Comparing Static, Adaptable, and Adaptive Menus

by

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Abstract

Software applications continue to grow in terms of the number of features they offer, making personalization increasingly important. Research has shown that most users prefer the control afforded by an adaptable approach to personalization rather than a system-controlled adaptive approach. Both types of approaches offer advantages and disadvantages. No study, however, has compared the efficiency of the two approaches.

In two controlled lab studies, we measured the efficiency of static, adaptive and adaptable interfaces in the context of pull-down menus. These menu conditions were implemented as split menus, in which the top four items remained static, were adaptable by the subject, or adapted according to the subject's frequently and recently used items. The results of Study 1 showed that a static split menu was significantly faster than an adaptive split menu. Also, when the adaptable split menu was not the first condition presented to subjects, it was significantly faster than the adaptive split menu, and not significantly different from the static split menu. The majority of users preferred the adaptable menu overall. Several implications for personalizing user interfaces based on these results are discussed.

One question which arose after Study 1 was whether prior exposure to the menus and task has an effect on the efficiency of the adaptable menus. A second study was designed to follow-up on the theory that prior exposure to different types of menu layouts influences a user's willingness to customize. Though the observed power of this study was low and no statistically significant effect of type of exposure was found, a possible trend arose: that exposure to an adaptive interface may have a positive impact on the user's willingness to customize. This and other secondary results are discussed, along with several areas for future work. The research presented in this thesis should be seen as an initial step towards a more thorough comparison of adaptive and adaptable interfaces, and should provide motivation for further development of adaptable interaction techniques.

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Chapter 1

Introduction

Everyday applications, such as the word processor and the spreadsheet, provide users with additional functionality in each new version release. Some have referred to this phenomenon as creeping featurism [25, 48] or bloatware [28]. One impact of this trend is that graphical user interfaces are increasing in complexity — menus, toolbars, and dialog boxes are all multiplying in size. On the positive side, the addition of new features can provide benefit to the user; for example, a feature may modernize an application, as in the case of a word processor that adds support for creating an html document for web publishing. The downside, however, is that most users only use a small fraction of the available functions [35, 43], while wading through many unused functions. In addition, users tend to use different functions from one another, even when they are performing similar tasks [16]. More so than ever before, there is a need to manage the interface, providing users with easy access to the functions that they do use. Therefore, this suggests the need for interfaces to be personalized to each individual user.

Adaptive and adaptable interfaces are two major approaches to personalization. The goal of both adaptive and adaptable interfaces is to provide personalization for the user; however, these two approaches differ in who is in control of the adaptation process. Adaptive interfaces automatically adjust the interface in a way that is intended to support the user. By contrast, adaptable interfaces provide customization mechanisms but rely on the user him or herself to use those mechanisms to do the adaptation. Though traditionally the system designer or administrator has also played a role in adapting the interface to the needs of a particular user or group, adaptable and adaptive interaction techniques are likely the only scalable approaches to personalization [62].

There has been some debate in the human-computer interaction and intelligent user interface communities as to which approach is best [53]. One side argues that we should provide easy-to-use predictable mechanisms that keep users in control of their system, while the other side believes that if the right adaptive algorithm can be found, users will be able to focus on their tasks, rather than on managing their tools. Despite this debate, there has never been an empirical comparison of the efficiency of adaptive and adaptable interaction techniques. Most research has focused on developing systems, with little formal evaluation and even less comparative evaluation of the two. One exception is a field study, performed by McGrenere, Baecker and Booth [42], which qualitatively compared the native Microsoft Word 2000 adaptive interface to an adaptable alternative. Our work builds on this more qualitative work by providing controlled lab evaluation of the two types of interaction, and including a static condition. In addition, to maintain a strong connection to the previous work, much of our methodology is based on the Microsoft Word 2000 interface.

1.1 Research Objectives

This thesis documents work done to compare the efficiency of static, adaptive, and adaptable interaction techniques. While adaptive and adaptable user interfaces differ with respect to who is in control of the personalization, they are both examples of dynamic interfaces and relate to the concept of interface variability. Interface variability refers to whether or not an interface changes over time, and can have one of two values:

- **Static**: The interface does not change during the course of use.
- **Dynamic**: The interface changes during the course of use. For dynamic interfaces, there are three possibilities for controlling changes to the interface.

    1. **Adaptive**: The system controls change.
    2. **Adaptable**: The user controls change. (Another term for this is customizable.)
    3. **Mixed-initiative:** Control is shared between the user and the system.

In this work, we focus on the pure adaptive and adaptable ends of the dynamic interface spectrum, which we consider to be an important step in the overall evaluation of dynamic interfaces.

The objectives of this research address the lack of comparative literature for static, adaptive, and adaptable interaction techniques. The principal goal of this research is to formally compare the efficiency of these three types of interfaces. In the process of attaining this goal, we also hoped to identify secondary trends which could aid our understanding of how users customize their menus and interact with these types of systems.

1.2 Overview

This research is divided into two studies that were designed to explore static, adaptive, and adaptable interaction techniques in the context of pull-down menus. Previous work relevant to this research is summarized in Chapter 2. We chose to use pull-down menus for these studies because menus are a common, relatively simple interface component and there are several industry and research examples of adaptive and adaptable menus. In particular, by basing our structure on the Microsoft

Word 2000 menu system, this research complements previous work by McGrenere, Baecker and Booth [42].

Many methodological decisions were made in the design of the two studies documented in this thesis. Chapter 3 discusses several of these decisions, such as the choice of menu conditions. The core static, adaptive, and adaptable menu conditions used were implemented as split menus, in which the top four menu items remained static, were adaptable by the subject, or adapted according to the subject's most frequently and recently used items.

Study 1, discussed in Chapter 4, was designed to measure performance by recording the respective speed and error rates of using static, adaptive and adaptable split menus. Qualitative feedback was also elicited to gain an understanding of subjective components such as preference and perceived efficiency. The study itself involved 27 participants. The results showed that the static menu was significantly faster than the adaptive menu, and that there was an interaction effect involving order of presentation; that is, under certain conditions the adaptable menu was also faster than the adaptive menu and not found to be significantly different from the static menu. The majority of users preferred the adaptable menu and perceived it to be the most efficient of the three types of menu. Several implications for interface design were derived from these results.

One conclusion of Study 1 was that it would be necessary to understand the nature of this interaction effect to predict the efficiency of adaptable menus in a more global sense. The experimental design of that study, however, did not allow us to isolate which specific component(s) caused this effect. After hypothesizing several explanations for the interaction, we chose to explore the possibility that prior exposure to different types of menus has an effect on the efficiency of the adaptable menu. Chapter 5 discusses this follow-up experiment, Study 2, in which 30 subjects were randomly assigned to one of three conditions, each providing a different type of exposure: traditional menu (one which does not contain a split), static split menu, and adaptive split menu. After subjects completed selection sequences with the exposure condition, they were given adaptable menus and an opportunity to customize. Though no significant effect was found for type of exposure on customization, possibly due to low statistical power, other secondary results were explored and ideas for future work developed.

To summarize, this thesis is organized as follows. Chapter 2 discusses related work and provides background for this research. Before presenting the studies themselves, Chapter 3 documents our experimental approach. The design and results of Study 1 are provided in Chapter 4, along with implications of those results. Chapter 5 documents Study 2 from design to results. Finally, Chapter 6 discusses limitations of the work and several ideas for future research, concluding the thesis.

Substantial portions of this thesis have already been published in the 2004 proceedings of the SIGCHI conference on Human factors in computing systems [10].

Chapter 2

Related Work

In this chapter we introduce adaptation and provide a general background on menu design. This is followed by a discussion on the advantages and disadvantages of various adaptation mechanisms, and relevant evaluation. Throughout, there is a focus on how these techniques have been applied to menu design.

2.1 Introduction to Personalization

There are several approaches to personalizing a user interface. Adaptive, or system-controlled interfaces, automatically change the interface based on knowledge of the user's needs and goals. Adaptable, or user-controlled interfaces, provide mechanisms with which the user can customize the interface him or herself. Between these two extremes lies a variety of mixed-initiative interfaces, where control over the adaptation process is shared between the system and the user. Finally, there has traditionally been a role for the system administrator to adapt the interface to specific users and workgroups. This last approach, however, may not be as scalable as adaptive or adaptable techniques [62].

Recent research on adaptive and adaptable interfaces has been motivated by several factors, including increasing software complexity [34, 42], the problem of information overload, particularly on the World Wide Web and in hyperlinked libraries [4, 23, 59], a shift towards more inclusive design, where interfaces are designed to be more universally accessible than they traditionally have been [11, 55, 56, 58], and the growth of ubiquitous computing [2, 62]. Additionally, Blom groups motivations for personalizing into three categories: enabling access to information content, accommodating work goals, and accommodating individual differences [3]. Personalization generally focuses either on control structures or information content. Graphical user interface components fall under the category of control structures; for example, buttons, menu items, or toolbars can be personalized. In contrast, personalized web sites, news delivery, and search engine results could be classified as personalization of information content. The division is not entirely straightforward; for example, personalizing hyperlinks to show or hide some links has elements of both content and control structures. Since personalization of content is not as relevant to the work presented in this thesis, it will not be discussed in depth.

2.2 Menu Design

Menus are a core control structure of complex software systems, and as such, they provide an important target for research on user interface adaptation. There has been a significant amount of research done on menu design in general, much of which is summarized in a comprehensive 1991 book on the psychology of menu design by Norman [49]. Some points from Norman's book which are especially relevant to our work are listed here:

- Speed and accuracy must be considered when measuring the performance of a menu system. Measures of speed can include (1) time to select an item from a single menu frame, (2) time to locate a target in a hierarchical structure of menus and submenus, and (3) time to complete an entire task within the system.

- Ordering of menu items can be used to facilitate searching, convey relationships between items, or simply create consistency with a user's knowledge base. Examples of orderings are random, alphabetic, numeric, frequency of use, and categorical grouping. Results show that alphabetic and categorical orderings are better than random ordering.

- Practice improves both speed and accuracy of menu selections, and may help users develop efficient methods for searching. The greatest improvement occurs when the exact item name is explicitly given as a cue, as opposed to using an implicit cue, such as the description of an item.

- Users take more time to answer questions about information that appears in inconsistent locations on the screen compared to a consistent location. (Teitelbaum and Granda (1993), reported in [49]). This may lead to frustration and confusion in the user.

- When menus change based on context it can be confusing or frustrating for the user. Graying-out menu items in this case is preferable to hiding them because it maintains positional consistency.

- Given the same level of practice and expertise, users vary greatly in their ability to find a command within a menu structure. This is dictated to a large extent by spatial visualization ability and vocabulary and comprehension abilities.

In recent years, several styles of menus have been proposed to better organize the increasing number of functions in software systems. For example, fisheye visualization has been applied to menu design to facilitate the display of extremely long menus [1]. In a fisheye menu, the entire menu is displayed at once, while items in a focus area around the mouse pointer are magnified for reading and selection. Another example of menu reorganization is simultaneous, or multiple active menus, which have been proposed as an alternative to the traditional hierarchical sequential menu layout [21]. With simultaneous menus, several levels in the menu hierarchy are presented at once, allowing the user to select multiple items at different levels in the hierarchy without having to backtrack.

One design which appeared earlier than the previous two examples is the marking menu [31]. The marking menu combines gesture input with pie menus (circular menus with pie-piece shaped items) to increase the speed with which practiced users can select menu items. Novice users can invoke the visual menu to determine how to select an item before making the mark (physical mouse gesture) required to actually select that item. Expert users, however, can simply make the mark without taking the extra time to invoke the visual menu. Results showed that expert users were able to use the marks, and that marking-only was significantly faster than using the visual menus. Even so, these types of menus have not been widely adopted in commercial applications.

Split menus are another approach to facilitating faster access to frequently used menu items, by dividing the menu into two partitions [51]. The items that are accessed frequently are located in the top partition, above “the split”. In both a controlled experiment and a field study, Sears and Shneiderman [51] showed that a static split menu, which contained predetermined frequent menu items in the top partition and did not change during the course of use, was at least as fast as a static traditional menu, and in most cases significantly faster. Their work suggested the need for an adaptive split menu, where the items in the top partition dynamically adapt based on a user’s usage pattern, but they did not evaluate such a design in their studies. In the experiments reported in this thesis, we use an adaptive variant as they suggest, and extend their split menu design to include an adaptable variant, where the user can specify the items in the top partition.

As an approach to organizing an extremely large number of menu items (1200 commands), the “Hotbox” combines several common techniques, such as popup/pulldown menus, modal dialog boxes, and radial (circular) menus, into one system [32]. The Hotbox was designed for a professional 3D animation application with the goal of providing both novice and expert users with efficient access in a single GUI widget system. Although no formal testing results have been published, beta users of the Hotbox reported perceived benefit, showing that the Hotbox design is useful at least for highly specialized applications. Such a complicated menu system is likely not required for more mainstream applications which generally contain far fewer commands.

As a final example, tracking menus, introduced by Fitzmaurice et al., are designed for use with mouse- or pen-based computers and PDAs [13]. A tracking menu contains graphical menu items, similar to a traditional menu, yet also uses transparency and can "track" or follow the cursor. Fitzmaurice et al. [13] implement the tracking menu using a pen-based interface and a menu that contains several tools. Once the user invokes the menu and selects a tool, the menu becomes transparent until the user lifts the pen off the input surface. The menu is then immediately available at the current location for the user to select a new tool. This technique has potential for tool palette-style menus or other menus where clusters of similar functionality are directly applicable to spatial components on the screen. As yet it is not a substitute for complex pull-down menu systems.

2.3 Adaptive Interfaces

The majority of work on adaptive interfaces appears in the research literature, and does not make comparisons with non-adaptive designs [41]. Adaptive interfaces employ user models, an internal representation of the user, to improve the user's interaction with the system. One definition of an adaptive system is:

> "An interactive system that adapts its behavior to individual users on the basis of processes of user model acquisition and application that involve some form of learning, inference, or decision making." [26]

It is important to note that adapting the interface is only one application of adaptive systems.

