Accommodating Individual Differences through an Adaptive User Interface

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Abstract

Computer systems vary in their structure, functionality, purpose, size and the way in which they represent their internal workings. Humans differ in background, sex, education, personality, cognitive skills and preferences, motivation, goals and mood. There is a social context to HCI which involves organizational and political factors, the user support which is available and the pressures of a situation. The complexity of human-computer interaction must be dealt with. Computer systems are designed and built to be used. The question before us is to what extent can we improve the usability of systems.

One solution to problems of usability, which is unique to computer systems, is to supply the system with a suitable theory of interaction and how interaction can be improved. The computer can then adapt itself to the needs of individuals or groups of users. A theory of adaptivity should help us to decide when an adaptive system solution to usability problems is appropriate. This paper provides some suggestions as to how we should approach adaptive user interface development and some user characteristics which may prove to be useful.

1. Introduction

Human-Computer Interaction (HCI) is a complex activity. Computer systems vary in their structure, functionality, purpose, size and the way in which they represent their internal workings. Humans differ in background, sex, education, personality, cognitive skills and preferences. They also vary in motivation, goals and mood. There is a social context to HCI which involves organizational and political factors, the user support which is available and the pressures of a situation. When it comes to interpreting computer displays - even the use of command names or icons on the screen - users will infer different meanings depending on the connotations which they associate with the signs and behaviours of displayed objects. Users will attend to different aspects of the display in different ways.

On the one hand, attempting to tackle this complexity appears an impossible task but on the other hand it must be dealt with. Computer systems are designed and built to be used. The question before us is to what extent can we improve the usability of systems. How can we make them easier to learn, easier to use and more secure? How de we make the interaction more effective and more satisfying?

One way is to continue to improve the human-computer interaction design so that the average user is better able to understand and exploit the system. This approach assumes that there is a single design which will suit everyone. Another approach is to provide a variety of help and assistance for users so that they can obtain advice appropriate to their needs, when and where they need it. The problem with this approach is that the very complexity of the systems makes simple instruction inadequate. Many of the functions of a system are irrelevant for many of the users until some task arises in which they need to make use of it. By this time they may have forgotten the instruction. Unlike riding a bicycle, the skills of computer use are easily lost from memory.

There is another potential solution to problems of usability which is unique to computer systems. Computer systems can monitor the interaction at a level of detail unavailable to other artefacts. If the system is supplied with a suitable theory of interaction and how interaction can be improved, the computer is in a position to change its functioning, its structure or the representations provided at the interface to better match the preferences, needs and desires of the users. The computer can adapt itself to individuals or groups of users.

The mechanisms of adaptivity are not difficult. Alternative displays and functions can be programmed into the system and selected according to specific well-defined criteria. So, for example, if this user is a French-speaking person display messages in French. If this user is English use English language messages. The preferences of users can be elicited by a piece of the program which asks them to select a language from a list.

The mechanisms of adaptivity may be expensive, but they are programmable. It is the theory which needs attending to. The theory underlying the example above is that naturally French speaking people prefer French messages and English speakers prefer English. Of course this theory may be flawed and there are many situations in which it would make the system less usable. In particular a system which asked this question every time the system was started up would soon become annoying. The mechanisms of adaptivity must become more sophisticated to deal with this. They need to infer likely events. This may be based on their representations of users and applications and experience of previous interactions. For example, a system may have recorded that the person using this terminal is a natural French speaker, that the data in the system is in French or that the last fifty people to use this terminal were French so the probability is that the next one will be.

A theory of adaptivity should help us to decide when an adaptive system solution to usability problems is appropriate. There is little to be gained if expensive adaptivity mechanisms are used to achieve a minimal improvement in usability. There is no point in adapting to some user characteristic if that characteristic cannot be reliably and unobtrusively inferred from the interaction. This paper provides some suggestions as to how we should approach adaptive user interface development and some user characteristics which may prove to be useful.

