TOWARDS A NOVEL APPROACH FOR WEBSITE INTERFACE DESIGN: FBS-WEB APPROACH

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ABSTRACT

Towards A Novel Approach For Website Interface Design: FBS-WEB Approach

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Website has become a major media for exchanging information because of its tremendous speed and easy access. Even a single website may contain tens of thousands of web pages nowadays. A website with tons of information, as an interface, should be designed well enough to ensure users to access appropriate information easily and quickly. This thesis describes a novel website interface design approach to achieve the aforementioned goal. Several ideas are behind the development of this approach. *First*, a website interface design is based on a general interface design model to the dynamic system. The model is based on a set of core notions: function, behavior, and structure. *Second*, this general interface design model is modified to suit the website interface design based on our observation of the difference between the website and the dynamic system. Third, the interface design axiom, i.e., the mental model should be equal to the design model is elaborated in the context of the developing the new approach. *Last*, the UML is used to represent the interface which is designed based on the new approach.

The new approach is validated based on an experimental study. Two interfaces are developed based on the new approach and a popular approach in the literature, respectively. The participants operate on the two interfaces, and their performance and mental workload are used to derive conclusions. Both experiment and data are statistically processed. The experimental results allow us to conclude that the new approach is very promising to the website interface design.

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CHAPTER 1

INTRODUCTION

1.1 General Motivation

Nowadays, the Internet has become a major media for exchanging information and knowledge because of its tremendous speed and easy access. A huge number of websites exist on the Internet. This number is still growing quickly. It is no surprise that a single website may have tens of thousands of web pages.

The web page or website (a group of web pages) is an interface between an organization and people who are potentially interested in that organization. We hereafter use the term website interface. When it comes to the interface, several generic issues with any interface are applied to the website interface. The *first* issue is how the interface functions, i.e., providing information and knowledge to the user. The *second* issue is how the interface makes the user comfortable while the interface is functioning; this issue may also be called the usability or ergonomic issue (in the computer science community the term usability is more popular). The *third* issue is how the interface makes the user pleasure while the interface is functioning; this issue may also be called the aesthetic issue. In this thesis study, we focus on the first and second issues only.

The interface has a structure which consists of a set of connected elements. Elements are vehicles of information or knowledge. The connected elements are meant to represent (1) the correspondence of an element to a piece of information or knowledge and (2) the temporal display of elements (element A first, element B second, etc.). It has been shown in general interface design theory that the interface structure is important to the function and the usability, especially in the area of process plants [Lin and Zhang, 2004]. The website interface differs from the process plant in the sense that: for the website interface, the organization, which interacts with the user, is not operable, controllable, or supervised by the user; while the process plant is operable by the user. This difference may have significant impact to our understanding of the following questions:

(1) Whether does the structure of a website interface significantly affect the function and usability?
(2) Whether is the approach to the interface for the process plant effective to the website interface?

The next section presents a preliminary test for question (1). Section 1.3 answers question (2).

1.2 A Pilot Survey Study

We may have a kind of experience: in the activity of shopping online, we might feel more comfortable on shopping website A; specifically when we are able to find goods and their relevant information easily and quickly. While on some other shopping websites (say, website B), we may totally get lost; specifically for example we are unable to track down goods we want.

The situation above may not be only because A is designed with more comfortable color than B; in other words, the structures of A and B may be very different, being a major responsibility for the situation. To confirm this point, we designed a test regarding the University website; specifically, we chose the University of Western Ontario (UWO for short; www.uwo.ca) and the University of Waterloo (UW for short; www.uwaterloo.ca).

The two university websites have the similar purposes: to promote the school, provide information for prospective students, and serve for current students and faculty members. Also, they all provide the information about faculty members, their research areas, admission, student life, and so on. We asked participants to perform two tasks on the two websites (respectively), specifically:

- Find out whether GRE is required for Ph. D. study in the computer science program.
- Find out the contact information of a professor in the computer science department or school.

An interesting finding was that regardless of the factors such as layout, color, picture, font, and font size, which might affect the user performance on these websites when they were searching and looking for the information, several users complained on the UWO website that there was no direct link to the school information from the university main page, which is a very critical way to fulfill the second task. As opposed to the UWO website, the UW website provided such a link, which did lead to a better performance with the UW website than that with the UWO website.

The test described above has shown that the structure of the website interface does matter, as the link is really meant to be something related to the structure. Each website has its own unique structure, and the structure can be implied by the menu, navigation bar, and hyperlink. The structure also implies that among web pages there are relationships.

Therefore, we made a hypothesis (for this research) that different website design methodologies cause different structures of the website interface, and the different structures can lead to different performances of the websites. A general research question is as this: is there any systematic methodology for designing the website interface to achieve the best performance. The next section studies this question.

1.3 Preliminary Investigation

Our first consideration was to review existing website design methodologies and to examine them for the suitability to the website interface design. Several website design methodologies were analyzed, and they are Hypermedia Design Model (HDM) [Garzotto et al., 1993], Object Oriented Hypermedia Design Model (OOHDM) [Schwabe et al., 2002], Relational Markov Model (RMM) [Anderson et al., 2002], and Araneus Design Methodology (ADM) [Merialdo et al., 2003]. One common feature of them was that they all exclusively focused on the web application software design. The web application considerably differs from the website interface because the behavior of operating application software is different from browsing a website. The application software is data-intensive and website is content-intensive [Spool et al., 1998]. That is to say, the application software mainly concerns on controlling data, while the website interface focuses on the meaning of data. More details will be explained in Chapter 2. From this point of view, these website design methodologies are not suitable to the website interface design.

There are several methodologies available which are claimed to suit the website interface design [Rosenfeld and Morville, 2002]. They can be classified into the categories: the audience-based approach, the function-based approach, and the organization-chart-based approach. These approaches focus on the structure of the website interface, but not on the usability issue.

Our search for a suitable approach to the website interface turned to the general interface design philosophies. Several philosophies for the general interface were proposed in the past decades: Perceptual Control Theory (PCT) [Powers, 1973], Proximity Compatibility Principle (PCP) [Wickens and Carswell, 1995], Ecological Interface Design (EID) framework [Rasmussen, 1983], and Function-Behavior-State (FBS) framework [Lin, 2003]. Among them, the FBS framework had the best efficiency [Lin, 2003]. Therefore, we considered adopting the FBS framework with some modifications to the website interface design in this study. In Chapter 2, a more detailed literature review will be presented to justify our view.