In a discussion of user modelling, Fischer identifies the major potential strengths of adaptive interfaces to be that (1) the adaptation process requires little or no effort on the part of the user, and (2) the user does not need specialized knowledge to use the system (i.e., to adapt the interface) [12]. While there has not been much reported success on the use of adaptive control structures, there is more evidence of success for adaptation of content and provision of help, such as with Intelligent Tutoring Systems (for examples, see [7, 54]). As an example of adapting content, Gustafson et al. examined the impact of adaptive assistance on the task of grouping and classification of news stories for a large college daily newspaper, and found that sorting time per story dropped 23.7% when an agent was introduced to the interface [20]. Though the study was small (three users), the results show the potential for real benefits with agent-assistance.

Adaptive interfaces are, however, commonly criticized because they threaten several well-known usability principles. In a summary of the current state of adaptive interfaces, Höök identifies the following problems [23]:

- **Lack of control:** Adaptive interfaces may not provide the user with control over the adaptive process. Providing mechanisms to modify the user model has proved problematic at times.

- **Unpredictability:** Since the user does not directly control the interface, he or she may not be able to predict the consequences of certain actions.

- **Transparency:** Often, the user does not understand how the adaptivity works in an interface. One issue in designing adaptive interfaces is to decide how much to make visible to the user.

- **Privacy:** The user must accept that a system which is based on user models will be maintaining a representation of his or her interaction with the system.

- **Trust:** The user's trust in a system is volatile and can decrease rapidly if an adaptive system gives the wrong advice, or otherwise adapts in a manner which is problematic to the user.

Shneiderman, an advocate of direct manipulation interfaces, echoes these criticisms, stating that interfaces need to be predictable, controllable, and comprehensible to the user [52, 53]. He suggests that direct manipulation is better because it gives the user control and a sense of responsibility with regard to the interface. Another usability challenge stated by Jameson is the issue of unobtrusiveness; that is, the need to make adaptive interfaces less distracting and irritating, drawing attention away from the user's primary task [26].

Many adaptive user interfaces have been developed and discussed in the research literature. Here, we mention a few examples related to the adaptation of control structures. There has been little or no user testing documented on most of these systems. One such example is adaptive prompting, introduced by Kühme, Malinowski and Foley [30]. Direct manipulation interfaces provide the advantage that visible objects on the screen can be used as a memory prompt for the user to facilitate recognition of how to use that object. The adaptive tool prompter leverages this advantage by displaying tools as visible objects, yet dynamically chooses which subset of tools to display based on the user's current context. The goal is to provide relevant functionality to the user while hiding functionality which is less likely to be used.

Another example of adapting functionality to facilitate novice and expert use is with the skill adaptive interface, proposed by Gong and Salvendy [15]. The skill adaptive interface was designed to combine the advantages of command line interfaces and direct manipulation interfaces by initially providing the user with the direct manipulation access to a command, then displaying a command prompt for that command once a certain threshold selection frequency has been reached. User studies showed that the approach is potentially useful.

More recent work has been done by Gajos and Weld to develop SUPPLE, a tool that automatically adapts user interfaces to different computing platforms [14]. SUPPLE treats the adaptation process as an optimization problem, by searching for the interface that best meets device constraints while minimizing the user's expected effort to interact with the system. Sample interface renderings are given to show how SUPPLE adapts the same software to pointer and touch-panel based devices, to a WAP cell phone simulator, and to a computing device with a small screen. Although a small, informal user evaluation suggests that SUPPLE may be able to render an interface similar to that designed by a human expert, no formal user evaluations have been performed.

A well-known commercial example of an adaptive user interface is the menu system in the Microsoft Office 2000 (MS Office 2000) suite, which was significantly redesigned from that in MS Office 97, and adapts to an individual user's usage [44]. When a menu is initially opened, a "short" menu containing only a subset of the menu contents is displayed by default. To access the "long" menu one must hover in the menu with the mouse for a few seconds or click on the arrow icon at the bottom of the short menu. When an item is selected from the long menu, it will then appear in the short menu the next time the menu is invoked. After some period of non-use, menu items will disappear from the short menu but will always be available in the long menu. Users cannot view or change the underlying user model maintained by the system; their only control is to turn the adaptive menus on/off and to reset the data collected in the user model.

2.4 Adaptable Interfaces

There has been little research on adaptable, or customizable, interfaces [41]. Programmatic customization involves scripting or programming languages that allow advanced users to modify features of an application in detail, while non-programmatic customization provides easier-to-use customization support through configuration files or direct manipulation of GUI elements [36]. Some examples of programmatic customization can be found in systems that support end user programming, or in some component-based systems which allow applications to be built from reusable software components [9, 19]. Our work focuses on non-programmatic customization mechanisms, rather than programmatic mechanisms.

The advantages of customization often complement the disadvantages of adaptive user interfaces. Since non-programmatic customizable systems often provide graphical user interface mechanisms to control the customization, these systems have many of the same advantages of direct manipulation interfaces in general. As mentioned in the previous section, Shneiderman summarizes the three main advantages of direct manipulation interfaces to be comprehensibility, predictability, and controllability [52]. Since the interface is comprehensible, users may experience less anxiety than they would using a system where they have difficulty understanding the interaction. In addition, they may gain confidence and a feeling of control over the system because their actions are predictable; a given action will result in a consistent outcome. A result of this increase in perceived control is that users may feel a sense of responsibility over the interaction, which can be important not only for giving users a sense of accomplishment about completing tasks, but also in situations where responsibility needs to be assigned to the user of a critical system.

Fisher states that one potential advantage of adaptable interfaces is that the user may know his or her task better than adaptive reasoning can determine [12]. This ensures that adaptations made to the interface are always done with the goal of supporting the user's actual task, rather than with the goal of supporting a potentially incorrect prediction of the task. However, in comparison to adaptive interfaces, a substantial amount of work generally needs to be done on the part of the user to adapt the interface. As well, customization mechanisms themselves increase the complexity of the system, with the potential to make it less usable, especially if these mechanisms are poorly designed [29].

Studies have found that the extent to which people customize is dependent on their skill levels and interest. For example, MacLean et al. identify three types of people: workers, tinkerers, and programmers [39]. Workers do not expect to be able to tailor the system, while programmers are highly-skilled in customizing the system. Programmers are not often directly accessible to workers, which makes transfer of knowledge from programmers to workers difficult. Filling this gap are tinkerers, a type of worker who enjoys exploring the computer system, and lies in between regular workers and programmers. Mackay also distinguishes between users who customize and those who do not [37]. A further distinction is made within those who customize: highly skilled engineers experiment and share customizations regardless of whether they are useful to others, while translators, who are less skilled technically, create customizations that are tailored to the needs of others.

Mackay examined the customization process in a study of 51 users of the UNIX operating system [38]. She found that customization was affected by external events (e.g., job changes), social pressure, software changes (e.g., upgrades), and internal factors (e.g., excess free time). Actual customization was minimal because of time, difficulty, and lack of interest. Two of the most common reasons to customize were to retrofit when the system changed, and to customize when the user noticed that he or she was frequently repeating a pattern of interaction and wanted to improve efficiency. One way to interpret Mackay's work is that customization facilities need to be easy to use, if we are to expect users to customize. Although this may seem obvious, it is a principle that has not generally been adopted in industry.

In a study of 101 users of a word processor, Page et al. have shown that almost all users (92%) did some form of customization [50]. This high number could be because the definition of customization was broad; many of the customizations were small, such as showing or hiding the ruler bar. The results also showed that the more the software was used, the higher the level of customization, and that customization features that were simple to use tended to be used more often.

2.5 Mixed-Initiative Interfaces

There has been a small amount of research into interfaces that combine adaptive and adaptable elements. Horvitz has identified several principles for the design of mixed-initiative systems that address how to best merge direct manipulation with interface agents [24]. The goal is to incorporate user direction into intelligent agent systems to resolve ambiguities about the user's goals and focus of attention. The interpretation of mixed-initiative user interfaces can vary widely, and since this type of interface is not the main focus of this thesis, we give only a few examples here.

One application example was introduced by Thomas and Krogsœter, who extended the user interface of a common spreadsheet application and showed that an adaptive component which suggests potentially beneficial adaptations to the user could motivate users to adapt their interface [57]. More recently, Jameson and Schwarzkopf studied the issue of controllability in an adaptive recommendation system for choosing conference itineraries [27]. Their results were inconclusive.

Another earlier example is the adaptive bar, introduced by Debevc et al. [8]. The adaptive toolbar is a modification of the customizable toolbar supplied in Microsoft Word for Windows. The system adaptively suggests additions or deletions of items on the toolbar based on a history of selection frequency. Results comparing the adaptive toolbar to the fixed Microsoft Word toolbar suggest that the adaptive prompting helped users more efficiently build their toolbar; however, this testing was done over two controlled sessions and there is no reported evaluation of more longitudinal use.

Taking a more theoretical approach, Bunt, Conati and McGrenere have used GOMS (Goals Operators Methods Selection rules) modeling to explore whether there are significant performance gains to be realized from customization [5]. The GOMS modeling showed that performance benefits could be achieved through effective customization, especially for novices. Combining this finding with previous work that shows many users do not customize efficiently suggests that there is a role for adaptive support in recommending when and what to customize, as well as in helping users maintain their personalized interface.

2.6 Evaluation of Adaptive and Adaptable Interfaces

There has been little evaluation of adaptive and adaptable interfaces in the research literature. Recently though, there has been increased recognition in the adaptive user interface community of the importance of empirical evaluations [6, 26, 61]. Empirical evaluations are not generally expected for contributions in the user modeling community, and the criteria for the success of adaptive systems have not been well established [61]. This lack of standard criteria makes it difficult to interpret results and generalize across studies. One issue, for example, is whether user modeling can be deemed worthwhile if users significantly prefer an adaptive system [6], or whether it is necessary to use efficiency measures as well.

Another issue cited by Höök is that many studies compare adaptive user interfaces to static systems, in which the adaptivity was meant to be an integral component of those systems [22]. Designers need to be careful to evaluate a fully functional static interface which provides static functionality comparable to that found in the adaptive interface. Höök also states that most adaptive systems will only be really useful when they are part of the user's work process for a longer period of time, which points to a need for longitudinal evaluations. Such evaluations are difficult and time-consuming, which is why they are relatively rare, even in the HCI community.

One evaluation which has appeared in the human-computer interaction literature is a study by Greenberg and Witten, which compared the performance of an adaptive menu to a static menu [17]. In a controlled experiment, users were asked to search for names in a telephone directory in each of the two menu conditions. Results showed that the adaptive structure, which provided a shorter search path to the most frequently accessed items, was faster than the static structure. The study was designed to be a proof of concept for the viability of adaptive interfaces. As such, certain characteristics of the task, such as a relatively simple and stable user model, were especially appropriate for an adaptive approach.

Conversely, Mitchell and Shneiderman presented a controlled experiment comparing adaptive (or dynamic) menus to static menus, and found that 80% of participants preferred the static menus [46]. The adaptive menus in this case were continuously reordered so that the more frequently an item was selected, the closer it would appear to the top of the menu. Speed and error rate were recorded and the results showed that the static menu condition was significantly faster than the adaptive condition. In contrast to the Greenberg and Witten study above, the adaptive menus in this study were not as amenable to efficient performance.

Cognitive modeling has also been used to study adaptive systems. Warren used the Model Human Processor to predict the cost or benefit of using an "intelligent" or adaptive split menu over a static split menu in a diagnosis system for physicians [60]. Results from applying the model showed that the adaptive system was beneficial in theory, however, their model is conservation and assumed that the user does not have enough familiarity with the menu to anticipate item locations. No adaptable design was evaluated.

While there has been little evaluation of adaptive systems, there has been even less work done to evaluate adaptable systems, or to compare the two interaction techniques to each other. One evaluation of an adaptable interface was done on the Favorite Folders file browser, developed by Lee and Bederson [34]. Favorite Folders is based on Windows Explorer but shows only a user-specified subset of directories, which are often the most frequently accessed ones. The goal of the system is to allow users to select the directory they want more easily and quickly. A simple direct manipulation customization process uses an "ellipsis" node in which users can hide folders. A preliminary field study showed positive user response, however, the study was too short to determine whether there would be long-term adoption of the system.

In a longitudinal field study, McGrenere, Baecker and Booth compared a prototype adaptable interface for Microsoft Word 2000 to the native adaptive interface of the same application [42]. Their adaptable interface included two interfaces between which the user could easily toggle: a personalized interface that the user constructed to include only desired functions, and the static full interface of Word 2000. The native interface provided users with an adaptively determined "short" menu as described in Section 2.3. The study showed that, given an easy-to-use customization facility, the majority of participants were able to customize their personal interfaces according to the functions they used. Most participants also preferred the adaptable interface to the native adaptive interface.

2.7 Summary

There have not been many studies to evaluate adaptive and adaptable interaction techniques, either on their own or as a comparison. The results which have been published are often conflicting, and as a whole can be considered inconclusive. Until now, the only comparison that has been performed of adaptable and adaptive interfaces was the field work conducted in McGrenere, Baecker and Booth's study [42]. Their work, however, did not compare the performance of these approaches and due to the field nature of the evaluation, they were not able to counterbalance the two conditions. Our study extends this research by specifically addressing the efficiency of the menu designs. The combination of results from McGrenere, Baecker and Booth's longitudinal field study and our controlled lab experiments provides a more complete understanding of the adaptable versus adaptive debate than either study on its own. By providing evidence to show that users can customize effectively, we hope to motivate further development of easy-to-use customization facilities so that users can play a role in the adaptation process.