2. Individual Differences

It must be one of the few certain things in the world that people differ from one another. Two important questions arise from this observation. Firstly, how do people differ? We might agree that people differ in physical characteristics such as height, weight and girth, but beyond that we enter a potential minefield. People have different personalities, but what is personality? People have different cognitive skills and preferences, but what cognitive skills do people have and how do they vary? Secondly, for our pragmatic purposes of improving the usability of computer systems, we must ask what differences are useful, which ones are stable and which ones really have an impact on the interaction.

The study of individual differences is usually traced back to Galton, a half-cousin of Darwin, and Binet who published the first general intelligence scale in 1905 (Willerman, 1979). Since then differential psychology, or the study of individual differences has gone through a number of phases. Some - such as the eugenics movement - now appear rather dubious. Attempting to selectively breed humans so that particular characteristics become dominant may be one way of improving usability, but one that would probably be deemed politically unacceptable.

Attempts to isolate characteristics have similarly foundered. Human activity is inevitably a social activity and so human characteristics interact with the social, environmental conditions in complex ways. Cronbach (1975) demonstrates this with a number of examples, highlighting the necessity of a science of aptitude-treatment *interactions*. We must consider both the characteristics of the individuals and the characteristics of the task and understand how these interact.

The lessons of the past suggest that individual differences are rather wayward, difficult to pin down and difficult to transfer from one situation to another. Yet the popularity of psychological tests, particularly for employment selection, suggests that many people do find such measures useful. The power offered by such methods is that a quick test of characteristics can lead to the avoidance of longer-term problems. It might take several months to discover that someone is not a good programmer unless something - tests, school grades, a performance at an interview - is used to assess the suitability of candidates before they start. The important point is to identify a stable and reliable correlation between the task and the tests.

Computer systems - along with may other artefacts - have to be used by a wide variety of people. A nomothetic approach to design excludes people who lie outside the norm. At a physical level, an increased awareness of this problem has led to better facilities for the physically less able; wider isles and ramps for wheel-chair users, larger handles for arthritics, speech input and output for the partially sighted. But computer systems have another dimension not shared by so many other artefacts. Using computer systems is to a large extent a cognitive activity. HCI is concerned with the acquisition, manipulation and expression of abstract symbols which signify something else. HCI involves information processing. Most other systems allow for some form of physical interaction which allows the user to look inside and see how it works. The user of such physical artefacts can employ a range of strategies which are unavailable to the computer user who must judge the system purely by its external displays. It is because of this that individual differences in cognitive abilities, preferences, methods and techniques become important in HCI.

2.1. Individual Differences in Cognition

Within what might loosely be labelled the Western tradition, attempts to isolate individual cognitive differences have been based around the production of various aptitude tests and other devices designed to isolate specific factors. Excellent reviews are provided in (Dillon and Schmeck, 1983, Dillon, 1985 and Sternberg, 1985).

Cognitive abilities, or cognitive skills seek to describe the methods by which humans process information. Cognitive abilities are relatively stable human characteristics which change very slowly over time (months or years) (Carroll, 1983). Underlying the distinctions which are made is a general model of cognition which emphasizes how data from the world is perceived, or input to the brain (employing the individual's verbal abilities, reading abilities, visual abilities, etc.), how it is stored (in short-term memory, working memory or long-term memory), how it is processed (inductive and deductive reasoning, problem-solving abilities and strategies, the use of mental imagery) and how solutions and decisions are expressed (e.g. language ability). Many attempts have been made to collate a range of abilities into measures of 'general intelligence' and to produce an intelligence quotient (IQ). Other research focuses on specific domains of cognitive activity such as learning, mathematical reasoning or first or second language acquisition.

Although there is no single taxonomy of cognitive abilities, some broad differences have been repeatedly observed. Cooper and Mumaw's (1985) review of research on spatial ability concludes that 'the spatial aptitude literature is quite clear in showing that a broadly defined spatial factor exists independently of verbal and quantitative factors' (p.71). There is also good evidence for holistic and serialistic learning styles (e.g. Pask, 1972; Entwhistle, 1978; Pask, 1980), though an individual may be able utilize both (a versatile learner).