1.4 Objectives

This thesis study sets up two objectives:

- *Objective 1: To develop a new website interface design approach, which is based on the FBS model and should address the problems stated in Section 1.3.*

We will extend the FBS approach, which has shown some success in the interface design for the power plant application, to the website interface. This new approach is called the FBS-WEB approach hereafter.

- *Objective 2: To conduct a comparative study on both the function and usability of two website interfaces designed by following the FBS-WEB approach and the approach which combines the audience based approach and function-based approach (called F-A approach for short) which is a popular website interface design methodology, respectively.*

The comparative study was experiment-based. A sufficient number of human subjects (called participants) were asked to evaluate two website interfaces, developed by following the FBS-WEB approach and the F-A approach. The measures used for the evaluation included two categories: performance measure and subjective measure.

1.5 Organization of the Thesis

Chapter 2 provides background information to facilitate the reader in understanding relevant subjects. There is a literature review that helps to justify the significance of the proposed work, specifically, with respect to the objectives stated above.

Chapter 3 proposes the function-behavior-state approach for the website interface (FBS-WEB for short). This chapter will include the basic concepts of the framework, the theory behind the framework, the implementation of the framework, and a case study to demonstrate how to apply the FBS-WEB to develop the website interface.

Chapter 4 presents an experimental study for comparing the FBS-WEB approach and the F-A approach.

Chapter 5 concludes the thesis and discusses the future work.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

This chapter gives the background information and further reviews the existing studies related to the research objectives presented in Chapter 1. Section 2.2 explains definitions of some concepts that are used in the present study. A common understanding of these terms is the basis for further discussion. Section 2.3 further elaborates on a concept called mental model, including types of mental models, importance of mental model to interface design. This section ends up with a conclusion: to make a successful interface design, a design methodology starting from user's mental model is necessary. Section 2.4 explains the gap between application software design methodologies and website interface design requirements. This section further reviews several philosophies to website interface design. Problems with these philosophies are explained. Next, this section introduces the general interface design framework and reviews several well-known methodologies for user interface design, among which the ecological interface design model and the function-behavior-state model are most sound. Section 2.5 gives a summary of this chapter.

2.2 Definitions

Definition 2.1 Human Factor Engineering. *The activity or science of designing, building, or equipping devices or artificial environments (or interface) to the anthropometric, physiological, or psychological requirements of the men who will use them. By studying the human factors that affect man's performance, it aims to ensure safe and effective operation in an operational system* [NASA, 2005].

Human factor engineering mainly deals with the connection between humans and machines. In concrete, it is "to apply knowledge of human capabilities and limitations to the analysis, design, and control of systems and equipment that human use" [Beevis, 1998]. It concerns not only the safety and limitation issue of an operational system, but also the efficiency of the system. With respect to the safety and limitation issue, human factor engineering ensures that humans work in a safe environment when interacting with the system. With respect to the efficiency issue, this discipline may improve the productivity of the system, which may somehow lead to a big economic advantage.

Definition 2.2 Mental Model. *A mental model is an internal representation of an individual's current conceptualization and understanding of a system* [Mayhew, 1992].

A more practical definition of mental model would be the total image or understanding on how things work or how they would behave in a particular situation. For example, having been trained to manipulate a computer, the operator can establish an "image" of using a computer. That is, the operator knows how to start the computer, interact with the operating system, and use the application software. When problems happen, the operator is able to solve these questions based on the understanding of the computer. A more discussion on mental model is given later in Section 2.3

Definition 2.3 Cognitive Model. *It is a representation of the cognition process that starts with the real world which to understand, perceive it, compare it with the mental model of the real world, refine the mental model with the gap between the real world and the mental model while such a gap is "small" enough; see Figure 2-1.*

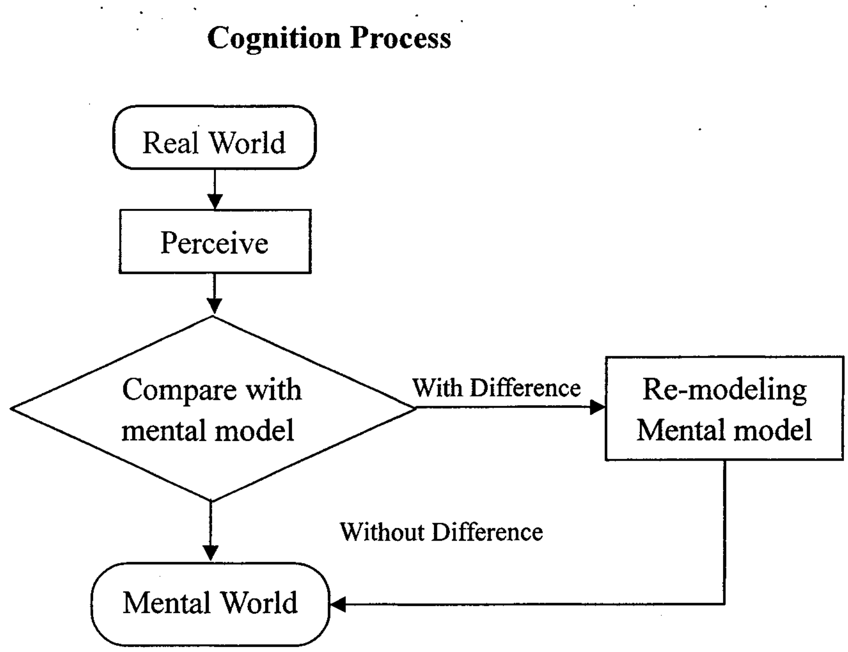

Figure 2-1 A simple flowchart of cognition process

It is noted that for individuals their mental models change with respect to time, which implies a process called learning (re-modeling activity illustrated in Figure 2-1). The teacher with respect to the learner in this process is either an axiomatic understanding of the real world based on the consensus among a group of individuals or the result of solving problems associated with that real world per se. The notion of learning and the notion of individual mental model change will be applied in later discussions.

Definition 2.4 Design Model. *This is an object model describing the realization of external world and serves as an abstraction of the implementation model and its source code* [UPEDU, 2005].

The definition implies that a design model is the representation of a "correct" mental model of the physical world under investigation. Typically, it includes information about components, relationships between components, and non-physical aspects such as the configuration of a system. It is also noted that the notion of the "correct" mental model is consistent with the notion of learning; see Figure 2-1.

Definition 2.5 Task. *It is the action that can or should be performed by one or more actors to achieve a particular goal* [Vicente, 1999].

General tasks are one or more functions to be performed. It can be described in terms of the goals or a desired result of activities. The task is related to the function in such a way that the task is extensional, while the function is intensional (in this case). This further means that a "total" set of tasks (the number of tasks may be indefinite) represents a function. The concept of function will be discussed later in Chapter 3.