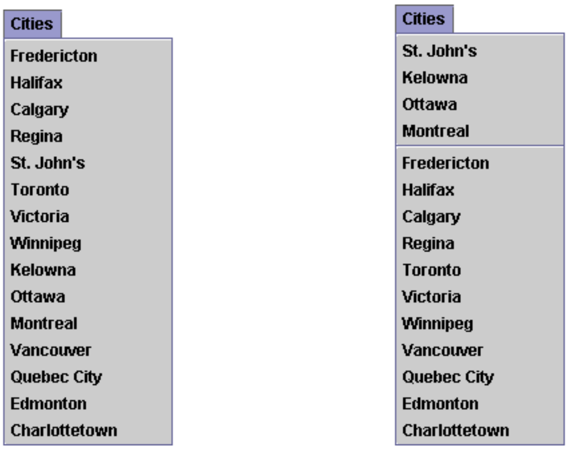
Chapter 3

Experimental Approach

The primary goal of this research is to compare the efficiency of static, adaptive, and adaptable menus in a controlled experiment. In the design of such an experiment, several methodological choices had to be made, such as how to define the menu conditions and task. To compare the efficiency of different types of menu items, the time to complete a sequence of menu selections and the number of errors made were recorded. This chapter documents the core experimental approach taken in our research. Although the focus is on design decisions made for our initial user study, almost identical methods were used for the follow-up study. The specific motivation and experimental design of each study along with other methodological differences will be given in further chapters.

3.1 Menu Conditions

The static, adaptive and adaptable menu conditions used throughout this research were implemented as split menus, a design briefly introduced in Chapter 2. While split menus were originally proposed as static menus, the layout provided in a split menu design can easily accommodate adaptive or adaptable behaviour. Items in a static split menu are placed in the top or bottom partition of the menu based on the frequency with which each item has been selected in the past. This is not



(a) Traditional menu (b) Static split menu

Figure 3.1: A traditional menu layout and a corresponding static split menu. In the static split menu the most frequently used items appear above the split (divider).

done dynamically, but rather when the menu is initially setup as a split menu. In a traditional static menu (one that does not contain a split), items may be ordered by strategies such as alphabetic or functional ordering. In a split menu, this relative ordering of items is maintained within each partition. For example, if `St. John's` appears before `Montreal` in the traditional menu layout, it will appear before `Montreal` if both are in the top or bottom partition of the split menu. Figure 3.1 shows an example of a traditional menu layout and a corresponding split menu.

Sears and Shneiderman used the following two preliminary design guidelines for their studies with split menus [51]:

1. At most four items should appear in the top partition.

2. The partitioning function first sorts items by frequency. Starting with the lowest frequency item, the list is scanned until the point when the difference between successive frequencies is greater than the mean of all frequencies. The top items on the high frequency side of that point are assigned to the top partition, up to a maximum of 4.

We adopted the first guideline, but relaxed the second one such that four items always appeared in the top partition for all three menu conditions. This was done so that the size of the top partition would not be a confounding factor. Although not explicitly listed as a guideline, Sears and Shneiderman implemented static split menus. The following subsections describe the three split menu conditions we used in greater detail, along with a fourth traditional menu condition that was used in our second study.

3.1.1 Static Split Menu

This is a classic split menu whose layout does not change during the course of use. The four most frequently occurring items in the selection sequence of the experimental task are determined in advance, and are placed in the top partition of the menu. Thus, this menu represents the ideal static split menu for the task. We chose to use a split menu for our static menu condition since Sears and Shneiderman had shown that static split menus were at least as fast as traditional menus [51]. Any result that shows an adaptive or adaptable menu to be at least as efficient as a static split menu would therefore suggest that the same would hold for traditional menus as well.

3.1.2 Adaptive Split Menu

An adaptive algorithm dynamically determines which items should appear in the top partition of the menu, based on the user's most frequently and recently used items. Frequency and recency are two characteristics that should be used for developing history mechanisms, as suggested by empirical observations of Greenberg and colleagues [16, 18]. Incorporating only the most frequently used items in the adaptive algorithm may be sufficient for selection sequences where individual items are evenly distributed over the entire sequence; however, temporal groupings of several menu items exist within our input data, so representing recently used items may also be useful.

Recency and frequency are also the two main characteristics of the Microsoft adaptive algorithm [44]. Since the primary focus of this research was not on developing an adaptive algorithm (a research problem which could be enough work for an entire thesis on its own), we chose to create a reasonable algorithm that would be practical to implement. Though there are problems with the Microsoft adaptive algorithm, it is the most well-known example of an adaptive menu system. We did not intend to model the Microsoft adaptive algorithm exactly; that algorithm allows the size of the short menu (analogous to the top partition in a split menu) to change dynamically, which is not supported in the split menu.

Our adaptive algorithm is shown in Figure 3.2. It designates two items in the top partition to be *frequency items*, and two to be *recency items*, and always ensures that there are four items in the top partition. The frequency items are the two items that have been accessed the most, while the recency items are the two most recently accessed of the remaining menu items.

```
(initially:  item.frequency = item.recency = 0)

selectedItem.frequency++
selectedItem.recency = 0

for each remaining item[i] in the menu
     item[i].recency++
     if the selected item is in the top partition already
         do nothing
     else
         leastRecItem = least recently used of the recency items
         leastFreqItem = least frequent of the frequency items
         if leastRecItem.frequency < leastFreqItem.frequency
              move leastRecItem to bottom partition
         else
              move leastFreqItem to bottom partition
              set leastRecItem.type = frequency item
         move selectedItem to top partition of menu
         set selectedItem.type = recency item
```

Figure 3.2: Adaptive algorithm.

The initial layout of the adaptive menu is meant to provide a reasonable starting point for the interface. Instead of priming the adaptive algorithm with the full set or a random sample of the task data, it is initially setup in the same way as the static split menu (i.e., the four most frequent items in the task sequence are placed above the split). We chose to do this rather than to leave the top part initially empty because it provides the user with a well-setup, though not fully-trained interface. This is similar to the experience of using a newly installed software package and is the approach taken with such commercial applications as Microsoft Word 2000.

3.1.3 Adaptable Split Menu

The adaptable menu is a dynamic menu controlled by the user. An important goal of the adaptable menu design was to make the adaptation process as simple as possible. Two levels of customization are provided: coarse-grained customization allows items to be moved to the top or bottom partition of the menu; fine-grained customization allows items to be positioned in specific locations within the top partition. This functionality also allowed users to move items back to the bottom of the menu if they decided they would rather choose a different item. As shown in Figure 3.3, arrow buttons allow the user to perform this customization with a single click. Note that the fine-grained customization allows an extra degree of precision not available in the other two menu conditions. The order of items in the bottom partition, however, remains static.

The top partition of the adaptable split menu is initially left empty and it is the user's responsibility to add items (to a maximum of four). The reason for this is that the literature suggests users are reluctant to customize unless forced to do so [38]. By placing default items into the top partition, subjects would not have been forced to customize, and therefore we expected they would have been less willing to do so.

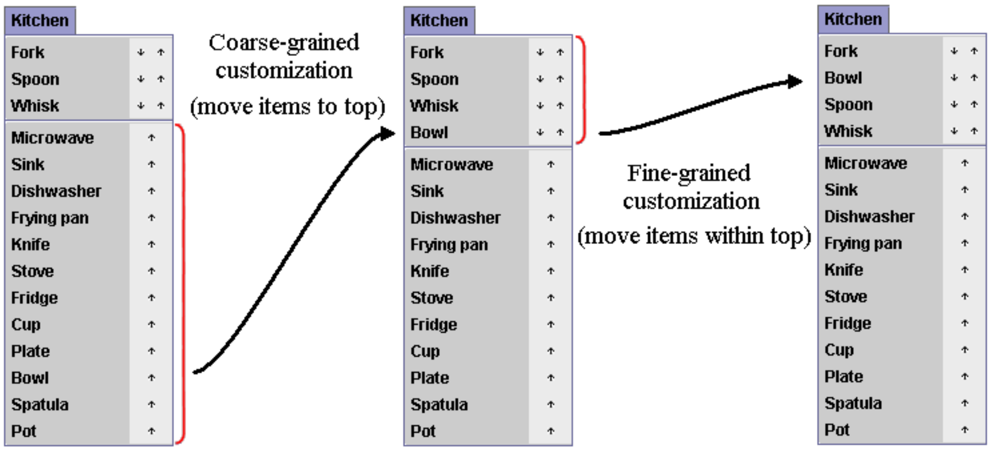


Figure 3.3: Coarse-grained and fine-grained customization of the split menu.

3.1.4 Traditional Menu

In addition to the split menu conditions just described, Study 2 used a traditional menu. This is simply a static menu which uses the original menu layout and no split. It is identical to the adaptable split menu before the adaptable menu is customized, but does not change dynamically through user or system control. Figure 3.1 shows a traditional menu.

3.2 Task

We took a similar approach to task construction as Greenberg and Witten [17]. Namely, we simulated a real-world task by constructing the experimental task based on real menus and real menu selection data. We used 20 weeks of log data from an office administrative assistant's use of Microsoft Word 2000 (MS Word 2000). The log data from this administrative assistant was collected in the year 2000, with the adaptive menus in MS Word 2000 turned off. She identified herself as an intermediate MS Word user. She had been using MS Word since 1987 and on average spent 3 to 5 hours per day word processing. The original 11,000 entries in the log included toolbar and shortcut key selections as well as menu selections.

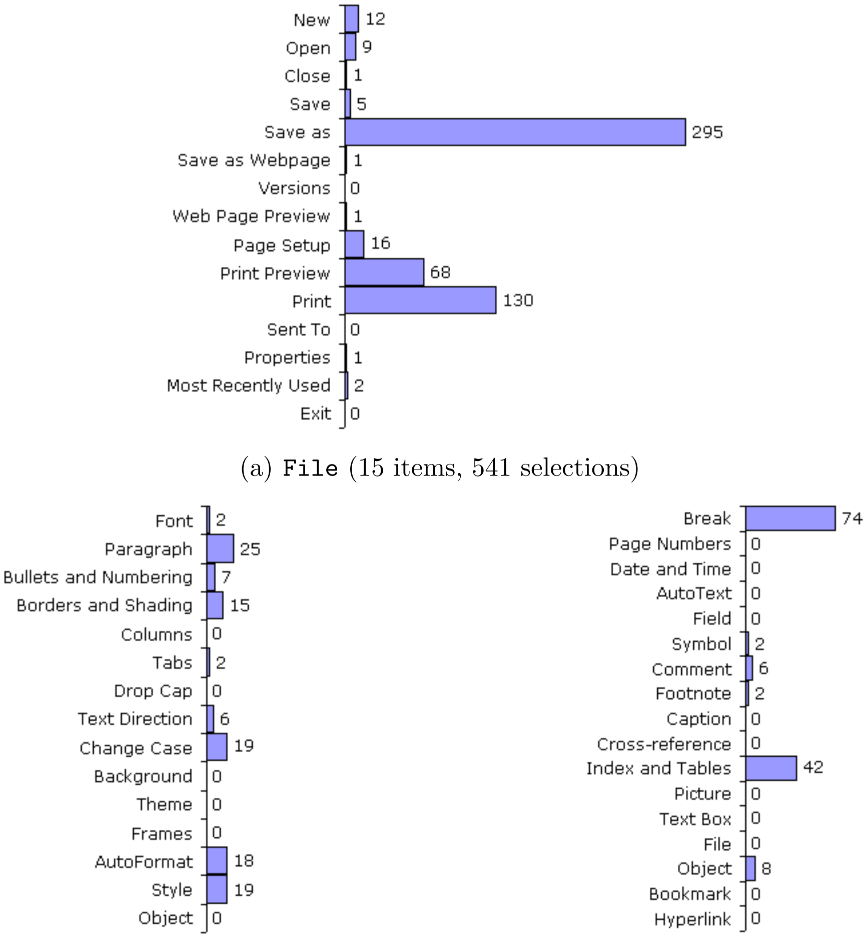
After removing the other items, 1387 menu selections remained.

Basing the task on the MS Word menu structure and usage data allowed us to assess the efficiency of the menu conditions on realistic menu lengths and complexities. While the use of a real task scenario would have given users context to help them understand the benefit of adapting their menus, this could have confounded performance results. For example, if the task were to format a document in MS Word, subjects' existing familiarity with the software and ability to format documents could have accounted for most of the variability in performance. For this reason, we abstracted away the task scenario, and set the task as a sequence of menu selections. This is similar to Sears and Shneiderman's second experiment [51].

Given that in our first user study we wanted to compare three types of menus (static, adaptive, and adaptable) using a within-subjects design, we required three isomorphic, or structurally equivalent, tasks. This was done by creating three similar menu *schemes*, or layouts, to use with a single underlying task sequence. This was most easily accomplished with a multiple of three menus; therefore, we selected the three most frequently accessed MS Word menus from the log data: `File`, `Format` and `Insert`, which together accounted for 788 menu selections. We chose not to include submenus because this would have introduced another variable into the study design, complicating interpretation of the results. Instead, selections from submenus were treated as a selection from the parent top-level menu item. The resulting aggregate selection rates are shown in Figure 3.4. `File`, `Format` and `Insert` represent a variety of item selection frequency distributions: `File` has a highly skewed distribution; `Insert` has a less skewed distribution; `Format` has a relatively even distribution.

Three menu schemes, shown in Figure 3.5, were created by the following steps:

1. We counterbalanced the location of the menus themselves by permuting the



(a) `File` (15 items, 541 selections)

(b) `Format` (17 items, 134 selections)

(c) `Insert` (15 items, 113 selections)

Figure 3.4: Frequencies of item selection from usage log data (total of 788 selections).

order of the underlying MS Word menus as follows: {`File`, `Format`, `Insert`}, {`Format`, `Insert`, `File`}, and {`Insert`, `File`, `Format`}. The result was that menu selections from the underlying `File` menu, for example, would not always come from the leftmost menu in our experimental setup.