Cognitive abilities are measured or assessed by getting subjects to perform a cognitive task (i.e. one that involves information processing). Frequently these are 'paper and pencil' activities such as completing a sequence of numbers or abstract shapes, selecting synonyms for words or choosing which of several diagrams matches some criteria. On other occasions the cognitive task may be a 'real world' activity using some complex device. Subjects are usually expected to try to complete the task to the best of their abilities and are assessed by how quickly or how accurately they perform the task.

One of the problems with studying cognitive abilities is that although differences may be observed and measured between individuals, it is difficult to judge exactly what the difference is. We cannot be sure precisely what caused the difference in performance. It may be that some subjects in an experiment did not understand the instructions sufficiently and this impaired their performance on the task. It may be that some subjects were less unfamiliar with the type of task, did not try as hard as other subjects or employed an inappropriate strategy for the particular task. Even if these problems can be controlled in an experiment, the interaction between cognitive factors presents further confounding factors. For example, do we see attention as a different function from perception or, as Neisser (1976) argues, as an integral part of perception? Johnson-Laird (1985) has shown that deductive reasoning ability is more a function of the mental model of the task which the subject possesses, than it is an innate characteristic. If the experimenter gives the subject a problem situation with which he or she is familiar, the subject will demonstrate improved deductive reasoning powers than if presented with an unfamiliar problem. Our own work (see below) suggests that spatial ability and field dependence may be different aspects of the same cognitive aptitude.

Although the study of individual differences in cognitive abilities cannot present a rigorous theory, it should not be abandoned. A promising approach lies in identifying the components of complex tasks and the cognitive abilities which are required in order to perform them successfully. For example, the cognitive characteristic of spatial relations, one type of spatial ability, involves the mental rotation of objects to see which of a number of other objects it is a copy of. This can be decomposed into the components; encode the stimulus (create a mental representation), transform the representation, compare with other stimuli and respond. Each of these components may involve a particular cognitive skill on which individuals will differ. Understanding the components and the associated skills then becomes the focus of attention.

2.2. Individual Differences in Personality

An appeal to the notion of personality probably derives more from a general 'folk' psychology than from scientific rigour. We sum people up with statements such as 'she is rather introverted' or 'he is too temperamental'. As with cognitive characteristics, personality traits are difficult to pin down the more we examine them. The intuitive appeal of personality, however, and the reliance put on personality testing means that we should at least consider what role such differences between individuals has to play.

Personality would normally be considered to be a collection of enduring characteristics of people '...those individual, relatively enduring patterns of reacting and interacting with others and with the world...' (Bee, 1981, p.295). Personality concerns characteristics which remain stable over time and across situations. We would assume that personality is changeable early in life, but that it settles down in adulthood. Unfortunately there is no simple measure of personality, nor general agreement on the traits which constitute personality. For example Cattell (1971) identifies sixteen personality traits. These are used as the basis of the most widely used personality test in the UK; the 16PF test. Eysenck (1967) on the other hand identifies three characteristics; psychoticism, extroversion-introversion and neuroticism, or emotionality. The discussion over personality traits continues unabated in Eysenck's *Journal of Personality and Individual Differences*.

The fact that cognition has been separated out from personality in this paper suggests that a view of personality which excludes cognitive characteristics is desirable. Thus personality would not include a measure of spatial or verbal ability. Personality is concerned with one's approach to the world in general and one's emotional and conative make-up. It is more to do with strategy than ability and, whilst it is controllable by most people to a large extent, it tends to dominate preferred approaches to specific tasks. Whilst there is no single definition of personality, the words employed by the 16PF scale give some idea as to its scope; sober v. enthusiastic, moralistic v. expedient, tough v. sensitive, zestful v. reflective, trusting v. suspecting, practical v. imaginative, self-assured v. apprehensive, conservative v. radical and so on.

2.3. Individual Differences and Human-Computer Interaction

The general theories of cognition and personality attempt to identify characteristics which are relatively stable across all domains. The concern of this paper is with human-computer interaction and an understanding of the application of these ideas to the demands of HCI.