Definition 2.6 Mental Workload/Mental State. *It refers to the factors that cover the effects of external conditions and psychological states of the operator* [Smidts et al., 1997].

Mental workload describes the external conditions (in working environment) and psychological state of tasks (e.g., 'simple'), which might be used to forecast the result of tasks. In the physical world, mental workload may represent the degree of difficulty of tasks or the degree of condition in a working environment. A less mental workload apparently helps to achieve the task fast and easily without error. Thus, when doing task analysis, the task requirement evaluation and the mental workload should be considered in a very front position. In such a way, the intended tasks can be accomplished with minimum (cognitive) effort [Stary and Peschl, 1998].

Definition 2.7 Interface. *It is the computer-based means by which operators obtain information about the state of a sociotechnical system, and it is composed of displays and controls* [Vicente, 1999].

Specifically, in a human-computer interaction system, an interface is a linkage between a computer and a user, through which the interaction occurs. Normally it refers to the elements of the software or hardware the user interacts with. The on-screen appearance of interface may contain windows, icons, menus, and dialogues. Although the interface is only part of a computer or machine, it is the only part via which operators perceive and understand the system. From this point of view, the interface of a system may somehow mean the entire system to the (end) users.

We bring together the mental model, task, function, and interface. A good interface should facilitate the performing of tasks by users (a process of externalizing the function of an understanding system) under a particular mental model per se. Repeating of the same task can improve the user performance because of the learning activity in the cognition process. The function is what the system can do, but its external indicator is the result of performing tasks through the interface. An extremely poor interface or a wrong mental model will result in that the user is unable to perform a task.

Definition 2.8 Framework. *It is a set of concepts or guidelines that govern what information should be put on the interface display and how they should be put on the display both temporally and spatially* [Lin, 2003].

Definition 2.9 Information Architecture. *It refers to the organization of a website's structure and content, the labeling and categorizing of information and the design of navigation and search systems. Information Architects are the librarians of web development. The aim is to help users find information and accomplish their task* [TechDis, 2005].

There are several factors to the quality of a website interface. Color, font, writing, and creativity all contribute to, but the structure or organization of a website interface affects most. Each website has its unique organization structure, and it can be shown by menu, navigation bar, and hyperlink, etc.

We bring together the framework and the information architecture. It can be found that they are the same with a different emphasis or scope. The information architecture is rooted in the information system perspective of the real world, while the framework is a methodology for developing the information architecture, using a particular information system modeling tool, e.g., UML (Unified Modeling Language [UML, 2005]). The information architecture can be used as a methodology to develop the website interface, and in this case, the framework serves as a core of the information architecture, see Figure 2-2.

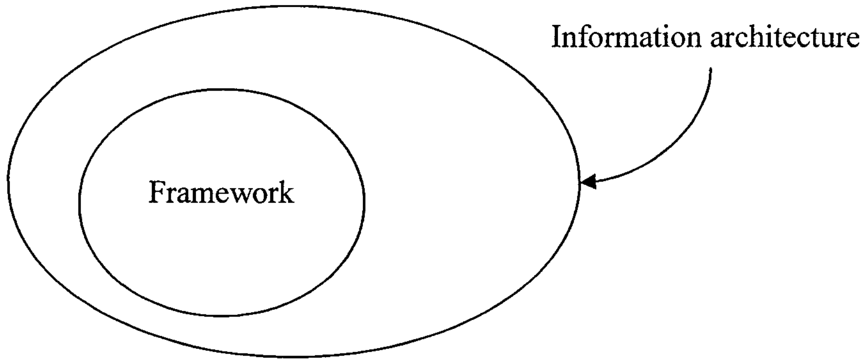

Figure 2-2 Framework versus information architecture

Definition 2.10 Web Usability. *It encompasses human-computer interface, information architecture, and usability testing, among other things. Accessibility is also an integral part of usability. It has unique concerns, but there is considerable overlap between the* *two. What makes a site more accessible often makes it more usable for everyone* [Pavaka, 2005]

Usability is "The effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments" [ISO 9241, 2005]. When it comes to web, we define the term "web usability" as to establish a website that users can retrieve information with minimum effort, time and frustration. In other words, users may access the established website with minimum mental workload. We often consider the web usability as an interdisciplinary field spanning interface, information architecture, and usability test (see Figure 2-3). It is noted that in Figure 2-3 we do not imply that the information architecture is not a part of interface design. Rather, we want to indicate the usability is not only related to the information architecture, framework, or the structure of the website interface, but also to the look-and-feel of the website interface. It is worth to notice that this thesis concerns how the structure of the website interface is related to the usability.

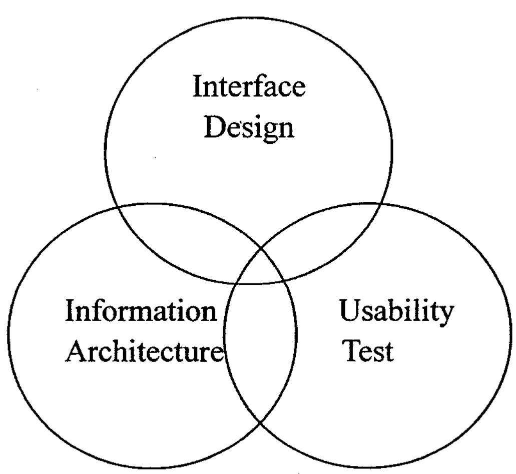

Figure 2-3 Components of web usability

2.3 Mental Model and Website Interface Design

Designers' understanding of users' needs and interests plays an important role when designing a product. Two products with the same function might be designed in a completely different understanding, and this kind of difference may turn out to be the success of one product and the failure of the other. For the same reason, a website can be organized in totally different schemes that lead to dramatic different performances of accessibility. The website interface of an organization has to be designed for users' needs and expectations so that users can retrieve information quickly and easily. Here users' needs refer to the function of a website interface; while users' expectations refer to what users think about an organization, (i.e., users' mental model of an organization).

2.3.1 Two types of mental models

Two types of mental models can be identified: *structural* and *functional* mental models [Chandrasekaran and Josephson, 2000]. Structural mental models represent the physical configuration of a system (i.e., structural relations among components). Functional mental models, also considered as task-action models, on the other hand, are procedural knowledge about how a system may meet user's needs. Take the computer as an example. A computer system comprises of several components such as CPU, memory, motherboard, video card, hard disk, operating system, application software, and so on; a formal representation of these components and their relations is a structural understanding of the computer. With a computer, we may control devices, do scientific calculations, process documents, and so on; by doing these, the computer meets our needs or plays some roles in service – i.e., the computer functions.

