge. For psychologists working in design teams, accurate concepts and words are also needed because they often have to debate with other experts not having a psychological education, including technicians and users, allowing them to have opinions on human behaviour.

In the experimental sections of each chapter we describe a practical design problem, the usual solution for the problem and what would be the alternative solution using the interface element approach. The final section of each experimental chapter of this thesis tests the generalizability of the theoretical and empirical results. The results are applied in the design for interfaces using other interface technologies. When the tests were performed with traditional ‘light’ and ‘button’ interfaces the results are then applied to ‘screen’ interfaces. Another generalizability test is
application using other domains. When the tests had been performed with
the presentation of travel information the results of the tests are then
applied to, for instance, the presentation on information on how to operate a Word processor.

When these empirical and theoretical generalizability tests are successful,
the knowledge obtained is fundamental and no further research is
required. At the most some fine-tuning at the product level should suffice.
It is not the aim of this thesis to promise the world. To illustrate the fact
that having fundamental knowledge no further research is required Figure
1 presents the very first proposal of a touch-screen ticket vending
machine (Verhoef, 1999). This touch screen interface was based on many
experiments on ‘hard button’ vending machines of which some are
reported in this thesis. The final touch screen interface was implemented
three years later. Figure 2 shows that, no fundamental changes in the very
first proposal were needed. There was some fine tuning based on
empirical research with several hundreds of passengers.
Figure 1. **One of the very first psychological drawings of the touch-screen train ticket vending machine (Verhoef, 1999)**

<table>
<thead>
<tr>
<th>Treintaxi</th>
<th>Aalten</th>
<th>Geen korting</th>
<th>2de klas</th>
<th>Enkele reis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railrunner</td>
<td>Abcoude</td>
<td>Korting</td>
<td>1ste klas</td>
<td>Retour</td>
</tr>
<tr>
<td></td>
<td>Akkrum</td>
<td></td>
<td></td>
<td>5- retour</td>
</tr>
<tr>
<td></td>
<td>Akhmaar</td>
<td></td>
<td></td>
<td>kaart</td>
</tr>
<tr>
<td></td>
<td>Almeo</td>
<td></td>
<td></td>
<td>Weekend</td>
</tr>
<tr>
<td></td>
<td>Almere</td>
<td></td>
<td></td>
<td>retour</td>
</tr>
<tr>
<td></td>
<td>Aphen ad Rijn</td>
<td></td>
<td></td>
<td>Avond retour</td>
</tr>
<tr>
<td></td>
<td>Ameland</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Amersfoort</td>
<td></td>
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<tr>
<td></td>
<td>Amsterdam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amsterdam B.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. **The final product as it is installed in 2002**

<table>
<thead>
<tr>
<th>Enkele reis</th>
<th>Almere Strand</th>
<th>1e klas</th>
<th>Vol tarief</th>
<th>Vandaag geldig</th>
<th>1 ticket</th>
<th>2 tickets</th>
<th>3 tickets</th>
<th>4 tickets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dagreiz</td>
<td>Wilzig bestemming</td>
<td>2x klas</td>
<td>Korting</td>
<td>Toorder datum</td>
<td>1 ticket</td>
<td>2 tickets</td>
<td>3 tickets</td>
<td>4 tickets</td>
</tr>
</tbody>
</table>

Why designers can’t understand their users
8. Visual size

8.1 What is 'visual size'?

Visual size of an element, in an ergonomic context, is defined as the projected size or the surface an element occupies on the retina. There are several differences between the perceived visual size of an element on the retina and the full size of an element, between what is there and what the viewer experiences.

a) Size constancy
The visual appearance of an object is focussed by the lens of the eye to make the image of a large object fit on the small retina. Because of this clustering visual size actually is two-dimensional. It is represented by an angle, a scalar value which is determined by the combination of the distance to an object and the size of that object. The interpretation of size by humans is one dimensional because of the process of size constancy (Kreh, Crutchfield and Livson, 1969). Humans are able to re-establish the full size using depth cues and experience to unpick the combination of object size and distance that result in the initial retinal projection area.

b) Visual angle
When the visual angle decreases from 90º, then the perceived size decreases as well. Consequently, visual performance decreases (Brand & Judd, 1993).

c) Irradiation
Irradiation can cause physical size and perceived size to differ. When characters are white, the background is dark and the text is back lighted, then some of the light of the white character area will cross the border of white and dark. This increases the white area and consequently, the size of the white characters. Walraven (1978) showed that irradiation and a
well-selected form could increase reading performance by 50%, even when visual size is decreased.