Interacting with a computer is certainly in part a cognitive task and so we can expect individual differences in cognitive preferences and abilities to affect performance on computer tasks. Personality is assumed to affect all interactions and so it, too, should have an impact. Gerritt van der Veer's thesis (van der Veer, 1990; see also van der Veer, 1989 and van der Veer, Tauber, Waern and Van Muylwijk, 1985) is one of the few attempts to consider what effects individual differences might have on HCI (Egan, 1988 gives a thorough review which is considered below). Van der Veer classifies some cognitive and personality factors along a 'resistance to change' dimension. He argues that personality factors (in which he includes intelligence, introversion-extroversion, fear of failure and (possibly) creativity) are most difficult for humans to change. When we provide a learning environment or design a human-computer interaction, we cannot expect the people to change. The environment must be flexible enough to cater for these personality differences. Cognitive styles and learning strategies (e.g. a preference for a holistic over a serialistic strategy) lie in the middle of the 'resistance to change' dimension. Humans may be able to alter their strategies, or develop their cognitive abilities given sufficient education, motivation and time. Personal knowledge, rules and skills are changeable by people (through education and practice).

His argument, then, and one which has been the motivation for much of our own work (Benyon, Innocent and Murray, 1988; Benyon, Murray and Milan, 1987; Benyon and Murray, 1988, Benyon and Murray, 1993) is that if people have characteristics which they can not easily change, or would prefer not to change, then the computer should change the way it appears or operates in order to better suit those user characteristics. It is worth putting effort in to changing aspects of systems where changing those aspects is likely to have the biggest effect.

Egan (1988) summarises the work on individual differences and human computer interaction. He identifies three main areas where large differences have been observed; text editing, information retrieval and programming. Some of the experimental work shows up differences between individuals performing these tasks as high as 30:1! (Rosson, 1983). That is to say, one individual takes thirty times as long to complete a computer-based task as another. For comparison he cites evidence from grocery checking where typical individual differences are less than 2:1 and illustrates the importance of the differences in computer tasks by pointing out that if grocery checking did demonstrate differences of 30:1, you could be waiting thirty times longer to get out of the supermarket than the person in the queue next to you!

He summarises the results from the literature by arguing that spatial ability is an important determinant of performance in evaluating detailed spatial patterns (e.g. in locating particular strings of characters) or other objects in a display and that reasoning ability underlies the development of appropriate searching and problem-solving strategies and in producing accurate symbolic expressions (e.g. formulating query statements or editing commands). Verbal ability did not seem to predict performance to any great degree. Nor was there much evidence that personality affected performance.

Egan (1988) is careful to point out that many of the studies which he cites involve relatively few subjects and there are also occluding factors such as different researchers presenting their results in different ways and in using different tests of cognitive and personality traits. However, there is now a significant body of research which points to the importance of individual differences in HCI.

3. Dealing with Individual Differences

The summary provided above indicates that, if possible, we should examine the extent of individual differences when designing computer systems and look at how they may be accommodated. In some cases, it is likely that redesigning the interface will be an effective method of dealing with differences. This was the approach adopted by (Vicente, Hayes and Williges, 1987 and Vicente and Williges, 1988) who found that by introducing some additional commands, the poorer performance of those users with a low spatial ability could be overcome. In other cases, training and education and other 'meta-communication' can be used (van der Veer, 1989; 1990). At other times, the differences may be small or insignificant and the system can be left alone. However, there are circumstances when these options will be inappropriate and when an adaptive solution will be the only viable answer. This was the focus of our research (Jennings, Benyon and Murray, 1991; Jennings and Benyon, in press).