2.3.2 The role of mental model in interface design

Mental model affects interface design on both designers' side and users' side. On designers' side, designers abstract the mental model of a system or a machine at the beginning of interface design procedure. They surely have a conceptual understanding of this system or machine (e.g., how the system works, what components it consist of, what is the function of each component, etc.). Next, designers create a design model based on the conceptual understanding (here this is the designer's mental model) of the domain to represent their mental model. Last, designers implement the design model to make it final products, e.g., an executable software or a machine. Part of these products is the interface; see Figure 2-4.

On users' side, the interface is the "entire" product, i.e., the users only see the interface. They understand and perceive the product by relying on the interface. For instance, when using a microwave oven, users seldom want to know what is behind the control panel, and what principle is used for this machine to function. Knowing how to use the control panel to set up a cooking time is the concern by most of them. Users have also their own mental model, which represents users' expectation of the system, e.g., what functions the system should have, what a kind of control panel the system should have, what positions those control elements should be located on the panel. Through the interface, users try to understand the system or the machine based on their mental model. The cognition efficiency would be extremely high, if users and designers have the same mental model.

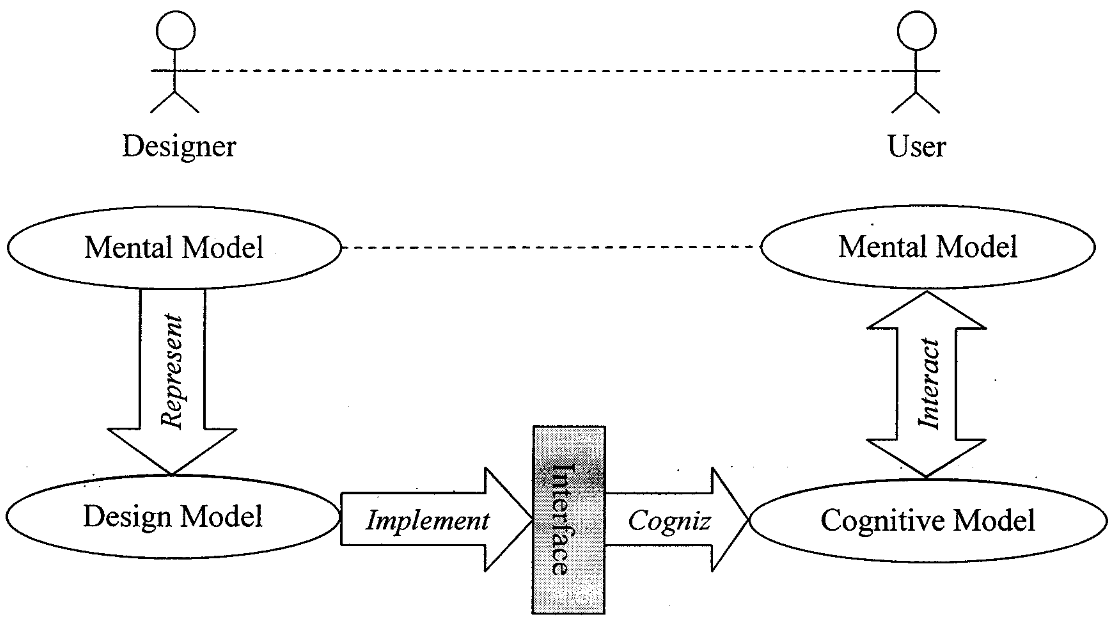

Figure 2-4 Mental model and interface

In design science, people always say, "design for users"; more accurately, a design should be designed for users' mental model. The interface provides a platform or a medium to present designers' mental model, on which users communicate with designers. Bad usability would certainly be the case if such a platform were not based on a common understanding of the application between the designer and the user. Therefore, a human-machine interaction, in its very nature, is an interaction between human A (designer) and human B (user). This communication is starting from designers' mental model, through the interface, and ending with users' mental model. This is exactly why mental model plays an important role in the interface design process.

2.3.3 Website interface paradox

The above discussion has shown that a system is designed by a human and for another human. Information flows from designers' mental model to users' mental model. The interface provides a medium to make this happened. Website, as an interface bridging between designers and users, to achieve the goal of making users access the information easily and quickly, must be designed based on users' mental model.

However, there exists a paradox in website interface design. On one hand, website interface design is based on a design model, while a design model of a website interface should be equal to users' mental model. In this way, the design model can exactly match users' mental model so that a website interface can be understood through the same way as users' expectation. On the other hand, an interface should tailor to individuals – a concept called personalization. Mental model is a subjective representation of an artifact in human's mental world. Different users apparently have a different understanding of an artifact (i.e., one mental model per user). Now the paradox of website interface design can be described as this: the interface has one design model which is the mental model of users, but users have different mental models (i.e., there are a multiple number of mental models). This paradox needs to be resolved; see the next section.

2.3.4 Resolution of the paradox

To resolve the paradox above, we propose a solution, which has two features: (1) applying an "average" mental model as the design model of a website interface, and (2) applying an adaptive interface. A so-called "adaptive interface" is an interface that may adapt or change according to different users' expectations. The average model is the model which reflects the more average understanding of a system among a user community. This also implies that a particular interface is always bound to a particular user community. The notion of the average model also implies the model deviation. The model deviation is an input to the adaptive interface management system. Figure 2-5 shows an interface design process that reflects the notion of average model and adaptive interface. In this thesis, the adaptive interface and the model deviation are considered to be out of the scope.