2. For each of the three permuted orders, we masked the menus to reduce the learning effect across conditions. Each mask was simply a renaming of the menu and the menu items. For example, the `File`→`New` menu item became the `Cities`→`Paris` menu item. The masks for the three orders were:

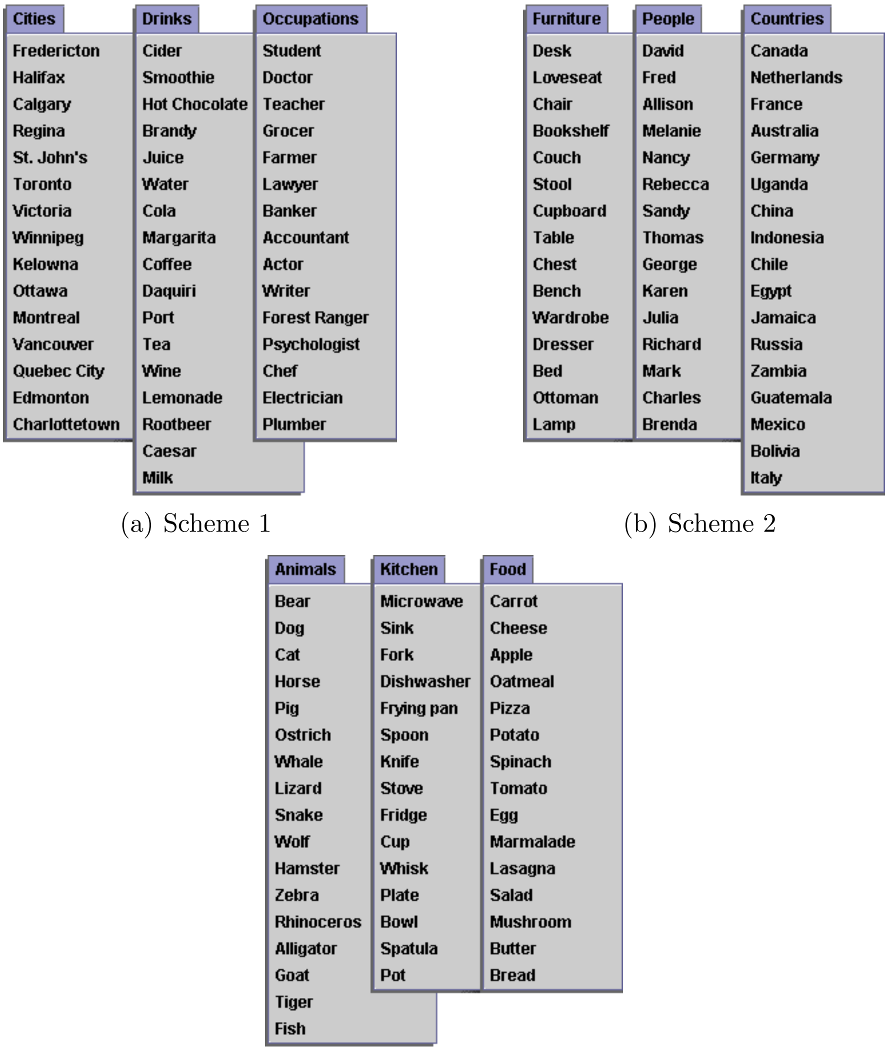
   (a) {`File`, `Format`, `Insert`}→{`Cities`, `Drinks`, `Occupations`}

   (b) {`Format`, `Insert`, `File`}→{`Countries`, `Furniture`, `People`}

   (c) {`Insert`, `File`, `Format`}→{`Kitchen`, `Food`, `Animals`}

   A mask is a one-to-one mapping, so each masked menu had the same number of items as the original menu. As well, since the original menu items were not organized alphabetically, we did not order the masked items alphabetically either. Although the original Word menus employed some semantic grouping (e.g., `Save`, `Save As...`, and `Save as Webpage...` appeared consecutively), no grouping of items within a menu was done for the menu masks in our experiment. This is because our task was meant to be abstract, thus not allowing for semantic grouping of items.

A task block consisted of a 200-item selection sequence. This corresponded to roughly a 4-week period from the original data. The sequence was a contiguous block of selections from the 788 `File`, `Format`, and `Insert` selections, thus reflecting temporal patterns in the original data which could be important to the adaptation process. The starting index for each subject's sequence was chosen randomly between 1 and 588, to mitigate the influence of any specific 200-item sequence. Sequences were considered valid if they had at least four unique menu items and 20 selections in any given menu. A selection sequence could be combined with each of



(a) Scheme 1

(b) Scheme 2

(c) Scheme 3

Figure 3.5: The three menu schemes used to create isomorphic tasks.

the three schemes to create three isomorphic tasks. For example, in Study 1 where each subject participated in multiple conditions, the same underlying sequence was used for that subject, although with a different scheme for each condition.

3.3 Experimental Design Issues

Designing a controlled lab experiment to test adaptive and adaptable interaction techniques presented unique challenges. Here, we highlight two such important challenges.

3.3.1 Training

Training is central for both adaptive and adaptable interaction techniques. The two issues to be addressed with respect to training are: (1) how to pre-train the adaptive system, and (2) how to help the user build a mental model of the task. With an adaptive interface, a user model can only function well if it has had sufficient exposure to the user's interaction, while with an adaptable interface, a user relies on previous exposure to a system or task to formulate predictions for future use. Issue (1) was discussed partly in Section 3.1.2, where we described the initial setup of the adaptive menu. The adaptive menus were reset to this initial setup at the beginning of each selection block. Some temporal patterns exist within the selection block data (e.g., grouped usage of `Save As...`) which means that selections of individual menu items may not be evenly distributed over the entire selection sequence. As such, items which appear in the top of the adaptive menu at the end of the entire selection sequence may not be relevant to the beginning of the selection sequence, so we chose to reset the adaptive menus at the beginning of both Block 1 and Block 2.

Issue (2) was addressed through the use of a split-block design in our experimental procedure. For each condition, subjects repeated the selection block twice; Block 1 acted as a training component, while Block 2, an exact repetition of Block

1, was the testing component. For the adaptable menu, an opportunity to customize was given during the break between the training and testing blocks. Since subjects were told prior to starting any menu condition that they would be repeating the exact same selection sequence twice, they were able to build a mental model of the interaction before being given the opportunity to customize. We chose to allow for customization at only one point because our main goal was to test the efficiency of the final customized menus, rather than the customization process.

3.3.2 Motivation

Users need to feel motivated if they are to customize. In a realistic setting, this motivation could be provided by a long-term understanding of a task and the potential effect of customization on that task. To simulate the desire for efficiency in a lab setting, subjects were told that an extra $10 would be provided to the 1/3 of subjects who completed the selection blocks the fastest. The goal was to encourage users to perform the task quickly, thereby motivating them to customize if they recognized that doing so would make them more efficient. The 1/3 ratio was chosen to encourage subjects to believe they had a reasonable chance of being paid the additional $10.

3.4 Measures

Both quantitative and qualitative measures were used for our two studies. Here, we present the quantitative measures; the qualitative measures were more dependent on the individual study and will be discussed in each respective study chapter.

3.4.1 Performance

Speed and error rate are the two most obvious performance measures for this research. We chose to use speed as the main dependent variable, and included an implicit error penalty; that is, subjects were required to correctly select an item before continuing on to the next menu selection. Speed is then defined as the total time to select all 200 items in the selection sequence. The use of an implicit error penalty increases the ecological validity of the experiment. This type of system behaviour corresponds more closely to real-world user interaction than if we had measured a more traditional speed versus accuracy trade-off. Error rate was, however, recorded independently for completeness.

3.4.2 Menu Layout

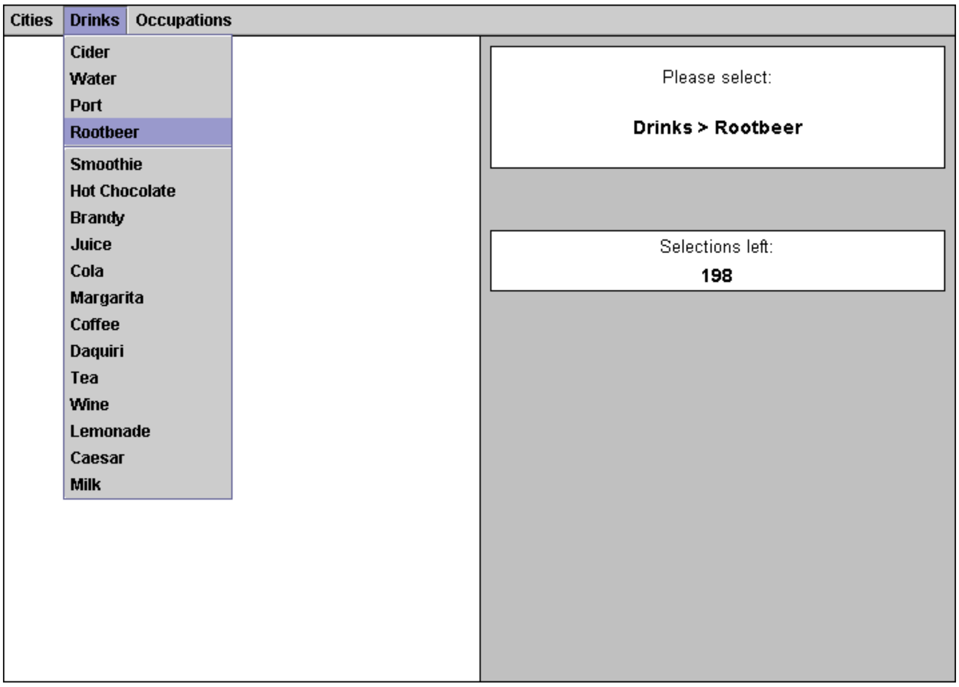
To further assess the effectiveness of customization, a straightforward menu layout score can be derived based on the location of each item and the frequency with which it occurred in the 200-item selection sequence. Although somewhat arbitrary, this is a simple metric that also enables two menu layouts to be compared for quality. The formula to derive a menu layout score is shown in Equation 3.1, where i is an item, n is the total number of items, $frequency_i$ is the frequency with which item i is selected, and $location_i$ is the location weighting of item i. The top item in the menu receives a location weighting of 1, while the second item receives a location weighting of 2, and so on.

$$score = \sum_{i=1}^{n} frequency_i * location_i \tag{3.1}$$

Using this formula, the score of a menu is an estimation of the minimum total distance the mouse has to travel to make all selections in the task sequence. Lower scores represent better layouts.

3.4.3 Apparatus

Both studies were conducted on five Apple eMacs running Mac OS 10.1.4 with Power PC G4 processors and 128 MB RAM. The experimental systems, including all menus, were fully automated and were coded in Java 1.3.1. A screenshot of the



Please select:

Drinks > Rootbeer

Selections left:

198

Figure 3.6: Screenshot of experimental system, showing the prompt area on the right-hand side and the menus at the top-left.

system used for Study 1 is shown in Figure 3.6. For each selection, a prompt specifying a menu and item was presented on the screen, for example, `Drinks`→`Rootbeer`. When the subject selected this item, the prompt changed to the next item in the selection sequence. Errors were indicated by the addition of a red 'X' next to the prompt, and the subject had to correctly select the prompted item before continuing. All instructions used in the experimental system are given in Appendix B, including the descriptions of the four menu conditions.

3.4.4 Procedure

While the overall procedure in each study will be discussed in the respective study chapters, the method for presenting a menu condition to the subject is the same for both studies. For each menu condition, the system provided a one or two sentence description and indicated that two identical sequences of selections would be given with a short break in between. Each condition was presented in the split-block design introduced in Section 3.3.1. Between the training and testing blocks, subjects were given a 2 minute break. For the adaptable condition, subjects were allowed to take extra time during the break to customize their menus if they wished to do so. That was their only opportunity to customize. Each condition took approximately 12 minutes from start to finish, and there was a 5 minute break in between conditions.

The background questionnaires used for Study 1 and Study 2 are almost identical (see Appendix A). Although it would have been interesting to determine if there was a correlation between performance on the adaptive split menus in these studies and previous exposure to the adaptive menus in Microsoft Office or Windows XP, we felt this specific type of question might have biased subjects' responses to the post-evaluation questionnaire by drawing their attention specifically to the adaptive menu condition. As a result, the background questionnaire includes only a more general question about what operating systems subjects regularly use.

3.5 Summary

The experimental approach outlined in this chapter provides the foundation for our two controlled lab experiments. We have outlined static, adaptive and adaptable split menu and traditional menu conditions, and have described the process of designing isomorphic tasks based on actual log data from Microsoft Word 2000. Design issues such as training and motivation, and the way in which these have been addressed are applicable to a wide range of research on adaptable and adaptive interaction techniques, not just to the studies discussed in the following chapters.

Chapter 4

Study 1: Efficiency of Static, Adaptive and Adaptable Split Menus

Study 1 reflects the primary goal of this research: to compare the efficiency of static, adaptive and adaptable menus in a controlled environment. The data gathered here is complementary to previous work by McGrenere, Baecker and Booth [42], and the results provide guidance for the remainder of the thesis. This chapter presents the study design, the results, and a discussion motivating a smaller follow-up study, namely Study 2 (Chapter 5).

4.1 Methodology

The methodology used for this study is based on the core experimental approach documented in the previous chapter. Only additions and clarifications are highlighted here.

4.1.1 Menu Conditions

Three menu conditions were used: static, adaptive, and adaptable split menus. We did not explicitly include a traditional static menu specifically because previous results showed that a static split menu is at least as efficient as a traditional static menu [51].

4.1.2 Measures

In addition to the quantitative measures of speed (which included an implicit error penalty) and actual error rate, a poll-style questionnaire was administered to assess qualitative measures once all conditions had been completed. Subjects were asked to rank order each menu condition according to the following criteria: overall preference, efficiency, error rate, frustration, and initial ease of use.