Database systems have exactly the characteristics through which to examine the importance of individual differences and HCI. In the first instance database systems are used by a wide variety of users, so we might expect a variety of cognitive and personality aptitudes to be demonstrated. Secondly the users have a variety of backgrounds in experience and of similar systems. Thirdly, we cannot expect people to be trained in using the system - *ad hoc* inquiries, by intermittent and discretionary users are exactly what databases are for. The interface to a database system has to support general goals (e.g. retrieve data) but it cannot be prescriptive about low level tasks. Flexibility is a key word in database use and users have to formulate specific queries. Help can be provided, but it is distracting from the main task and understanding the help may take much longer than expressing the problem. Discretionary users, such as departmental managers, senior clerks and the general public are precisely the users which we want to encourage to use the system.

In their work, Egan and Gomez (1985) suggest a three stage approach to dealing with individual differences. Firstly, it is necessary to 'assay', or assess the extent of the differences. This involves considering what to measure and how to measure it. Once differences have been observed, the essential differences have to be isolated from confounding factors. Thus there is a need to consider the features of the interaction, features of the users and the stability of the features. When the important features have been identified it is then necessary to accommodate these features.

Our experimental work with adaptive user interfaces embodies this philosophy. We want to assess, identify and isolate individual differences which have a significant impact on the human-computer interaction. Some of these differences can be accommodated through training, education and improvements to the interface. Others, however, will need to be accommodated through adaptive mechanisms built into the interface. It is those characteristics of users which are difficult for the users to change which will have the largest pay-off in respect of the usability of the computer system and it is those characteristics which we should concentrate on.

3.1. Assaying the Differences

In the first experiment (reported fully in Jennings, Benyon and Murray, 1991) we wanted to examine which characteristics - of both the user and the system - were important in determining performance on database retrieval. Five functionally similar interfaces to a database were designed and were each used by 24 subjects to perform comparable retrievals. Each subject was tested on five personality/cognitive variables; spatial ability, verbal ability, field dependence (the ability to distinguish an object from its environment), short term memory (STM) and a thinking/feeling personality test. Subjects were then assigned to a 'high' or 'low' group according to their score on the test. The time taken to complete the task was used as the measure of performance.

Significant differences ($p < 0.05$) were observed between the high and low spatial ability and verbal ability groups on the menu interface, but the largest and most significant difference ($p<0.01$) was found between the performance of the high and low spatial ability groups on the command interface. Here the high spatial group achieved an average completion time for the 12 tasks of 278 seconds. The low group took 377 seconds. Thus the average task completion time for the low group was 35% greater than the high group. In comparison, there was only a difference of less than 1% between the two groups using the menu interface and 3% using the iconic (a pictorial) interface. No significant differences were found between the short-term memory groups and only small differences for the other groups and the other interfaces. However, a correlation was discovered between scores on the field dependence and spatial ability tests, with 18 out of the 24 subjects being in the same group for each. The probability of this occurring by chance is less than .05.

3.2. Isolating the Differences

There are clearly performance differences between users and between interfaces, some of which are highly significant and could not be put down to chance. Some of these are due to the characteristics of the particular interface (for example the iconic interface generally required less mouse clicks than the other interfaces) but the relative differences indicated something more fundamental.

In order to isolate these differences, we decided to concentrate on the level of spatial ability/field dependence and the characteristics of the command interface. This was were the most significant difference in performance had been observed. The command interface had an open and flexible dialogue; a user-determined dialogue (Thimbleby, 1990). Users specified their query by typing the required item name and its attributes according to a particular syntax, in response to a simple prompt. Egan (1988) suggests that formulating such statements may be related to spatial ability. If the users needed help in order to formulate the query, they had to leave the query mode and enter a help mode, returning to the query mode in order to specify the query. Intuitively there appeared to be some conceptual spatial activities concerned with moving around such a dialogue which was reliably measured by the spatial ability test we had used.

Other differences were clearly much less important. For example, there seemed to be no particular demands on short term memory by any of the interfaces. Other systems may make STM demands (e.g. Benyon, Murray and Milan, 1987). Also there were no significant differences between the different groups using the menu interface and only marginal differences using the button and the iconic interfaces.