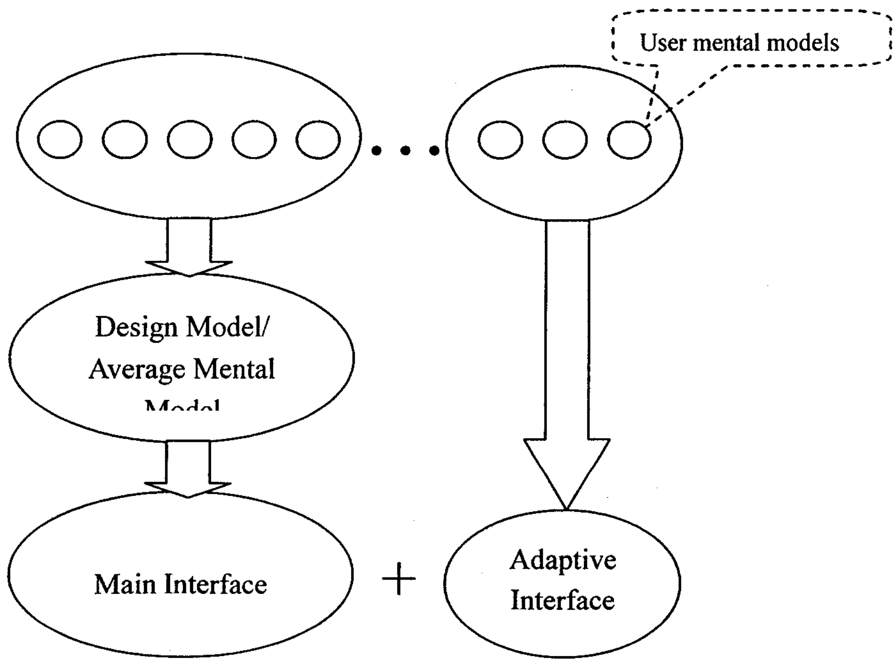

Figure 2-5 Website interface + Adaptive interface

2.4 Website Interface Design: Revisit

We revisit the methodologies for website interface design in this section. The justification of the statement that the web application design methodology is not suitable to the website interface design is given in Section 2.4.1. In Section 2.4.2, we review some existing website interface design methodologies and argue why they do not meet our needs. In Section 2.4.3, we discuss a combined function-based and audience-based approach (F-A approach for short). In Section 2.4.4, we put our attention to general interface design methodologies and examine how they may meet our needs.

2.4.1 Web application software design methodology

There are a number of methodologies and tools that support web application design: Hypermedia Design Model (HDM) [Garzotto et al., 1993], Object Oriented Hypermedia Design Model (OOHDM) [Schwabe et al., 2002], Relational Markov Model (RMM) [Anderson et al., 2002], and Araneus Design Methodology (ADM) [Merialdo et al., 2003]. They cannot be applied to the website interface design because of some significant differences between the application software and interface designs. These differences are elaborated in the following.

Data is a vehicle of information or knowledge. Both the application software and interface have to deal with data. The application software concerns the states of the data and the control of the data; whereas the interface does not. For an application software program, the use of data is coded in the program; while for an interface, the use of data is in the mind of users who are browsing the data. Therefore, the application software design starts with the specification of the application requirement, a so-called requirement analysis; while the interface design starts with the analysis of the user's mental model.

In general, the website interface design differs from the web application software design in the following aspects [Spool et al., 1998]. From the point of view of design, the application software design focuses on efficiency of a system, and as a result, its interface would be simple. From the point of view of purpose, website is an information repository used for the user to acquire information or knowledge. From the ease of use viewpoint, website should have a more simplified and direct structure so that it would not take users much time and effort to find the information they need. Web application software, on the other hand, focuses on how to implement the functions associated with the application.

2.4.2 Website interface design philosophies

With the Internet phenomenon, the website interface design becomes a focus of research. Consequently, several methodologies for website interface design are proposed. Note that they are for the conceptual design phase (see next section for details) for a website interface design [Rosenfeld and Morville, 2002]. These methodologies are commented in the following.

- **Audience-based**

The basic assumption of the audience-based approach is that different groups need different kinds of information. Designers should organize different kinds information for different groups so that users can focus on the information only relevant to them and have less interference from unrelated information.

The problem with this approach is the ambiguity when there is an overlap between two groups of users. For instance, when designing a university website, financial aid information might be placed under the "prospective students" category and might also be put under the "current students" category. There are two confusions that may arise: Confusion one: a potential user does not know exactly which group he or she should fall into. In this case, she or he might reach the financial aid information through the group called "current student", while he or she actually falls into the group called "perspective students". The financial aid information for the perspective student group may be different from that for the current student group. So she or he may get wrong information. Confusion two: he or she may not be confident which group she or he certainly belongs to.

- **Function-based**

We tend to divide a complex task into several subtasks which are less complex. For instance, when purchasing goods online, customers search the item, compare the price, save the information into the shopping cart, and check out in the end. A shopping website, thus, might be structured into searching items, comparing prices, adding items into shopping cart and checking out categories.

The problem with this approach is that sometimes we may even not know the task domain or topic. In this case, there is no sense to talk about the tasks as well as their sequence of execution which may very much depend the task domain. For example, if a customer wants to buy a Swiss Army watch, he or she would like to find the Jewelry & Watch department first instead of searching it directly among tons of items on the whole shopping website.

- **Organization-chart-based**

The organization-chart-based approach uses common organizations to structure a website. The basis of this approach is that users are supposed to share knowledge about the organization of a website. For instance, users should know the organization of the university when the university website is concerned. Rosenfeld and Morville [2002] argued that it was an unadvisable idea to organize a website by the organization chart of a company because users do not care about the organizational structure of a company but about retrieving the information they need directly.

2.4.3 A combined function-based and audience-based philosophies

In practice, designers often use a combination of the function-based philosophy and the audience-based philosophy (F-A philosophy for short) to take advantage of both of them. Information, then, was organized by following the principle of the function-based philosophy and put under different audience groups. When browsing the website designed based on the F-A philosophy, users first find out which user group they belong to and then search the information based on the functional understanding of an organization within a certain audience group.

We argue that the organization chart of a unit can be useful. On one side, users do not care about the organization chart because it is not the information they need; on the other side, whether users can finish their tasks may depend on knowing of the structure of the company. Besides the functional purpose of a task, the domain of the task is also the critical information for the task. As we discussed in Section 2.3.1, users have two kinds of mental models about a website: structural mental model and functional mental model. The F-A philosophy only provides the functional understanding of an organization, while the organization-chart-based philosophy provides the task domain information. Thus, we believe that to establish a more accessible website interface, the structure or the organization of a unit is also important.

2.4.4 General interface design framework

The website interface is a kind of the interface, so the general interface design framework may apply.

An interface can be seen as an artifact, which is an artificial object produced by human craft. In general, the design of an artifact can be divided into three phrases: conceptual design, basic design, and detailed design [Pahl and Beitz, 1996]. Lin et al. [2004] further divided the general interface design into three phases: conceptual design, basic design, and detail design; specifiedly.

- *The conceptual design phase concerns what information needs to display and how to display the information on an interface media.*
- *The basic design phase concerns the layout of information on an interface media.*
- *The detail design phase concerns the form of display icons/texts/windows.*

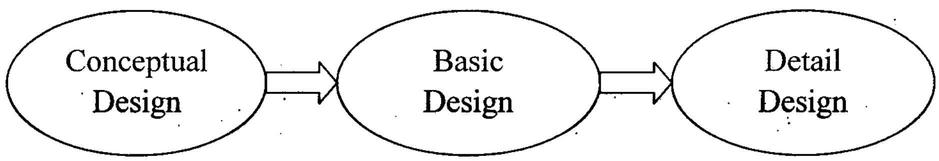

Figure 2-6 General interface design phases

The relation among the three phases is shown in Figure 2-6. Some more specific remarks on these design phases are given below.