8.2 Why ‘visual size’?

Psychologists and ergonomists have investigated the effects of visual size quite extensively for its effect on readability - how easy it is to read letters, words and whole texts (Adams, et al., 1984; Bouma, 1989; Dul and Weerdmeester, 1994; Grandjean, 1988; Vartabedian, 1971; Voskamp, 1991). Handbooks such as Sanders and McCormick (1992) have summarised the results of these investigations under the heading ‘visual acuity’. It has been shown that, in practice, character height is a good predictor of readability. As the height to width ratio of characters is fixed within quite small margins, size could be reduced from a two-dimensional area property to a one dimensional height property, as a way of indicating readability. For designers size is relevant because a designer has to select a size for an element. Designers must also solve the problem of fitting the required numbers of objects, having specified sizes, within the total area available. When sizes are not specified a designer will either be unable to materialize the design or has to make personal assumptions about what is needed in order to complete the design task.

Every visual object has a size that can be represented as a meaningful scalar quantity. There is no formal relationship between size and other visual properties such as form, luminance, colour and flashing, except for those effects on perceived size mentioned above due to visual angle and irradiation.

As there are both physical and physiological bases for the property size, and as size is a relevant property for a designer and is independent of other visual properties, the proposal here is to consider visual size as a fundamental visual property in a structure of human performance.

8.3 Which ‘visual sizes’?

The lower threshold for identifying differences in one-dimensional sizes for characters have been well established. Wickens, in his handbook (1992), states that the region of the fovea with the highest acuity forms an
angle of 2 degrees surrounding the centre of fixation. Grandjean (1988) reports a figure of 1 degree. Leebeek (1983) states that a detail of 1 millimetre is visible from a distance of 3 meter, which is approximately 1 sec of arc, within foveal vision. Using characters that are much larger than necessary for readability will actually decrease reading performance because fewer words can be read per eye fixation and more return sweeps are needed. There may, therefore, be an optimal range of sizes depending, nevertheless, on the task being required of the viewer.

A threshold for searching elements in a visual field is more difficult to establish. The process behind tasks like identification within the visual focus, such as reading, and search within a visual field, such as finding an entry in a list of destinations, have something in common. Both tasks require the discrimination of differences. For reading, the different letters that can and have to be discriminated are presented within the focus area (McConkie & Rayner, 1975), and for search the difference is within a larger area, for instance a page with railway destinations, thereby often requiring eye movements although internal search processes operate equally well within single fixations. It is to be expected that for searching elements in a field there is also a lower threshold. Vartebedian (1971) found an effect of character size on search speed. Displays of uppercase letters (large size) are searched 13% faster than those of lowercase letters (small size).

The first experiment reported here demonstrates how visual size was isolated to solve a design problem and how the effect of visual size on visual search performance, in practice, was established.
8.4 Experiment: the effect of size on visual search performance

8.4.1 Introduction

The effect of size on visual search performance can be established by searching for an element in a list. In practice passengers perform such a search task frequently; for example, when they are searching for a departure time in a timetable and looking for a specific station on a ticket vending machine. For the latter, alphabetic lists are commonly used and the entries are formed using the letters and order of the alphabet. There is no common (standard) way to present the entry of a list of destinations on train ticket vending machines. The British, the Swiss and the Italian Railways had no special presentation for entries (see Figure 3).

Figure 3. Entries and elements presented in the same way, (Swiss Railways)
Netherlands Railways, in contrast, used a variety of solutions to the problem of how to present entries in a list of destinations on a ticket machine.