A second database system was developed which we hoped would pin down the differences. This system had just two interfaces. One (a command interface based on SQL) was a user-determined dialogue, designed to be open and flexible and to require moving between modes to get help. The other, a system-determined dialogue, was a menu interface which was more constrained. It required users to respond to questions concerning the content of the query. From the answers, the system constructed the query.

The hypothesis we were testing was that users with a good spatial ability would perform better using the SQL-type interface. Being a command interface, we expected to observe a similar effect as that demonstrated by high spatial subjects on the first experiment. The SQL-type interface would be quicker for user who did not get 'lost' inbetween modes and who could formulate syntactically correct commands. By its nature the menu interface which provided a constrained dialogue was slower and more restrictive and so it would take longer for users to complete a task. However, poor spatial ability users were expected to perform better on the menu interface since they would make more mistakes and spend more time thinking when using the command interface.

Another controlled experiment was conducted in which 30 subjects performed similar retrieval tasks using both interfaces (reported fully in Jennings and Benyon, in press). Initially only one half of the hypothesis was confirmed, namely that people with a high spatial ability would prefer the command interface. However, the results did not show a significant performance difference for those with low spatial ability. The results were re-examined and it was discovered that there was an additional factor involved - the level of experience with a command interface. When this was taken into account, the performance difference in the groups is significant (see Figure 1). Differences in performance could be explained by spatial ability *plus* previous command experience. The number of errors made shows this quite convincingly (Figure 2).