The conceptual design phase mainly concerns two issues: (1) information contents (what information we need) and (2) the logical relationships among these contents. The conceptual design phase represents the structure of a system in a high level. Two reasons make the conceptual design phase very important in the whole interface design life-cycle. (1) To create any kind of artifacts, a blueprint or a plan is necessary. Whether the artifact is successful or not mainly depends on the conceptual design phase. (2) If any modification is needed, the cost would be always more expensive starting from the conceptual design phase than from the detail design phase. This point can be seen from the Figure 2-6; any change from the conceptual design phase will cost much more work than the other two phases.

The basic design phase concerns the layout of information on a display. It is a visualization phase of conceptual design. The conceptual model expressed by some modeling method during the conceptual design phase needs to be visualized as a layout in this phase. Questions in this phase include: What kind of style will be used to represent the interface, such as single window or multi-window? What components should be settled down in each window, e.g., for a website, is a navigation bar shown in this page? Where to put these components, e.g., the position of a logo on a website? Does the position of components represent the relation and the structure of the conceptual model?

In the detail design phase, designers primarily concern on each element/widget design in both functional and aesthetic manners. The term widget here means the elementary units composing the window of interface. Note that, as we discussed in Chapter 1, aesthetic design factors will not be included in this thesis study.

Several methodologies for developing an interface (not specifically to the website interface) were proposed in the past decades: Perceptual Control Theory (PCT) [Powers, 1973], Proximity Compatibility Principle (PCP) [Wickens and Carswell, 1995], Ecological Interface Design (EID) framework [Rasmussen, 1983], and Function-Behavior-State (FBS) framework [Lin, 2003]. None of them runs out of the general interface design phrases. Among them, the EID framework and the FBS framework were two most sound methodologies. Lin [2003] further compared the EID and FBS and showed that the EID framework had some weakness. Therefore, we will consider applying the FBS framework to website interface design in this study.

2.4.5 A brief comparison of the EID and FBS frameworks

The ecological interface design framework was rooted in the work done by Rasmussen [1983] regarding the human problem-solving behavior. Its key concept is based on five levels of abstraction hierarchy. Rasmussen [1983] showed a case study on the EID control interface design of power plants to explain these five concepts:

- *functional purpose* (the purposes for which the system was designed).
- *abstract function* (the causal structures of the process in terms of mass, energy, information, or value flows).
- *generalized function* (the basic functions that the plant is designed to achieve).
- *physical function* (the characteristics of the components and connections between them).
- *physical form* (the appearance and spatial location of these components).

Umeda et al. [1990] proposed the function-behavior-state model for the AI (Artificial Intelligence) research. Lin [2003] proposed a modified FBS framework whose key concept is parallel to the FBS model and employed this framework on interface design. The FBS framework has five layers of concepts. They are, respectively, structure, state, principle, behavior, and function (see Chapter 3 for more details). With respect to the five levels of abstraction hierarchy of the EID model, a comparison is shown in Table 2-1.

Table 2-1 Comparing the EID and the FBS framework

The EID framework	The FBS framework
Physical form	Structure
Physical function	State
Generalized function	Behavior
Abstract function	Principle
Functional purpose	Function

Some weaknesses of the EID model, compared with the FBS model, were reported by Lin [2003]: (1) In the EID framework, the generalized function concept is only applied to the components level. While in the FBS framework, the behavior is applied to the components, sub-systems, and systems. It is important to make the behavior follow system decomposition. (2) The function purpose level in the EID framework also has this problem; it is only applied to the system level. (3) Because of lack of a clear definition of the system decomposition, the EID framework may confuse users sometimes. For instance, when talking about the same concept, the reservoir (a tank) of a power plant was considered as a sub-system [Janzen and Vicente, 1998] and a component [Ham and Yoon, 2001]. (4) In the EID framework, the abstract function is only applied to those components that have a "storage" function (e.g. a tank in a power plant). In fact, the abstract function/principle is not only for those "storage" components or sub-systems, but also for other kinds of system. The application of the abstract function concept in the EID framework is too restricted to be applied to some problems (e.g., the website interface design).

2.5 Conclusion

In this chapter, we first gave the background information related to this study. Mental model plays an important role in the interface design. Web application design methodologies reported in the literature do not match the website interface design requirement because the website interface design starts from a mental model and the web application design starts from the functional analysis of a system. We also reviewed some existing website interface philosophies and found that there were some problems with these philosophies. We turned our step to general interface design and overviewed several well-known interface design methodologies. Among them, the FBS model appeared to be the best. Therefore, we plan to adopt the FBS model to the website interface design in this study. More details will be explained in Chapter 3.

CHAPTER 3

THE FBS-WEB APPROACH

3.1 Introduction

This chapter presents a novel approach to website interface design. The approach is based on the function-behavior-state (FBS) approach proposed by Lin [2003]; specifically the FBS approach is extended to the website interface design. As such, the approach is called the FBS-WEB approach. In Section 3.2, we revisit the FBS approach proposed by Lin [2003]. In Section 3.3, we present the FBS-WEB approach. Section 3.4 presents the whole design process of the website interface, including the FBS-WEB approach to designing the structure of the website interface, basic design and detail design of the website interface. Note that the basic and detail designs of the website interface are not our concern, but they are necessary for the development of the test bed which will be discussed in Chapter 4. Section 3.5 presents a case study to demonstrate how the FBS-WEB approach works. Section 3.6 gives a summary of this chapter.

3.2 Overview of the FBS Approach [Lin, 2003]

3.2.1 Core concepts in the FBS approach

The FBS approach is based on the following core concepts: (1) structure (state), (2) behavior, and (3) function.

Structure and state

A system is composed of a set of entities which are connected in a meaningful way, and this set is called the structure. Each entity has a set of properties that can be perceived, and these properties are called the states [Lin, 2003]. The name of the state is called the state variable. The state of a particular state variable changes from one value to another. For instance, if we consider a department as an entity and the employee number as a state variable, the value of the employee number (a state variable) changes as the employees could leave the department or new employees could be hired by the department.

Basically, two types of states can be defined: (1) active states and (2) passive states. The active states are those states that can be manipulated directly by operators, and the passive states depend on the active states. The dependency or relationship between the active states and the passive states is governed by the "principle" or "effect". More details about the principle or effect are discussed below.