- One solution was an empty line with a large entry character having a reversed luminance contrast direction (see Figure 4 or the application of this solution on the 80 buttons/destinations ticket vending machine of the eighties). This solution was applied to the Makomat N-126, a 120 destination button ticket vending machine used in the seventies (Lagrand, 1978).

Figure 4. Empty button with a large entry character having a reversed luminance contrast direction for entries, NS

- Contrast is a very effective way (Petersen & Dugas, 1972) of marking an entry.
- The effect of using an empty line for presenting an entry was a reduction of the number of stations for which the vending machine could sell tickets by approximately 20%. When empty lines are used for entries, these lines could no longer be used for destinations. This approach supports visual search, especially if the empty line is filled.
with a single letter (See Figure 4 and 6), as the search problem is reduced in the first instance to one in 26. However the extra space required makes this a potentially expensive option. More economic and equally effective ways of presenting the entry might be possible.

- The other solution was a slightly larger first character of an entry. This approach changes the nature of the search task without sacrificing buttons on a display or requiring significantly extra space on the button. Readers now can start searching on the initial letters before concentrating within the section delineated by the appropriate initial letter on the button.

**Figure 5. A slightly larger character for a new entry, NS.**

*Here all the buttons can be used to sell tickets.*
Which of all these ways to mark entries is the most effective? What makes a particular design choice fit for purpose?

In accordance with the theoretical framework described in Chapter 5 an entry of a list can be presented by having different visual element or visual field properties, i.e. a different size, form, luminance, colour, flashing rate, number, distance or structure. It was expected that the property of difference in form (e.g. another font), would not make the entry more conspicuous. Having a few characters in another font is not very conspicuous and therefore inappropriate for search purposes, especially outside the fixation area. There are other reasons for using form differences systematically, but these relate to different tasks, other than visual search, and can mark cognitive structures. Presenting entries in another luminance (e.g. grey characters) would reduce contrast and consequently, readability. That would not normally be acceptable for search either except for cueing the requirement that lower luminance elements are to be ignored from the start. Using colour as a code for an entry would not make the entry much more visually conspicuous because
peripheral sensitivity for colours decreases, especially when the elements are small.

The properties that remain as candidates for coding the information are: size, distance, structure and contrast. Where colour gives the strong impression of helping visual search processes this may well be the result of the discriminable contrast differences associated with differences in hue. These are all factors that can be distinguished in both foveal and peripheral vision. Presentations using these properties for entries were designed (see figure 7) and the effects of these properties were investigated.

This Chapter focuses on the effect of size. It was hypothesized that the larger the size of the entry is the shorter the search time will be. However, the maximum size chosen in the experiment was the maximum size possible on the labels on the vending machine. Therefore an effect of size might not be measurable using the sizes in the experiment. To increase any effect, stress was introduced in the experiment. In addition, it can reasonably be argued that stress is realistic for departing passengers.
8.4.2 Method

90 employees of Netherlands Railways and 80 students of Utrecht University participated in this experiment. The independent variable was the presentation of the entry. There were three presentations differing in size only (see figure 7).

- No difference in size of the first character and subsequent characters: there was no label for the entry (the destinations starting with a specific letter of the alphabet) and the first element of an entry was presented in the same way as the other entries. There was no difference in size although the first letter of a destination name was larger because it was in the upper case of the same font size.
• Small difference in size of the first character of the first element in the entry.
• Large difference in size of the first character for the first element in the entry.

The experiment also included entries differing in contrast and entries having the letter of the entry in a separate field. Those presentations are not relevant for size and not discussed in this chapter. As the differences in search performance were expected to be small, stress was introduced, in order to magnify the differences in performance, in half of the subjects. Those subjects were told that the better they performed, the higher the reward would be. Netherlands Railways employees were rewarded with coffee machine coins and the students were rewarded with free travel tickets.