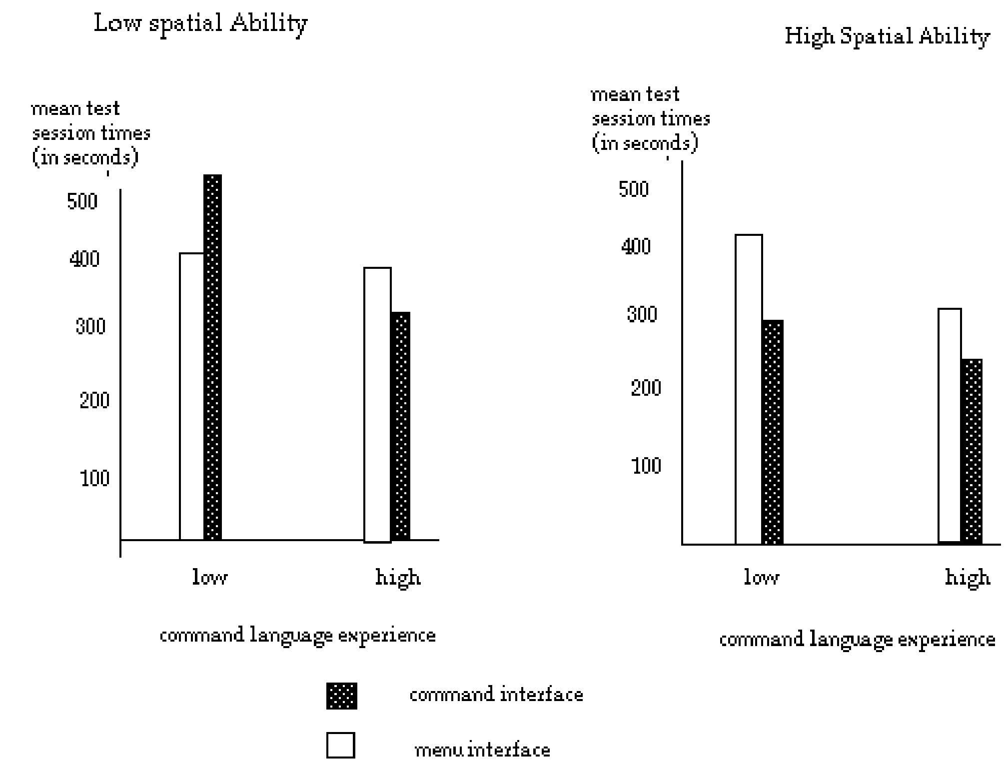

Figure 1 Mean test session times

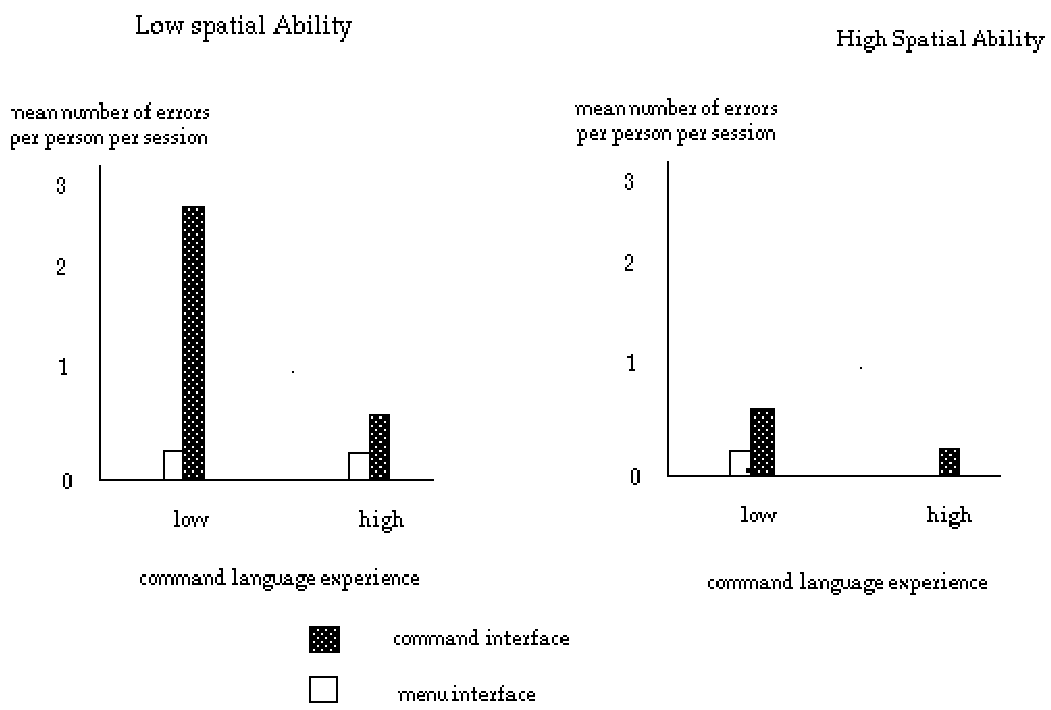

Figure 2 Mean number of errors per person per session

3.3. Accommodating the Differences

The experimental work described above should be seen as a part of the systems analysis, or evaluation, of possible interfaces to a database system. It may be hoped that over a period of time, some robust, general results concerning individual differences and interface characteristics may be determined. However, it may always be desirable for system developers to sample their expected user population in respect of particular interface designs. Let us assume that the designer has undertaken some experimental work along the lines described above. The system designer is now better equipped to produce a more usable system. Significant differences between members of the user population have been discerned. The differences have been identified as the spatial ability and experience of command languages. Experience will vary with frequency of computer use. The designer now has to decide how best to deal with the different aptitudes of the users.

One solution is to provide the database system with a menu interface. All users could then use this. However, this solution reduces the usability of the system for a significant majority of the user population who could perform their retrievals more quickly if a command interface was provided. If the command interface is the only interface to the system, it is likely that many users will be put off using the system. Discretionary users may decide not to use the system at all and hence will never develop experience with the command interface. Infrequent users may forget how to phrase their queries and again will have an impoverished interaction. Help and advice can be provided to compensate for these users, but this is then distracting from their primary task and may become annoying.

The designer would weigh up these alternatives and possibly perform other analyses in order to evaluate other possible designs. Which ever way the designer decides to proceed, an adaptive system solution is one more option. Giving the system an adaptive user interface is one way to accommodate individual differences.

4. The Adaptive User Interface

In this case it was decided that an adaptive user interface would be appropriate. The database system was implemented with two interfaces - a command interface and a menu interface - and an adaptive mechanism. The purpose of the adaptive system was simply to select the more appropriate interface for the users. Hence the system was developed to achieve this purpose.