Behavior

A sequential change of one or more states is considered as the behavior. We consider the causal relationship or connection among a set of related states as the B-S relationship. The change of the state is under the governing of the B-S relationship. The B-S relationship is also known to be governed by the principle or effect (see the previous discussion about the state). Two examples of the principle are: (a) if voltage (State 1) changes from V1 to V2, current (State 2) will change from A1 to A2 based on the Ohm's equation: I=U/R (the Ohm's equation is the principle); (b) if a student is admitted to a graduate program and she/he has registered in a graduate school (State 1), his/her status (State 2) would change from undergraduate to graduate based on the school principle (i.e., the school has the undergraduate and graduate principles, and they are such that the latter is after the former).

Function

The function is the purpose the system supposed to fulfill. It can be perceived by users through the perception of certain behaviors of a system. *The semantics of the function are given by an assertion, which has the following syntactic form:*

Function: = verb | noun | [proposition] | [value 1] | [proposition] | [value 2],

where the notation '[ ]' means optional, and the notation ':=' means the assertion [Lin, 2003]. For instance, a dynamotor has the function to generate the electric current from 100A/hour to 1000A/hour. Another example of the function is that a school is supposed to train students from a lower-level skill to a higher-level skill. The correspondence between the behavior and the function is represented as:

$$\Gamma_{ab}: B \rightarrow F,$$

where B represents a set of behaviors and F describes a set of functions. We call this correspondence the F-B relationship. The F-B relationship may not be the one-to-one correspondence. That is to say, one function may be fulfilled by more than one behavior; while one behavior may be used for different purposes. We note that the function is the abstraction of a set of behaviors in human's mind.

3.2.2 The FBS architecture

The whole FBS architecture is shown in Figure 3-1. The structure and state are located at the bottom level. The behavior level follows the structure level. The B-S relationship connects these two levels. Above the behavior level is then the function level. The F-B relationship lies between a set of behaviors and a set of functions.

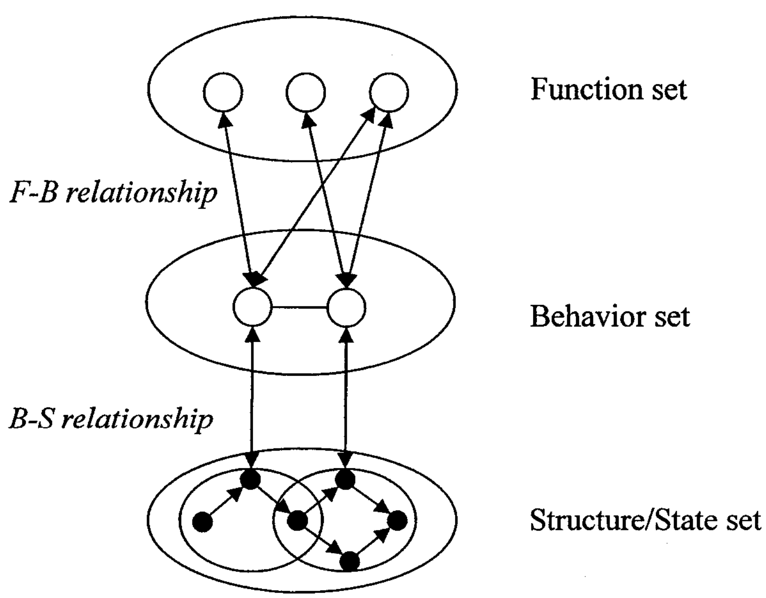

Figure 3-1 FBS architecture

3.2.3 System decomposition

The system decomposition is the process of breaking down a system into subsystems and components. The function, behavior, and structure concepts are applied to the system, subsystems, and components. Considering the system decomposition, the FBS model is shown in Figure 3-2. For instance, the college is a subsystem of the university, and the department is a component of the college; see Figure 3-3. The FBS concepts are applied to the university, college, and department; in the case of Figure 3-3, we see the structure of the engineering college, the structure of the mechanical engineering department, as well as the behavior and function of the university, college, and department.

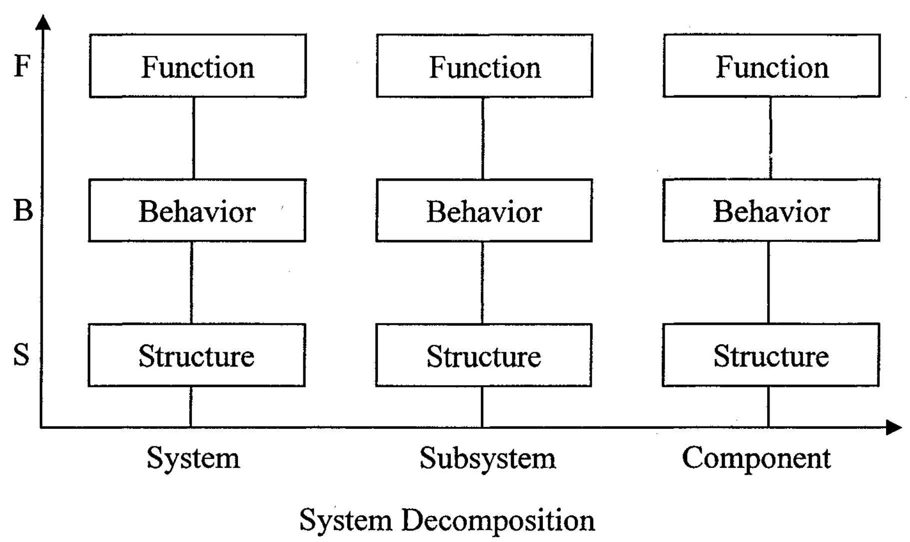

Figure 3-2 FBS model with decomposition

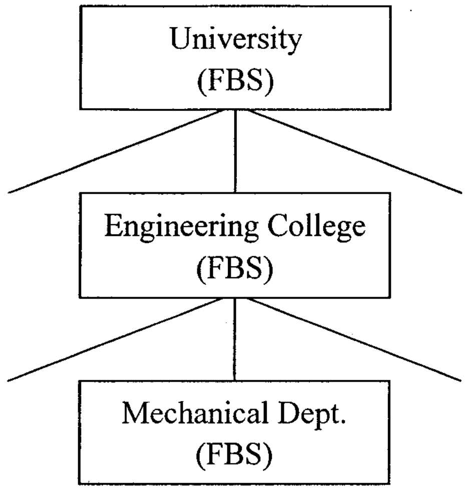

Figure 3-3 University with decomposition

3.2.4 The summary of the FBS Approach to the interface design

The FBS model is based on the five concepts: structure, state, principle, behavior, and function. Together with the system decomposition, the FBS model makes it possible to view a system along with two dimensions:

Dimension one: the structure, state, principle, behavior, and function;
Dimension two: the system, subsystem, and component.