4.1.3 Experimental Design

This study used a repeated measures design with menu type and scheme as within-subjects factors (3 levels each), and blocked on order of presentation for both factors. Menu type was chosen to be a within-subjects factor because this increased the power of the design, and allowed for comparative comments on the three types of menus. To provide isomorphic tasks, subjects were presented with a different scheme for each menu type (although the underlying selection sequence was the same), thus requiring that scheme be a within-subjects factor as well.

To minimize learning effects, we counterbalanced the order of presentation for menu type and scheme, which we refer to as *menu order* and *scheme order* respectively. The factors of menu type and scheme both have three levels, so fully counterbalancing the orders would have required 3! x 3! = 36 cells in the design. Due to cost and time constraints, a design this large was not desirable. To address this, we used Latin squares to block on the two orders of presentation. As shown in Figure 4.1, each Latin square had three levels: M1, M2 and M3 for menu order,

Order of	*Block*		
Presentation	M1	M2	M3
1	*A*	*B*	*C*
2	*B*	*C*	*A*
3	*C*	*A*	*B*

A = Static
B = Adaptive
C = Adaptable

(a) Menu order

Order of	*Block*		
Presentation	S1	S2	S3
1	*D*	*E*	*F*
2	*E*	*F*	*D*
3	*F*	*D*	*E*

D = Scheme 1
E = Scheme 2
F = Scheme 3

(b) Scheme order

Figure 4.1: Latin squares used for the blocking variables of scheme and order.

and S1, S2 and S3 for scheme order. When the two Latin squares were fully crossed with each other, the number of required cells was reduced from 36 to 9, allowing us to use a multiple of 9 subjects in the experiment. Using this approach, a sample presentation order for one subject could be M1-S1, M2-S2, M3-S3, that is, the static menu paired with scheme 1, followed by the adaptive menu paired with scheme 2, and finally the adaptable menu paired with scheme 3.

4.1.4 Procedure

The experiment was designed to fit in a single one hour session. The procedure was as follows:

1. A questionnaire (see Appendix A) was used to obtain information on user demographics and computer experience.

2. Verbal instructions, supplementary to the online instructions, were given to subjects. These provided an overview of the experiment and stressed the importance of speed, introducing the extra $10 cash prize based on speed.

3. Users were given a short block of 20 selections on a static split menu to introduce them to the experimental system. This was followed by a 1 minute break.

4. The three menu conditions were presented one at a time, with a 5 minute break between each. For the adaptable condition, additional time was given for customization.

5. A feedback questionnaire (see Appendix A) was used to rank the menu conditions on the qualitative dependent variables and to record additional comments. Brief, informal interviews were also conducted with some of the subjects based on their questionnaire data.

Instructions for customization were included in the experimental system after Block 1 of the adaptable condition as follows:

> "To customize the menus above, move items to the top section of the menu using the single up arrows. There can be at most four items in the top section. When an item is in the top section of the menu, two arrows will appear beside it. These can be used to move the item within the top section, or to move it back down to the original menu. When you are done customizing, click the button below to continue."

4.1.5 Pilot Study

Prior to running the full experiment, we performed two iterations of pilot testing with a total of 8 subjects. All subjects were computer science or psychology students who volunteered to participate and were paid $10 or $15 (corresponding to two testing locations). The first iteration, with 3 subjects, was used primarily to test our experimental procedure. Based on feedback, modifications were made to clarify written instructions in the system and questionnaires. In addition, the data collection process proved tedious and was further automated.

During the customization break (see Step 4 of Section 4.1.4), subjects did not immediately realize when the menus were available to be customized. The menus were not usually visible during break periods, so it was inconsistent that they were visible during this break period. To solve this, we added a red box around the menu bar, attracting the user's attention. We also added a dialog box to confirm when the customization process was done.

The second pilot study, with 5 subjects, was used to get a sense of whether our experimental conditions had been well chosen and would yield significant differences. The mean completion times for the testing block of the static, adaptive, and adaptable conditions were 332.5, 369.1, and 330.8 seconds respectively. In addition, all subjects customized their menus when given the opportunity to do so. The results suggested that our experimental design was sufficient, so we proceeded with the full study.

4.1.6 Study

The study was run over three days in September and October 2003.

Subjects

Subjects were recruited through the Department of Psychology at the University of British Columbia and were paid $10 to participate for one hour. In total, 27 subjects participated, resulting in 3 subjects per cell. All were between the ages of 18 and 39; there were 6 males and 21 females. Ten described themselves as novice computer users, 16 as intermediate users, and 1 as an expert user. All subjects regularly used a Microsoft Windows operating system (ranging from Windows 98 to Windows XP); in addition, Mac OS X and UNIX were used regularly by one subject each. Five specified they used a computer 1-5 hours per week, while 13 used a computer from 5-10 hours per week, and 9 used a computer more than 10 hours per week.

Hypotheses

Based on our survey of related work, we wanted to test the following hypotheses:

- **H1**: Adaptive is slower than both static and adaptable. Since previous results have shown that the majority of users prefer adaptable menus to adaptive ones [42], we predicted that efficiency would be correlated. In addition, we predicted that the dynamic nature of the adaptive menu would cause it to be slower than an efficiently laid-out static split menu.

- **H2**: Adaptable is not slower than static. After an initial training period, users would be able to customize their menus well enough for the adaptable menus to compete with the static menus.

We also tested the following qualitative hypotheses to replicate previous results by McGrenere, Baecker and Booth [42]:

- **H3**: Adaptable is preferred to both adaptive and static.

- **H4**: Static is preferred to adaptive.

4.2 Results

To obtain measures for 27 subjects, 31 subjects completed the experiment. Three data sets were discarded because of incomplete results (the experimental system crashed midway through the experiment, most likely due to a resource issue with one of the machines). The fourth data set was discarded because the subject did not follow the given procedure, taking a 20-minute break in the middle of the experiment. This extended rest period could have confounded results.

Of the 27 subjects who were retained, only 22 customized based on the task sequence. Three subjects did not customize at all, and two did not appear to understand the customization process, each placing four items in the top partition of one out of the three menus before continuing to Block 2. For one subject, none of the customized items were ever used in the selection sequence, and for the other, two of the items were never used. The average time spent on customization for all 27 subjects was 142 seconds; for only the 22 who customized, it was 150 seconds.

As expected, because we had used an isomorphic task, no significant main, interaction or ordering effects were found for scheme. Therefore, we collapsed across scheme and all further analysis of the quantitative data was performed only on menu and menu order. For simplicity, throughout the remainder of this thesis *order* refers to menu order only.

4.2.1 Performance

Separate two-way ANOVA's (order x menu) and post-hoc pair-wise comparisons were calculated for both the speed and error dependent measures on the data recorded in Block 2. Along with statistical significance, we report partial eta-squared (partial η^2)), a measure of effect size. Effect size is a measure of practical significance, and is often more appropriate than statistical significance in applied research in human-computer interaction [33]. To interpret partial eta-squared, .01 is a small effect size, .06 is medium, and .14 is large.

Speed

The ANOVA results for the speed dependent variable are shown in Table 4.1; a graphical representation is given in Figure 4.2. There was a significant difference in speed based on the menu type used; that is, a significant main effect of menu ($F(1.44, 34.64) = 12.54$, $p < .001$, partial $\eta^2 = .343$). Additionally, the order in which the menu conditions were presented disproportionately affected the speed of performance for each menu type, that is, there was a significant interaction effect between order and menu ($F(2.89, 34.64) = 6.14$, $p = .002$, partial $\eta^2 = .338$).

Table 4.1: Two-way ANOVA (order x menu) for the speed dependent variable.

Source	**SS**	**df**	**MS**	**F**	**Sig.**	**Partial η^2**
Menu	8509.34	1.44	5895.31	**12.54***	.001	.343
Menu $*$ order	8322.34	2.88	2882.87	**6.13***	.002	.338
Error(Menu)	16278.45	34.64	469.90			

* Significant at $p < .05$

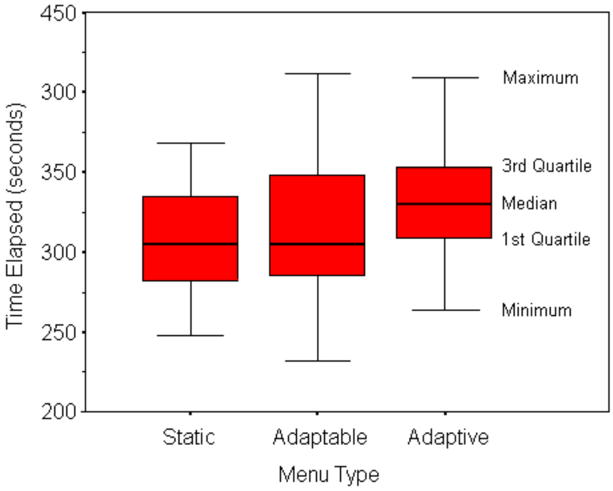


Figure 4.2: Boxplot of menu type versus speed (N=27), showing relative medians of the three conditions, and the greater variation in the Adaptable condition than the other two conditions.

The data was non-spherical[1], so we used the Greenhouse-Geisser adjustment to the degrees of freedom to compensate for this. We had expected to find an ordering effect, whereby subjects would perform more quickly as the experiment progressed, but we had not expected an interaction effect between order and menu.

To examine the interaction effect in more detail, we compared each possible pair of menu types for each of the three orders. The results are shown in Table 4.2. This was done with post-hoc pair-wise comparisons, computed using a Bonferroni adjustment. The three levels of order were: (1) Static-Adaptive-Adaptable, (2)

[1] One assumption of a repeated measures ANOVA is that the data be spherical. When this assumption is violated, the Greenhouse-Geisser adjustment is commonly used to compensate for non-spherical data.

Table 4.2: Pairwise comparisons for the speed dependent variable.

Menu (i)	**Menu (j)**	**Mean Difference (i-j)**	**Std. Error**	**Sig.**[a]	**Partial η^2**
Order 1: Static-Adaptive-Adaptable					
Static	Adaptable	6.084	9.785	1.00	.065
Static	Adaptive	**-20.787****	5.356	.002	.681
Adaptable	Adaptive	**-26.871***	10.082	.041	.556
Order 2: Adaptive-Adaptable-Static					
Static	Adaptable	-.623	9.785	1.00	.001
Static	Adaptive	**-29.478***	5.356	.001	.719
Adaptable	Adaptive	**-28.854***	10.082	.026	.500
Order 3: Adaptable-Static-Adaptive					
Static	Adaptable	**-42.327***	9.785	.001	.672
Static	Adaptive	**-25.048***	5.356	.001	.810
Adaptable	Adaptive	17.278	10.082	.298	.225

* The mean difference is significant at $p < .05$

[a] Adjusted for multiple comparisons using Bonferroni

Adaptive-Adaptable-Static, and (3) Adaptable-Static-Adaptive. The comparisons showed that static was significantly faster than adaptive for all three orders (p = .002, $p < .001$, and $p < .001$ for orders 1, 2, and 3 respectively).

The interaction effect can be explained by looking at the relationship between the adaptable menu condition and order. To aid in understanding the following discussion, Figure 4.3 shows a graphical representation of the interaction. When adaptable was not presented first, it was significantly faster than adaptive (p = .041 and p = .026 for orders 1 and 2 respectively). In addition, it was not significantly different from the static condition. When adaptable was presented first (order 3), however, it was significantly slower than static (p = .001), and not significantly different from adaptive. In other words, those subjects who saw the adaptable condition first were significantly slower, relative to the other conditions, than those subjects who saw the adaptable condition as the second or third condition. In fact, 4 out of the 5 subjects who did not customize were in the adaptable condition first (order 3). Table 4.3 shows that the mean speed for the adaptable condition in Block

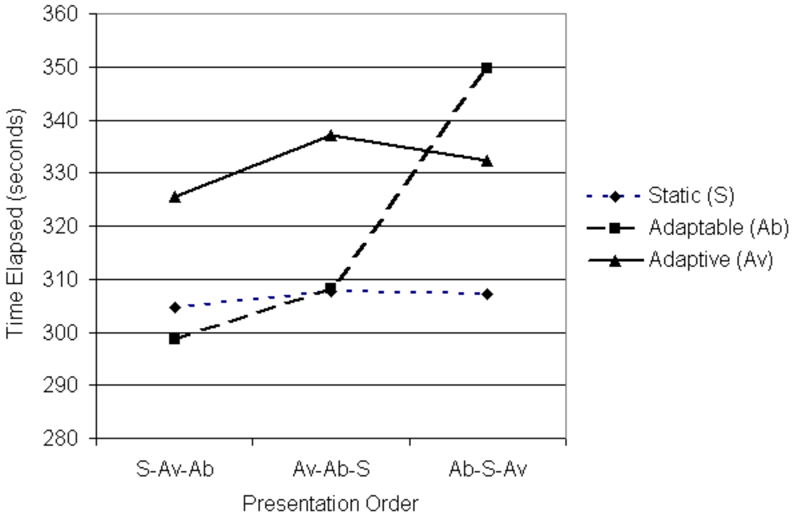


Figure 4.3: Interaction of speed dependent variable.

Table 4.3: Means for selection speed of all subjects, and for only those subjects who customized (N=27).

	All 27 Subjects		**22 Who Customized**	
Menu	*Block 1*	*Block 2*	*Block 1*	*Block 2*
Static	327.23	306.51	323.79	301.76
Adaptable	410.71	318.80	402.28	300.72
Adaptive	354.22	331.62	352.37	326.86

2 drops from 318.80 to 300.72 seconds when only the 22 subjects who customized are considered. This is almost identical to the static condition (301.76 seconds). Implications of this finding are considered in Section 4.3.