The adaptive system only needs to know enough about the domain in order to provide the required functionality. It therefore requires a definition of a task, an error, the average task completion time and an interface. The adaptive system needs to know enough about each user so that it can offer the most appropriate interface. From the experimental evidence, we know that the number of errors made by users using the command interface correlated significantly with the level of their spatial ability and command language experience. In turn, command language experience is affected by the frequency of computer use. Hence the adaptive system needs knowledge of the number of tasks the user has completed using the command language interface and the number of errors which they have made. The relevant user characteristics are spatial ability, command language experience and the frequency of system use.

The adaptive system needs to make some inferences from the interaction and requires an ability to alter the interface. In addition it must elicit the user's level of experience with command languages and the frequency of the user's usage of the system. These two facets can be obtained by asking the user when the user first uses the system. A record of the dialogue between user and system which records details of the number of errors made and the number of tasks completed is then sufficient to infer the users level of spatial ability using the simple rule;

If interface = command and errors> 1 and tasks = 12 then spatial ability = low and command experience = none

Adaptations are accomplished using three rules;

If spatial ability = high then interface = command

If spatial ability = low and command experience = none and computing = frequent then interface = command

If spatial ability = low and command experience = none and frequency of computer use = occasional then interface = menu

5. Discussion

This paper has illustrated a practical approach to the development of AUIs. Differences between individuals in a sample of the user population were analysed and their importance assessed. Spatial ability coupled with field dependency suggested a class of users who would have trouble with a command interface. However, the benefits of the command interface in terms of speed of task completion, was a significant one for a large proportion of the users. The problem stemmed from the openness and flexibility of the dialogue style which helped one group of users whilst hindering another. These differences could only be successfully accommodated by providing an adaptive interface. The feasibility of the proposed adaptations was considered and an error count seemed to offer an unobtrusive method of identifying the group of users. Frequency of computer use which would affect command language experience was included in the user model to allow for users improving their performance over time.

On its own, this work may be considered 'good practice' in the development of adaptive systems. The decision to have an adaptive capability arose from a consideration of the purpose of the system and the characteristics of the user population. Browne, Totterdell and Norman (1990) recommend the use of 'adaptivity metrics' to help the adaptive system designer evaluate the capabilities and extent of an adaptive system. The work presented here can be seen as complimentary to this approach.

Their suggestion is that when developing adaptive systems, the designer should be quite clear as to the purpose of the adaptation, its generalisability, the recommendations and theory underlying the adaptivity and the trigger mechanisms which initiate the change. This is a vital part of adaptive systems development because without a measured and thoughtful approach to adaptive system development, the system may perform less effectively than a non-adaptive system. In this paper we have argued that the AUI arose in response to a particular set of circumstances.

The final implementation of the AUI described here used a co-operative approach to adaptation. Initially users were presented with the command interface since this was generally faster and most appropriate for three out of the four user groups (see Figure 1). When the system detected that a user was experiencing difficulties with the command interface (based on the number of errors made), the user was advised that a menu interface was available. At this point users could inspect their user model and amend it if required. For example, users could amend the value of the frequency of computer use attribute to 'frequent' and thus continue to be offered the command interface. Using this co-operative approach users were kept fully informed of the basis for the computer's recommendations.

Besides the AUI itself, the work presented here raises important considerations for HCI in general. In particular, the idea of navigation through information spaces is a large question concerning HCI and individual differences. Navigation, even in traditional applications of psychology such as moving around cities or across oceans is still poorly understood. We may appeal to the notion of mental models (Johnson-Laird, 1985) or cognitive maps (Neisser, 1976), but the question still arises as to how these are best constructed for particular environments. Hypertext systems and large networks demand a huge load from their users which may be related to their spatial ability, field dependence and personality factors such as an individual's propensity to explore, take risks and enjoy the sensation of discovery. The results of our experiments suggest that high and low spatial ability/field independent people may require very different help and guidance facilities for navigating the abstract spaces presented by large and distributed information systems.

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