The subjects started with an exercise to practice the search procedure. Subjects were first presented with pictures of objects like a suitcase, a clock, a car and they had to press the button next to the appropriate label when a target such as suitcase, clock or car was presented. After these three practice examples the experiment started.

After pressing a start button the target destination to press appeared on a computer screen. The subject pressed the button of that destination on a panel having destinations and entries presented in one of the seven ways. A computer recorded the time between the moment the destination was presented on the monitor and the time the subject pressed the button. The subjects pressed the buttons for 17 destinations that were presented in a random order. Each destination was presented an equal number of times. When a subject made an error and noticed this error they had the opportunity to press the correct button. The administration of the experiment was carried out by a student assistant and reported in a student’s paper (De Bruijn, 1986).

8.4.3 Results

The over-all mean reaction times for the three sizes were 3.31 seconds. With no difference in size, reaction time was 3.2 seconds, with a small difference in size the reaction time was 3.17 seconds and with a large difference in size the reaction time was 3.15 seconds. In the no size difference the reaction time was longest 3.3 seconds. There was no significant main effect for size (T (1185)=1.35; p>-.05). This failure to find an effect of size was anticipated, which is why the stress condition was used. Size did interact with stress (T(387)=1.69, v=406, p<0.05) and
for no size difference - large size difference a significant effect was found (T(387)=2.13, p<0.025). Unfortunately the effects of stress on large and small size are not reported. 

It is concluded that an effect of size was found, even though a degree of stress was required for it to make a significant difference in performance.

8.4.4 Discussion

When interpreting the results, it should be noted that an empty line also coded the entries differing in size. This empty line was needed for all conditions to have the same number of elements. This empty line could also be used as a visual cue to find an entry and so reduce any effects of size that were to be found in this experiment. The first letter was always somewhat larger, being in upper case. This will also diminish any effects of letter size measured in this experiment.

The effect of an empty line and the effect of having only size values in the lower part of the size range impaired the measurement of an effect of size. Nevertheless, under stress, an effect was measured. It can be concluded that entries having a larger font first letter will be found faster than entries having first letters of the same font size.

The experiment revealed that the more economic large size entry was better than the far less economic but common way of presenting the entries as had been used up to that time. Netherlands Railways accordingly implemented the large size entry. See figure 8 for an example of the improved presentation.
Figure 8. Large entry character, redesign for NS
8.5 Generalisation of knowledge

8.5.1 Interface technology generalisation: numerical code train ticket vending machines

The experiment described in this Chapter was conducted for the 80-destinations ticket vending machine of Netherlands Railways (1985). This machine is no longer in use. In order to select a destination on the interface of that machine the passenger had to press a button to the right of the label indicating the destination.

Today, Netherlands Railways is using another interface technology for selecting destinations. The second-generation destination-code ticket vending machine has a list with approximately 400 destinations. Each destination has a numerical code. The passenger has to enter the code for their destination (see Figure 9). Although the interface technology is different, the knowledge obtained in the experiment above could be applied directly and there is no need for new experiments. On the new interface users have to search in a list and finding the entries of this list can be improved by having large first letters. Figure 9 shows the new ticket vending machine with the large character entries. The technology

![Figure 9. Large size entry of a destinations list, the B8060 Netherlands Railways ticket vending machine](image)

- Aalten 7120
- Abcoude 1390
- Akkrum 8490
- Alkmaar 1800
  - Noord 1820
- Almelo 7600
  - de Riet 7601
- Almere CS 1310
  - Buiten 1300
  - Muziekwijk 1320
  - Parkwijk 1330
- Alphen a/d Rijn 2400
- Amersfoort 3800
- Driebergen-Zeist 3970
- Drieujs 1985
- Dronrijp 9035
- Druten (bus) 6650
- Duiven 6920
- Duivendrecht 1115
- Echt 6100
- Ede Centrum 6710
- Ede-Wageningen 6700
- Eibergen (bus) 7150
- Eijsden 6245
- Eindhoven 5600
changes, the task remains the same as does the insight about size and search!