Error rate

Since this study design used an implicit error penalty, we cannot analyze a traditional speed versus accuracy tradeoff. However, to justify our use of an implicit penalty in the speed measure, error rates had to be relatively flat across conditions. For example, if two conditions had a similar mean speed but the second had a higher error rate, the second may actually have been faster once the time to recover from errors is factored out. A two-way ANOVA (order x menu) was run for error rate and no significant main effect was found ($F(2,\ 48)$ = .139, p = .870, partial η^2 = .006). Though this result cannot be considered conclusive because the observed power was low (.070), it does not contradict the choice of study design. On average, 6.8, 6.6, and 6.9 errors were made during Block 2 of the static, adaptable, and adaptive menu conditions respectively. A significant interaction effect was found between order and menu (F(4,48) = 2.94, p = .030, partial η^2 = .197), suggesting that subjects made more errors at different points in the experiment, perhaps as they were learning, or as they got tired. Using a Bonferroni adjustment, however, no pair-wise comparisons were significant.

We note that the error rate results may not reflect real error rates because subjects were told to maximize speed, rather than minimize error rate. A separate study would need to be done to explore whether there is an actual difference in error rate between the three menu conditions.

4.2.2 Self-reported Measures

For each of the five self-reported variables, we analyzed the frequency with which each menu condition was ranked first. This was done by calculating the Chi-square statistic to determine if actual frequencies were significantly different from the case in which all frequencies are equal. A summary of the results is shown in Table 4.4. There were no significant correlations between order and the results for any of these variables.

Chi-square was significant for four out of the five self-reported measures. The adaptable menu was ranked the most positive for each of these four variables. For overall preference, the most popular choice was the adaptable menu (15 subjects, χ^2(2,27) = 6.89, p = .032). Sixteen subjects also perceived adaptable to be the most efficient condition (χ^2(2,27) = 8.22, p = .016). Only one person found adaptable

Table 4.4: Chi-square statistic for qualitative results (S=static; AV=adaptive; AB=adaptable) (N=27).

Dependent Variable	**Ranked 1st (frequency)**			**df**	**Chi-square**	**Sig. Level**
	S	AV	AB			
Preferred overall	4	8	15	2	**6.89***	.032
Most efficient	6	5	16	2	**8.22***	.016
Fewest errors	9	6	10	2	1.04	.595
Most frustrating	10	15	1	2	**11.62***	.003
Initially easiest to use	5	4	17	2	**12.08***	.002

* Significant at $p < .05$

to be the most frustrating (χ^2(2,27) = 11.62, p = .003). Seventeen people found the adaptable condition to be initially the easiest to use (χ^2(2,27) = 12.08, p = .002). This was also reflected in additional comments, where several subjects noted that the adaptive condition was initially more difficult to use until they had become familiar with it (it is possible this is due to the initial period that it takes for the adaptive menus to stabilize (see Section 6.1 for discussion)). No significant deviation from the expected equal frequencies was found for perceived error rate, reflecting the quantitative error results.

To test hypotheses H3 and H4 (preference hypotheses) we compared the preference ratings using pre-planned comparisons. There was a significant difference between adaptable and static for the overall preferred dependent variable (χ^2(2,27) = 6.37, p = .012), where 15 subjects specified adaptable as their most preferred menu type and 4 specified static as their most preferred. No other significant differences were found, although the frequencies of preference rankings for adaptable versus adaptive (15 vs. 8) suggest that with a larger number of subjects this would also be a statistically significant difference.

Additional comments that subjects included in the post questionnaire reflected a division between those who liked the adaptive menus and those who did not. Several people made positive comments, for example, saying the adaptive

Table 4.5: Mean layout scores for customization for the 22 subjects who customized based on the task sequence. (Selection sequences were randomly generated, so subjects had slightly different menu layout scores from one another, even for the traditional menu.)

Menu Layout	**Mean Score**	**Standard Deviation**	**Improvement over Traditional**
Adaptable	446.7	70.1	66.9%
Traditional (MS Word)	1349.1	119.4	—
Ideal adaptable	386.9	27.3	71.3%
Static	453.1	42.8	66.4%

menus are fast "...before you know where things are really". This refers to the fact that one has to familiarize oneself with the menu structure before the adaptable and static menus can be used efficiently. On the other hand, six people commented on the inconsistency of the adaptive menus, saying that this made the menus frustrating to use.

4.2.3 Menu Layout

As mentioned at the beginning of this chapter, only 22 of 27 subjects customized based on the task sequence. Using these 22 data sets, menu layout scores were calculated for each subject's adaptable condition. In addition, a layout score was computed for each of the following: traditional menu (original MS Word menu), static split menu, and ideal adaptable split menu. Each of these was calculated based on the specific 200-item selection sequence for a given subject. With the ideal adaptable menu, the four items above the split were ordered from most to least frequently used within the sequence; with the static split menu, the original relative ordering of items (i.e., the ordering from the menu masks described in Section 3.2) was maintained above the split. Table 4.5 shows a summary of the layout scores.

The results show that although subjects did not reach the optimal menu layout afforded by the ideal adaptable menu ($M = 446.7$ and $M = 386.9$ for adaptable and ideal adaptable respectively), they were able to achieve menu layouts that were comparable to the static split layout ($M = 453.1$). This is complementary to the results obtained from the speed analysis.

4.2.4 Summary of Results

We summarize our results according to our hypotheses:

- **H1** (Adaptive is slower than both static and adaptable): The adaptive menu was slower than the static menu. The adaptive menu was also slower than the adaptable menu, except when subjects used the adaptable menu first.

- **H2** (Adaptable is not slower than static): The adaptable menu was not slower than the static menu, except when subjects used the adaptable menu first.

- **H3** (Adaptable is preferred to both adaptive and static): The adaptable menu was preferred to the static menu. There was also a trend, though not statistically significant, that suggested the adaptable menu is preferred to the adaptive menu.

- **H4** (Static is preferred to adaptive): Static was not preferred to adaptive.

4.3 Implications

Several factors for interface design can be drawn from the results of this study.

Influence of Exposure on Customization

Four of the five subjects who did not customize were given the adaptable condition first. This interaction effect suggests that some users do not recognize the value of customizing, even when the customization mechanism is easy to use. Subjects who had seen the static or adaptive menus first recognized that placing the most frequent items near the top resulted in better performance. Previous work had suggested that users do not customize because the mechanisms are difficult to use [38]. Our work suggests that easy-to-use mechanisms are not sufficient; exposure is also a factor.

To understand the effect of exposure on customization, we need to understand what caused the interaction effect. We hypothesize the following explanations for the interaction:

- **H1** The exposure to different menus, in particular those with frequently or recently accessed items at the top, impacts the user's willingness to customize (*type of exposure*).
- **H2** The number of previous menu selections impacts the user's willingness to customize (*duration of exposure*).
- **H3** It is a combination of type and duration of exposure that impacts the user's willingness to customize (*combination of exposures*).
- **H4** This is simply a statistical artifact of our data and would not be present in a replication of the study.

If the effect is produced by type of exposure, this suggests that for effective customization, we may also need to guide users by providing examples, such as an efficiently organized static split menu. Previous work using GOMS modelling has shown that it is more efficient to customize up-front, prior to starting a task, than as-you-go, throughout the task [5]. If the effect of exposure on customization is produced by the duration of exposure, it may not be practical to expect users to customize up front. In that case, further work would need to be done on how to better encourage users to customize early on. In our Study 2, we chose to explore the type of exposure (H1) as an explanation for the interaction.

Users Can Customize Effectively

Static split menus are the most efficient static menus documented in the literature. Optimal efficiency can be achieved for a static split menu when the actual frequencies of item selection are known in advance of the task, as was done in our experiment, but would be difficult to achieve in practice. The Block 1 data (Table 4.3) allows us to compare the static split menu to the non-customized version of the adaptable menu and shows that the static split menu was indeed 20% faster. (Recall that Block 1 of the adaptable menu had the same layout as the traditional menu, which is a straight menu mask of the original MS Word menu.) Therefore, the ability of users to customize their own menu (in two of the three orders) to achieve a result that was not found to be significantly different from the optimal efficiency of the static split menu is a strong result. Combining this with the finding that the adaptable condition was faster than the adaptive one (again for the same two orders), shows that adaptable interaction techniques can be effective and that more emphasis should be placed on them in interface design. In a previous field study, McGrenere, Baecker and Booth showed that users were willing and able to customize their menus based on their function usage [42]; thus, the comparable findings we report here are not simply an artifact of our laboratory study design.

Majority of Users Want a Personalized Interface

Users value an interface that can be modified to suit their individual needs. Although the adaptable menu was preferred by the majority of subjects (55%), the adaptive menu did have support (30%). By contrast, only 15% of subjects preferred the static menu, even though it was the optimal split menu. This distribution differs somewhat from that of McGrenere, Baecker and Booth, who found that 65% preferred adaptable, 15% adaptive, and 20% of the subjects requested static menus (although no static variant was actually evaluated in their field study) [42]. The slightly greater support for an adaptive menu found here (30% vs. 15%) suggests that an adaptive split menu may be preferable to the Microsoft adaptive menus used by McGrenere, Baecker and Booth.

Perceived versus Measured Performance

The majority of subjects perceived themselves to be the most efficient with the adaptable menus, even though they were actually less efficient than with the static menus in one order, and were not significantly more or less efficient in the other two orders. This is a surprising result for which we have no concrete explanation. The results suggest, however, that providing users with control over their menus can lead to both better perceived performance and higher overall satisfaction.

4.4 Discussion and Follow-up Study

This study found that the static split menus were significantly faster than the adaptive split menus, and that there was an interaction effect between the type of menu and the order of presentation, such that the adaptable menus were faster than the adaptive menus under certain conditions. As mentioned previously, we had not anticipated that there would be an interaction effect between menu condition and the order of presentation. Understanding this effect is crucial to predicting the actual efficiency of adaptable menus.

One assumption of the Latin square design is that there are no interactions between blocking variables (such as order) and treatments, or between blocking variables themselves [47]. Since pilot testing with 8 subjects had indicated that there would not be an interaction effect that included order of presentation, the Latin square design appeared to be a valid approach to decrease the number of cells from 36 to 9. An interaction effect was found in the full study, but because Latin square designs are not fully-counterbalanced, we must be cautious about drawing strong conclusions about the interaction.

In Section 4.3 we hypothesized several explanations for the effect of exposure on customization. Given the results from Study 1, we considered the most likely hypothesis to be that the type of exposure affects the user's willingness to customize

(H1) and chose to explore it further. Since the Latin square design in Study 1 was not fully counterbalanced, those subjects who were not presented with the adaptable condition first were presented with either the adaptive condition or both the adaptive and static conditions before starting the adaptable condition. Therefore, it is not possible to discern whether exposure to the adaptive menu alone affected the user's willingness to customize, or whether exposure to the static menu would have had the same positive effect. Both of these possibilities are explored in Study 2.

Chapter 5

Study 2: Effect of Exposure on Customization

The results of Study 1 showed that there was an interaction effect involving the order of presentation and speed on the three menu types. Four out of the five people who did not customize effectively in that study were those who had seen the adaptable menu condition first, without the prior exposure to static and adaptive menus that was given with the other two orders of presentation. In Section 4.3, we hypothesized several explanations for this interaction effect. The study presented in this chapter was designed to investigate the first hypothesis: that the *type* of exposure a user has prior to using the adaptable menus impacts the user's willingness to customize. In particular, we hypothesized that exposure to menus with frequently or recently accessed items at the top provide the necessary experience to motivate the user to customize.

We chose different types of exposure for this study based on the results from Study 1. Each subject was presented with two conditions: one of three possible exposure conditions and an adaptable condition. For both conditions, each subject repeated the same selection sequence twice. In determining which types of exposure to use, static and adaptive split menus were first selected because some subjects were exposed to these conditions prior to the adaptable menu in Study 1. It was unclear from Study 1 whether there is a difference in effect on customization efficiency between the static and adaptive split menus as a type of exposure. In addition, we chose to use the traditional menu as a type of exposure. With the split-block design used in these studies (training block and testing block), subjects performed the same task in a given condition twice; for the adaptable menu, the training block was done on the original menu layout, which is essentially a traditional menu. For this reason, we considered the traditional menu to be a third type of exposure which may have contributed to the interaction in Study 1.

To take greater advantage of the investment required in running a study, a secondary goal was also identified: to verify that a traditional menu layout is significantly slower than the static and adaptive split menu layouts. Since each subject in this study will use one of traditional, static split or adaptive split menus as a type of exposure prior to using the adaptable menus, we can compare the performance on these three types of menus to each other. Although we did record data on the traditional menu in Study 1 because it was an implicit part of the adaptable menu condition, that data represented only the training block that was used in our split-block design. The analysis done for Study 2 compares traditional, static split and adaptive split menus with both training and testing blocks, in the same manner as the three menu conditions were compared in Study 1. The comparison between traditional and static split menus is a partial replication of Sears and Shneiderman's split menu work [51]; however, the comparison of a traditional menu to an adaptive split menu is novel and was not answered in Study 1.

5.1 Methodology

Unless otherwise noted, the methodological details such as instructions for menu conditions and apparatus used are as described in Chapter 3. Throughout this chapter, we refer to types of exposure as "practice" menu conditions.

5.1.1 Practice Conditions

Traditional menu, static split menu, and adaptive split menu were chosen as three types of practice.

5.1.2 Task

Two similar tasks were needed: one for the practice menu blocks, and one for the adaptable menu blocks. These did not need to be isomorphic tasks, but to maintain consistency with Study 1, we chose to use two of the isomorphic tasks described in Chapter 3. In Study 1, no significant differences were found between the isomorphic tasks, so we arbitrarily chose to use the first two schemes for Study 2. The schemes were then paired with a different underlying 200-item selection sequence for each subject.

5.1.3 Measures

In addition to speed and error rate, an obvious measure to analyze is the binary variable of whether a subject customized or not. Given the variability we found between subjects in Study 1, we predicted that we would need more subjects than realistically possible for our subject pool and time-line to achieve statistical significance for this measure, so it was not included as a dependent variable.

Preference was recorded as a qualitative, self-reported measure on a post-evaluation questionnaire (see Appendix A). Subjects were asked to rank their menu type preference (practice menu vs. adaptable menu) on a 5-point Likert scale.

5.1.4 Experimental Design

Since we wanted to measure the effect of exposure, each subject could be exposed to only one type of practice menu, thereby eliminating any possibility of learning or transfer effects. As such, the design was between-subjects with one factor: type of practice. Subjects were randomly assigned to one of the three levels of practice so that each condition had an equal number of people. Separate one-way ANOVA's were used to calculate the main effect for each of speed and error rate.

Rather than assigning a randomly chosen selection sequence to each subject, as in Study 1, we generated only 10 sequences, and used each sequence once in each practice condition. Sequences were then randomly assigned within each condition. This increased power by decreasing variability between groups, while still reducing the effect of any one particular selection sequence.

Trade-offs always need to be made in designing a study, for example, between- versus within-subjects designs, deciding on the total number of subjects required in total, and the number of cells in the design. As discussed in this section, it was necessary to use a between-subject design for Study 2. The statistical power of Study 2 is therefore lower in than in Study 1, even though a roughly equal number of subjects was used in each study.

5.1.5 Procedure

The experiment was designed to fit in a single 45 minute session. To clarify terminology, we refer to each subject as having completed two *practice* blocks (which could be on a traditional, static, or adaptive menu) and two *adaptable* blocks. The procedure was as follows:

1. A questionnaire was used to obtain information on user demographics and computer experience.

2. Verbal instructions, supplementary to the online instructions, were given to subjects. These provided an overview of the experiment and stressed the importance of speed, introducing the extra $10 cash prize based on speed.

3. Short block (20 item selections) to introduce the subjects to the experimental system and to allow for questions, followed by a one minute break.

4. Practice menu blocks: 200-item selection sequence, two minute break, repetition of the same 200-item selection sequence.

5. Five minute break.

6. Adaptable menu blocks: 200-item selection sequence, two minute break, customization period, repetition of the same 200-item selection sequence.

Extra $10 cash prizes based on speed were awarded as in Study 1, with the additional step that we took into account each subject's practice condition when assessing comparative performance.

5.1.6 Apparatus

The experimental system used was similar to that of Study 1, with changes where appropriate to accommodate the procedure for Study 2.

5.2 Study

After piloting with three subjects to test our experimental procedure, a study was conducted in March and April 2004.

5.2.1 Subjects

Subjects were all undergraduate students with varying majors and were recruited through the Department of Psychology at the University of British Columbia. In total, 30 people participated. Each was paid either $5 or $10 (increased for the end-of-the-semester period) to participate for a 45 minute session. All subjects were between 18-29 years of age, with 6 males and 24 females. On the background questionnaire (see Appendix A), 6 identified themselves as novice computer users, 20 as intermediate users, and 4 as expert users. All subjects specified that they regularly used a Microsoft Windows operating system (ranging from Windows 98 to Windows XP); additionally, two people used Mac operating systems regularly. Three used a computer 1-5 hours per week; 11 used a computer 5-10 hours per week; 16 used a computer more than 10 hours per week.

5.2.2 Hypotheses

This study is designed based on one explanation for the interaction effect found in Study 1; that is, this study is based on the theory that exposure to different menus, in particular those with frequently (and possibly recently) accessed items near the top of the menu, impacts the user's willingness to customize. The following hypotheses were thus derived:

- H1. Efficiency of customization is no different for the adaptive and static split menu practice conditions, since these menus share the characteristic that the most frequently accessed items appear at the top of the menu.

- H2. Users customize least efficiently with the traditional practice condition (i.e., a practice condition similar to the initial layout of the adaptable menus), since the most frequently accessed items may be found anywhere in the menu.

5.3 Results

In total, 30 sets of data were obtained. Seven out of 10 subjects in each of the traditional and static practice conditions customized according to the task sequence, while all 10 subjects in the adaptive practice condition customized their menus. Although a frequency analysis of this data would not be statistically significant due to the small sample size, there may be a trend that people are more likely to customize when they have seen the adaptive menu.

5.3.1 Performance

One-way ANOVA's were calculated to assess the effect of practice on the speed and error rate of the adaptable menu. In addition, by examining the practice blocks only, a one-way ANOVA was calculated to compare the difference in efficiency of the static, adaptive and traditional menus, and descriptive statistics were calculated to examine learning between Block 1 and Block 2 of the static, adaptive and traditional menus.

Performance of Adaptable Menus with Varying Practice Conditions

No significant main effect was found for practice on speed in the adaptable condition using a one-way ANOVA ($F(2, 27) = 1.379$, $p = .269$, partial $\eta^2 = .093$); that is, the type of exposure did not seem to impact performance of the adaptable menus. The test had relatively low statistical power (observed power = .271), however, so the finding should not be considered conclusive. The mean completion times for all subjects who were in the traditional, static, and adaptive practice conditions were 347.0, 320.1, and 319.5 seconds respectively. To summarize the speed results, Table 5.1 shows the mean completion times for both blocks of the adaptable condition, broken into those subjects who did not customize, and those subjects who did. The percentage improvement between Block 1 and Block 2 for those subjects who customized was between 22.9% and 25.5% on average across the three practice conditions. If we include the data for those subjects who did not customize, however, the average percentage improvement for subjects in the traditional and static practice conditions decreases.

Using a one-way ANOVA, no significant effect was found for practice on error rate ($F(2, 27) = .033$, $p = .968$, partial $\eta^2 = .002$). On average, 7.0, 7.6, and 7.9 errors were made during the adaptable Block 2 for the traditional, static, and adaptive practice conditions respectively. The observed power was low (.054), similar to the error rate ANOVA from Study 1, so the result is not conclusive.

Table 5.1: Means for selection speed for Blocks 1 and 2 of the adaptable condition, comparing those subjects who did not customize according to the task sequence to those subjects who did customize (N=30).

Practice	**Did Not Customize***			**Customized**†		
Condition	Block 1	Block 2	Improvement	Block 1	Block 2	Improvement
Traditional	407.37	383.42	5.9%	429.83	331.40	22.9%
Static	432.48	370.93	14.2%	397.47	298.34	24.9%
Adaptive	–	–	–	428.68	319.50	25.5%

$^*N$=3 for traditional and static, N=0 for adaptive
$^\dagger N$=7 for traditional and static, N=10 for adaptive

However, this does not contradict the choice of an implicit error penalty (see Section 4.2.1 for detailed discussion).

Performance of Traditional, Static and Adaptive Menus

To compare performance of traditional, static split and adaptive split menus, we analyzed the speed and error results from Block 2 of the practice conditions. Performance of the static menus was fastest (M = 323.28 seconds), followed by the adaptive menus (M = 356.07 seconds); the traditional menus were the slowest (M = 413.01 seconds). A main effect was found for type of menu on speed ($F(2, 27)$ = 13.803, $p < .001$, partial $\eta^2 = .506$). To compare each possible pair of conditions post-hoc pairwise comparisons were performed on the data. The results are shown in Table 5.2, adjusted for multiple comparisons using a Bonferroni adjustment. The traditional menu type was significantly slower than both static and adaptive (p = .001 and p = .008 respectively). Unlike in Study 1, however, no significant difference was found between the adaptive and static conditions. This is most likely due to the lower power of Study 2 compared to Study 1.

Table 5.2: Pairwise comparisons for speed dependent variable for Block 2 of the practice conditions.

Menu (i)	**Menu (j)**	**Mean Difference (i-j)**	**Std. Error**	**Sig.**[a]	**Partial η^2**
Traditional	Static	**89.731***	17.2834	.001	.574
Traditional	Adaptive	**56.943***	17.2834	.008	.377
Static	Adaptive	-32.788	17.2834	.206	.183

* The mean difference is significant at $p < .05$

[a] Adjusted for multiple comparisons using Bonferroni

Table 5.3: Summary of self-reported preference measures (N=30).

Practice Condition	**Adaptable Preferred**	**Adaptable Not Preferred**	**Undecided**
Adaptive	7	2	1
Static	8	1	1
Traditional	7	1	2
Total	22	4	4

Learning of Traditional, Static and Adaptive Menus

To compare learning between traditional, static and adaptive menus, we calculated the mean percentage decrease in completion time between Block 1 and Block 2 of the practice conditions. There was an improvement of approximately 9% for all three types of menu (N = 10 for all types of menu; M = 9.4%, SD = 3.3% for traditional; M = 9.7%, SD = 2.5% for static; M = 8.5%, SD = 8.5% for adaptive). Thus, our data did not show any difference in learning across the three types of menus. However, since we only used two selection sequence blocks for this data, a longitudinal study would be required to determine if there is a change in relative learning performance over time.

5.3.2 Self-reported Measures

The preference rankings recorded by subjects are summarized in Table 5.3. The results are similar to the preference results from Study 1, with the addition of the traditional menu condition. Most people (22 of 30) in all three practice conditions preferred the adaptable menu to the menu they used in the practice condition. A Chi-square analysis to assess whether the total rankings differ from the case where all categories are rated equal shows that there is a significant difference in the number of people who preferred the adaptable menus to their respective practice menu condition ($\chi^2(2,30) = 21.60$, $p < .001$).

All subjects who used the customization mechanisms stated that they did so based on the frequency with which items appeared in the task sequence. Beyond that, three subjects specified as well that they would choose an item closer to the bottom of the menu if they needed to select between two items of approximately similar frequency. Three subjects further ordered their items alphabetically within the top partition.

For the five participants who did not customize, the reason given was that they were already familiar with the menu layout and felt that it would be inefficient to change it. For example, one subject noted: "... I have familiarized myself with the location of items so did not want to change them."

5.3.3 Customization (Menu Layout)

The mean menu layout scores for the adaptable menu are presented in Table 5.4. When the layout scores of all subjects are compared, the subjects in the adaptive practice condition have the lowest (best) mean score (M = 283.2), while mean layout scores for the traditional and static practice conditions are more similar (M = 553.5 and M = 495.7 respectively). With only those subjects who customized their adaptable menus, the mean scores are all relatively close (M = 278.3, M = 250.1, and M = 283.2 for traditional, static, and adaptive practice conditions

Table 5.4: Layout scores for customization for the 24 subjects who customized based on the task sequence in Study 2.

Practice Condition	**Mean Score**	
	All Subjects	Those Who Customized
Traditional	553.5*	278.3†
Static	495.7*	250.1†
Adaptive	283.2*	283.2*

*N=10, †N=7

respectively). Though the sample size is small, this suggests that a future study may not find an effect of practice on the ability to customize (i.e. on the quality of the menu layout). Although the average layout scores for *all* subjects suggests there will be a difference in the quality of menu layout across different practice conditions, the real effect is likely on whether users choose to customize or not.

5.4 Summary of Results

No significant effect was found to support either H1 (efficiency of customization is no different for the adaptive and static split menu practice conditions) or H2 (users customize least efficiently with the traditional practice condition). Though not statistically significant, we found that all 10 subjects in the adaptive practice condition customized their adaptable menus, whereas only 7 subjects in each of the static and traditional practice conditions customized. This suggests that the adaptive nature of the practice condition may have contributed to the subject's willingness to customize. As well, we built on the results of Study 1 by showing that the traditional menu is slower than the adaptive split menu, and that the adaptable menu is preferred to the traditional menu.

5.5 Discussion

Unfortunately, the study design had lower statistical power than we had anticipated. This was the result of combining a between-subjects design with a task that had relatively high individual variance. In estimating the number of subjects that would be required to obtain significant results, we relied on similar individual variance as in Study 1; however, this was not enough to compensate for the drop in statistical power when using a between-subjects design over a within-subjects design. One possible trend which we identified was that subjects may customize more efficiently after exposure to the adaptive menu. If this trend were to hold for a larger sample size, given the observed power of this study, we estimate that at least twice as many subjects per cell would be needed to achieve statistical significance.

Study 2 tested the first of four possible explanations for the interaction effect that was found in Study 1 (see Section 4.3): that the type of prior exposure affects the user's willingness to customize. Although no statistically significant effect was found to support this hypothesis, we cannot safely conclude that the type of prior exposure does not have an affect on willingness to customize because of the study's low power. This hypothesis should be retested in a future study. In addition, the other three proposed explanations for the interaction effect in Study 1 have not yet been tested and remain for future work. A larger sample size would also be needed to determine if there is an effect of practice on the frequency of subjects choosing to customize or not (i.e., to analyze frequency data using Chi-square would require a much larger number of subjects).

Chapter 6

Conclusions and Future Work

The primary goal of the work presented in this thesis was to compare the efficiency of static, adaptive, and adaptable interaction techniques. While previous work has compared adaptive and adaptable interaction in a field setting [42], there has never been a controlled comparison of the efficiency of these three techniques. Our work addresses this gap and provides complementary results to strengthen the existing body of research on adaptive and adaptable systems, and more generally on menu design. Two separate studies were run to measure several aspects of the efficiency of static, adaptive, and adaptable interaction techniques in the context of pull-down menus. The implications for interface design and questions that have arisen will be useful for guiding further research in the area.

6.1 Limitations

These studies were conducted as lab experiments, and as with any lab experiment, there is a trade-off of realism and generalizability for increased precision [40]. The limitations are tempered by the close connection with previous field study work conducted by McGrenere, Baecker and Booth [42] in a more natural setting, and by steps taken to maintain a degree of ecological validity, such as basing the task on real usage data. Nonetheless, these issues should still be discussed.

In a realistic setting, several variables could affect the user's ability to select menu items and to customize a menu, including such factors as an extended time between selections, switching between tasks, and the range of distractions that can occur in a busy workplace. Since these experiments were performed over a relatively short period of time, memory requirements placed on the user will inevitably differ from those in a more realistic setting. In addition, though we addressed factors such as motivation and training in our studies, these cannot be accounted for perfectly in any lab setting.