Figure 10. Large size entry of a destinations list on a touch screen computer interface (Verhoef, 1999)

<table>
<thead>
<tr>
<th>Pijnacker</th>
<th>Purmerend</th>
<th>Purmer.Overhere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raalte</td>
<td>Ransdaal (Klimmen-)</td>
<td>Ravenstein</td>
</tr>
<tr>
<td>Reuver</td>
<td>Rheden</td>
<td></td>
</tr>
</tbody>
</table>

8.5.2 Interface technology generalisation: screen train ticket vending machines

The ticket vending machines Netherlands Railways have recently introduced have a screen interface technology. This screen generation technology will support selling more than 400 destinations and more types of products. The interface for the list with approximately 400 destinations initially was a scrolling list. The machine is aimed at experienced users and the advantage should be the need for very little time to obtain a ticket. One of the options to increase speed is, as concluded in previous experiments, providing entries that reduce visual search time. Therefore one of the options proposed was having entries with a large first character (see Figure 10).

Although the interface technology for the year 2002 is quite different, the knowledge obtained in the experiment held in the mid 1980’s could again be applied and there is still no need for new experiments. It should be noted that scrolling was not implemented because selection of the first letter of the destination and then presenting all destinations
beginning with that letter proved to be faster than scrolling and did not require computer interface operation knowledge such as how to scroll.

8.5.3 Domain generalisation: lists in computer interfaces

The knowledge obtained proved to be applicable for several interface technologies for selection destinations on ticket vending machines. Is the knowledge also applicable in domains other than ticket vending? Figures 11 and 12 present some common ways of presenting elements of directories for computer users. There are similarities on the level of design and on the level of the user.

Several designers of ticket vending machines did not mark entries or used several ways to mark entries, none of these being the most efficient one. Designers of computer directories do not mark entries at all but use several ways to present these lists (large icons, small icons, alphabetic list with details, and graphical representation of content). On the level of the user passengers selecting a destination and computers users selecting a file perform the same type of visual task and consequently, the same visual and cognitive activities. Presenting entries more prominent, e.g. using a large first character, will improve user’s search performance.

The domain is different (destinations and file names), the task remains the same (for the designer: design an efficient search list and for the passenger/ computer user: search your destination/file). It can be concluded that the cognitive psychologist can apply the obtained knowledge in different domains. In addition, they can also suggest improvements not originally foreseen in that domain.
8.6 Conclusion

A theoretical analysis including physiological, physical and perceptual psychology suggested that visual size is a fundamental property of a field with visual elements.

A simple experiment reported in this chapter supports this suggestion. The experiment showed that changing the visual size of characters in an interface affects human search performance. Having search entries with a larger first character than other elements of that list, humans will perform better than all labels having first characters of the same size. The displays commonly used with the type of interface investigated and in the domain investigated are less efficient, for instance the presentations used by Netherlands Railways, Swiss Railways, Italian Railways, British Railways and London Underground.

The interface technology used in the machine, originally investigated in the Eighties, was a 'one destination one button' interface technology. In the Nineties this technology was replaced using a 'enter the numerical code of the destination' interface technology. Today, the interface technology has changed and is superficially quite different from both the previous two. The interface technology now uses touch-screen interface technology on which a scrolling list was one of the options considered. The knowledge obtained with the interface type of the eighties could be applied to these later interface technologies without any need for further experiments. These new interface technologies were not foreseen when the first experiments were carried out. The knowledge obtained proved to be interface technology independent.

To test domain independence of the interface application the knowledge about visual size to the computer operation domain was evaluated theoretically. The way file lists in common computer operation domains are presented was analysed. The analysis suggests that these lists (for instance Microsoft and Apple applications) do not use visual size to enable the user to jump to entries. In the computer domain there are several ways to present long lists but none of these use any visual property to enable the user to apply an efficient visual jump strategy in long lists.

The general conclusion is that theoretical considerations on visual size, an effect on human search performance found in an experiment, and inter-
face technology and domain independence, support the conclusion that visual size is a fundamental property of an element of the interface.