The issue of generalizability arises for multiple reasons. First, our subject pool was relatively constrained. Almost all subjects identified themselves as students between the ages of 18 and 39. It is possible that due to the age and education level of this population they have, in general, relatively high technical exposure and expertise compared with other populations.

Furthermore, this experiment tested very specific adaptable and adaptive systems. Questions remain as to how generalizable these menu conditions are to other applications, and also how generalizable menu adaptivity is to other interaction techniques. In particular, the adaptive algorithm used here was based on simple values of frequency and recency, so that it would maintain some consistency with Microsoft's adaptive algorithm and would be reasonable to implement within the scope of this research. A more sophisticated adaptive interface, however, may behave differently and yield more positive (or possibly negative) results in comparison to an adaptable interface.

Another possible limitation of the adaptive algorithm is that it required an initial training period at the beginning of each selection block to attain a relatively stable state (i.e., for the two most frequent menu items to remain unchanged throughout the rest of the selection sequence). We chose to reset the adaptive algorithm at the beginning of each selection block because data from a previous selection block, or even from the end of the same selection block, may not have been relevant to the current block. The result, however, was that 1, 8, and 18 selections were required on average from the `Insert`, `Format`, and `File` menus respectively for those menus to stabilize in a given 200-item selection sequence. While this behaviour may have had a negative impact on the performance of the adaptive menus, the extent of this impact is unclear. Finally, the choice to initially populate the top part of the adaptive split menus (consistent with the common commercial application, MS Word) may have removed an opportunity for the user to better understand the decisions of the adaptive algorithm. That is, if the top part of the adaptive split menus had been initially empty and subsequently populated as a subject performed a selection sequence, this may have given the subject a clearer understanding of the adaptive algorithm.

6.2 Satisfaction of Thesis Goals

The research goal defined at the outset of this research was to compare the efficiency of static, adaptive, and adaptable interaction techniques in a controlled setting. We hoped that in the process of accomplishing this goal, we would also be able to identify other trends about customization.

The primary goal was met through two studies. Study 1 was designed with the initial aim of comparing the efficiency of static, adaptive, and adaptable split menus, while Study 2 was designed as a follow-up study. The main measure of efficiency used in both studies was speed, which included an implicit error penalty.

The results of Study 1 showed that static split menus are significantly faster than adaptive split menus. In addition, the adaptable split menus were disproportionately affected by the order of presentation. When the adaptable menu was the first condition presented to the subject, the adaptable menu was slower than the static menu, and not significantly different from the adaptive menu. However, when the adaptable menu was not the first condition, the adaptable menu was faster than the adaptive menu, and not significantly different from the static menu. Understanding this interaction is important to predicting the overall performance of adaptable menus; however, we were unable to draw strong conclusions about the nature of this effect because Study 1 used a Latin square design, which did not allow us to identify which component of the study caused the interaction effect.

Several possible explanations can be hypothesized for the interaction effect. In Study 2, we chose to explore whether the type of prior exposure affects the user's willingness to customize because we considered this to be the most likely explanation given the results from Study 1. No significant effect was found for type of exposure (i.e., traditional, static split, and adaptive split menus) on the performance of the adaptable menus. However, due to high individual variation on the experimental task, the study had low statistical power and the results should not be considered conclusive. This remains to be explored further, but leaves open the possibility that the duration of practice may have a stronger effect on the efficiency of the adaptable menus than does the type of practice.

Study 2 further contributed to the primary objective of this thesis because it allowed for the evaluation of a traditional menu (i.e., no split) to static and adaptive split menus. As expected, the traditional menu was significantly slower than the static split menu, replicating previous results by Sears and Shneiderman [51]. In addition, however, the traditional menus were found to be significantly slower than the adaptive split menus. Since a static split menu may not be feasible in a realistic setting because the frequently used menu items need to be known in advance of deployment to the user, traditional and adaptive menus may be more useful in practice. In such a situation, our results show that an adaptive alternative may be preferable.

Through Study 1, we have shown that adaptable menus can be as efficient as an optimal static split menu, and more efficient than an adaptive split menu. Study 1 implies that there are conditions that need to exist in order to achieve this efficiency, in particular the duration and/or type of prior exposure; however, we have not yet proven which of these conditions is required.

Implications and secondary trends have been discussed throughout this thesis, contributing to a deeper understanding of customization. The results of Study 1 suggested that giving users control over their menus through an adaptable mechanism may increase the perceived efficiency of the menus. In Study 2, based on the post-evaluation questionnaires, we found that subjects unanimously chose to place items in the top section of their adaptable menu based on the perceived frequency with which those items had occurred in the selection sequence. In addition, a few subjects chose to further arrange menu items alphabetically within the top part of the menu. Finally, our studies found overwhelming support for personalized menu design. Even though more users preferred the adaptable menu to the adaptive menu in Study 1, the users who preferred the adaptive one expressed strong support for it. This suggests that combining the two in a mixed-initiative design may be the best way to satisfy a wide range of users.

6.3 Future Work

In addition to retesting the hypotheses of Study 2, several possibilities for future research arise from our results. Some of these are direct extensions that explore specific trends we have identified, whereas others are broader, more open possibilities that build upon these results to examine new issues. The following points briefly outline some areas for potential research.

Adaptive versus Adaptable Interaction for Different User Groups

Adaptable and adaptive approaches need to be explored in the context of accessible interfaces for diverse user populations. Our sample was quite homogeneous; the generalizability to other populations is worth further study. For example, children may acclimatize easily to an adaptive interface, while elderly users may find adaptive interfaces to be relatively incomprehensible.

Mixed-Initiative Interfaces

In mixed-initiative interfaces, the system and the user share control of the interaction. Evaluation of this interaction style has received little attention in the research literature. One possibility for extending our work into this area would be to provide periodic suggestions from an adaptive system on what to add or delete from the top partition of a user's split menu, and measure the effect of these suggestions on the user's customization efficiency (as proposed in [5]). Another option would be to use a "pinning" metaphor like the Microsoft Windows XP start menu; that is, an adaptive algorithm would place items in the menu, and users could permanently choose to keep items in the menu by "pinning" them to the menu [45]. These types of approaches have potential to produce more efficient interfaces than either adaptive or adaptable interaction alone.

Adaptive Algorithm Transparency

The issue of predictability has been identified as a major challenge facing adaptive interfaces [23]. One question that is a direct extension of this work is whether knowledge of the internal process of the adaptive algorithm will affect the user's satisfaction and perceived efficiency. One could examine, for example, three levels of knowledge: no knowledge, a high-level overview (i.e., this algorithm chooses the most recent and most frequent items), and detailed understanding.

Other Types of Menus: Replication with Microsoft's Personalized Menus

The adaptive menus found in Microsoft Office 2000 and XP display only a subset of the menu items when they are initially opened. The full set is opened by hovering the mouse pointer in the menu for a few seconds, or by clicking on an arrow at the bottom of the menu. The performance differences between the static, adaptive, and adaptable approaches may in fact be larger for menus with hidden items than for split menus, as it takes longer for people to search for an item that is absent than for an item which is visible [63]. As well, the delay or extra click to view the full set of menu items is likely to slow down performance on this type of adaptive menu even more. These two aspects combined could exaggerate differences between the three types of menu.

Field Study

The hypotheses from the studies discussed in this thesis should be retested in a field study to explore issues that would arise in a more naturalistic setting. In particular, a field study would be useful to follow-up on the trend (identified in Study 2) that suggests that exposure to an adaptive interface could encourage users to customize. Although we dealt with the issue of motivation in our lab study, it will be important to determine what types of differences there are in a setting with realistic time and motivation constraints. For example, when users are distracted by tasks and environmental factors, or are under other external pressure (such as deadlines at work), their willingness to customize may decrease but could be partially offset by providing exposure to an adaptive interface.

6.4 Concluding Remarks

This work should be seen as an initial step towards developing a thorough understanding of the efficiency of static, adaptive, and adaptable interaction techniques. The results and implications presented in this thesis should in particular motivate further research on customization and the factors which affect it. Before developing guidelines and theories that will be appropriate for a wide range of applications, further work needs to be done to evaluate these interaction techniques in terms of other interface components and interaction metaphors.

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Appendix A

Study 1 Questionnaires

Part I: Background Questionnaire

1. In what age group are you?

   □ 19 and under
   □ 20 - 29
   □ 30 - 39
   □ 40 - 49
   □ 50 - 59
   □ 60+

2. Gender:

   □ Male
   □ Female

3. Are you right-handed or left-handed?

   □ Right-handed
   □ Left-handed

4. How many hours a week on average do you use a computer (including work and non-work related activities)?

   □ < 1
   □ 1 - 5
   □ 5 - 10
   □ > 10

5. Which operating systems do you currently use on a regular basis (at least on a weekly basis)? Please tick all that apply.

   □ Windows (Microsoft)
      □ Windows XP
      □ Windows 2000
      □ Windows ME
      □ Windows 98
      □ Windows 95
      □ Other - please specify: ________________
   □ Mac (Apple)
      □ OS X
      □ OS 9 or lower
   □ Unix - specify window manager: ________________

6. In terms of computer expertise, would you consider yourself to be:

□ Novice
□ Intermediate
□ Expert

7. In terms of your current occupation, how would you characterize yourself?

□ Writer
□ Administrative Assistant
□ Journalist
□ Secretary
□ Academic
□ Professional
□ Technical expert
□ Student
□ Designer
□ Adminstrator/Manager
□ Other, please specify: ________________

Part II: Feedback Questionnaire

To refresh your memory, there were three menu schemes used in the experiment:

Static scheme: Locations of items in the menu did not change while you used the menus.

Adaptive scheme: Placement of items was adjusted by the computer as you used the menus.

Adaptable scheme: The menus did not change as you used them, however, you were given an opportunity to customize them yourself.

Please answer the following questions. A space below each question is provided for any additional comments you may wish to make.

1. Which menu scheme did you prefer overall? Please put a 1 beside that scheme and a 2 beside the next preferred scheme.

   ___ Static scheme   ___ Adaptive scheme   ___ Customizable scheme

   Comments:

2. With which menu scheme did you feel you were the most efficient (quick)? Please put a 1 beside that scheme and a 2 beside the scheme with which you were the second most efficient.

   ___ Static scheme   ___ Adaptive scheme   ___ Customizable scheme

   Comments:

3. With which menu scheme did you feel you made the least number of errors (incorrect menu selections)? Please put a 1 beside that scheme and a 2 beside the scheme with which you felt you made the second least number of errors.

   ___ Static scheme   ___ Adaptive scheme   ___ Customizable scheme

   Comments:

4. With which menu scheme did you feel the most frustrated? Please put a 1 beside that scheme and a 2 beside the scheme that was the second most frustrating.

   ___ Static scheme   ___ Adaptive scheme   ___ Customizable scheme

Comments:

5. Which menu scheme did you **initially** find the easiest to use? Please put a 1 beside that scheme and a 2 beside the scheme that you initially found the second easiest to use.

   ___ Static scheme   ___ Adaptive scheme   ___ Customizable scheme

   Comments:

Please use this space to make any additional comments on the menu schemes, or the study:

Thank you for your participation!

Appendix B

Online Instructions

This appendix contains all textual descriptions and instructions included in the experimental system.

B.1 Study 1

Study 1 used the following descriptions:

Introduction screen

> *Introduction*
>
> This experiment tests three different menu schemes. For each scheme you will be given a sequence of menu items. When an item name appears on the screen, please select that item as quickly as possible from the corresponding menu. If you select the wrong item by mistake, you will need to select the correct item before continuing.
>
> To get used to the task, you will be given a short untimed practice session. To select an item, click once to open the menu, then click on the item.

End of practice session

> This is the end of the practice session. If you have any questions before starting the experiment, please ask the researcher.

Static condition

> *Static Menu Scheme*
>
> The locations of menu items will remain the same throughout the course of the selection sequence.
>
> You will be given a sequence of 200 items to select. This will be followed by a short break, then you will be asked to repeat the same sequence.

Adaptive condition

Adaptive Menu Scheme

The top four items in each menu may change as you use the menu.

You will be given a sequence of 200 items to select. This will be followed by a short break, then you will be asked to repeat the same sequence.

Adaptable condition

Customizable Menu Scheme

The locations of menu items will remain the same throughout the sequence.

You will be given a sequence of 200 items to select. This will be followed by a short break, then you will be asked to repeat the same sequence.

Between the two repetitions, you will be given time to customize the menu yourself by moving items around.

Break between Block 1 and Block 2 of Static and Adaptive conditions

This is the end of the first repetition for the [current condition] menu scheme.

Please take a 2 minute break before continuing.

Break between Block 1 and Block 2 of Adaptable condition

This is the end of the first repetition for the adaptable menu scheme.

Before starting the second repetition, you will be given a few minutes to customize or change the menus if you would like to do so.

Please take a 2 minute break before continuing to the customization step.

Customization instructions

Instructions

To customize the menus above, move items to the top section of the menu using the single up arrows. There can be at most four items in the top section.

When an item is in the top section of the menu, two arrows will appear beside it. These can be used to move the item within the top section, or to move it back down to the original menu. When you are done customizing, click the button below to continue.

Confirmation dialogue box

You will not be able to change the menus after this point. Are you sure you are done customizing?

Break between conditions

This is the end of the [current condition] menu scheme. Please take a 5 minute break before continuing on to the next scheme.

End of the study

This is the end of the [current condition] menu scheme.

This is the end of the study. Please let the researcher know that you are done. Thank you for participating!

You completed all menu selections in [x] minutes and [x] seconds.

B.2 Study 2

The instructions for Study 2 were the same as those for Study 1, with appropriate modifications (e.g., "This experiment tests *two* different menu schemes..."). The only addition was the following:

Traditional practice condition

Traditional Menu Scheme

The locations of menu items will remain the same throughout the sequence.

You will be given a sequence of 200 items to select. This will be followed by a short break, then you will be asked to repeat the same sequence.