The FBS model is a conceptual model of the interface and a general methodology to represent a domain of interest. The FBS model is applicable to complex dynamic systems, such as process plants. The next section extends the FBS approach to the website interface design.

3.3 Adapting the FBS model to Website Interface Design

We first revisit the characteristics of the website interface and then modify the FBS approach to website interface design, resulting in a new approach to website interface design. The new approach is called the FBS-WEB approach.

3.3.1 Website interface characteristics

First, a website is about what it is of an organization (e.g., a university). It does not expose why things happen posted on the website. The user is not supposed to intervene the process of an organization which underlies the website. This characteristic is very different from a process plant, the interface of which serves as a medium for the user to intervene the plant operation. As such, in the process plant, the user has a responsibility of detecting an error (if any) and corrects the error in addition to manipulating the plant through the interface. As Lin [2003] elaborated, the principle information plays a role in fault correction or diagnosis. This means that in the process plant application, the principle information needs to be communicated with the user. In other words, the website interface may not require the principle information.

Second, the website would more emphasize the "richness" of the presentation of the information and knowledge, as the goal of the website is to provide information and knowledge. The state and structure are more merged in the case of website, because the behavior (i.e., when one state changes, how and why other states follow the change) is not important to a website. As opposed to the website, the behavior is very important to the process plant. In the process plant, the state is selective to those that make sense to a behavior in interest.

3.3.2 Adaptation of the FBS model to Website Interface Design

As we explained in Chapter 2, the axiom of interface design is that an average mental model should be the same as a design model. Note that the FBS model corresponds to the design model. In Chapter 2, we have further shown that when the user operates a website interface, there are basically two types of mental models (in shifting): functional mental model and structural mental model. That is to say, the mental model of the user is a linkage between the structure and function when the user is browsing on the website interface. Therefore, the design model of the structure should represent both the structure and function concepts.

According to the previous discussion of the characteristics of the website interface, we can readily merge the state concept with the structure concept. Also, because there is no user intervention needed, the principle information as well as the behavior information is removed. Finally, only the function and structure concepts are left from the FBS model for website interface design.

It is noted that the system decomposition concept is still valid to the website interface. In fact, the concept of information architecture, as described in the literature [TechDis, 2005], is the information model of an organization from the point of view of the structure. The basic structure of an organization can be viewed from two angles: system decomposition and system connectivity [Zhang, 1994]. The system decomposition was explained before. The system connectivity represents the association of one component or subsystem with other components or subsystems. The system connectivity is usually a network.

With the above adaptation of the FBS model, we further modify the concept of function into the concept of role. The function is more related to the behavior and thus more suitable to the dynamic system which requires the user's intervention based on the function-behavior relationship, while the role appears less behavior-related. The FBS-WEB model is briefly illustrated in Figure 3-4.

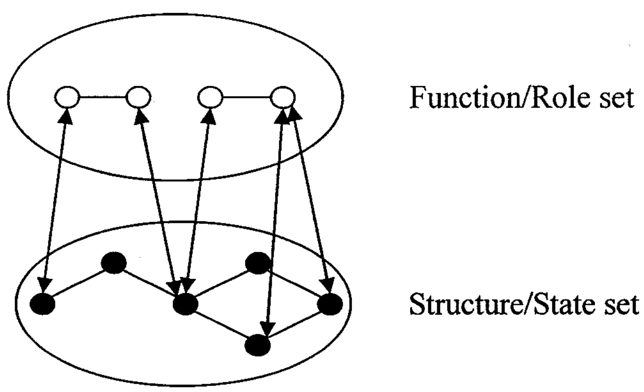

Figure 3-4 The FBS-WEB model

3.4 The FBS-WEB Approach

3.4.1 Data representation of the FBS model

The website interface development is essentially a software engineering task which requires a tool for the information and knowledge representation. In this case, we use Unified Modeling Language (UML). The UML was introduced by Grandy Booch, James Rumbaugh, and Ivar Jacobson [1996]. With a large-scale collaboration from several IT corporations, it has become one of the most successful modeling languages. Basically, the UML provides a set of graphical notations and rules (vocabulary and syntax) for modeling an artifact. Specifically, the UML has a concept called view; see Table 3-1 for five views in the UML. Based on illustration of these views in Table 3-1, we will use the use case view for modeling the role and the logic view for the structure.

Table 3-1 The UML views

Views	Representation
Use Case view	Functionality
Logic view	Structure
Process view	Performance, Scalability
Implementation view	Software management
Deployment view	System topology, Delivery, Installation, communication

3.4.2 The design phase of the website interface

As we mentioned before in Section 2.4.3, the interface design can be divided into three phases: conceptual design, basic design, and detail design. The definitions of the basic design and detail design can be found in Chapter 2. The proposed FBS-WEB approach applies to the conceptual design phase (see Figure 3-5).

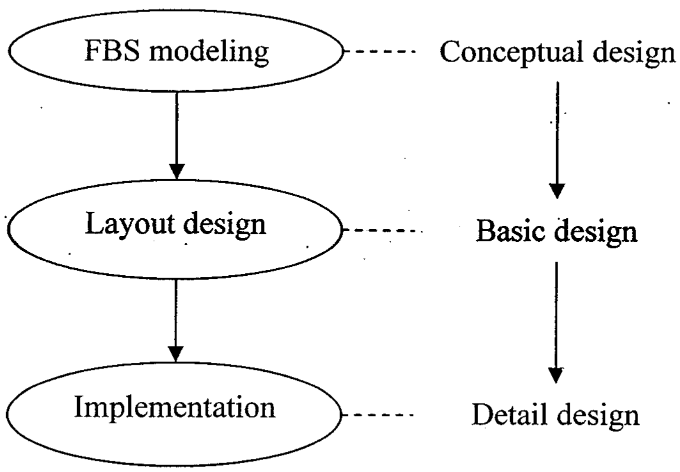

Figure 3-5 The FBS website interface design framework

3.4.3 The FBS modeling phase: the conceptual design phase

In this phase, the website is visualized by using the use case view and the logic view, which is governed by the FBS modeling principle. These two views connect to each other through the notion of responsibility. This phase is shown by each view as follows.

(1) Use case view. It represents the function view of a website; see Figure 3-6.

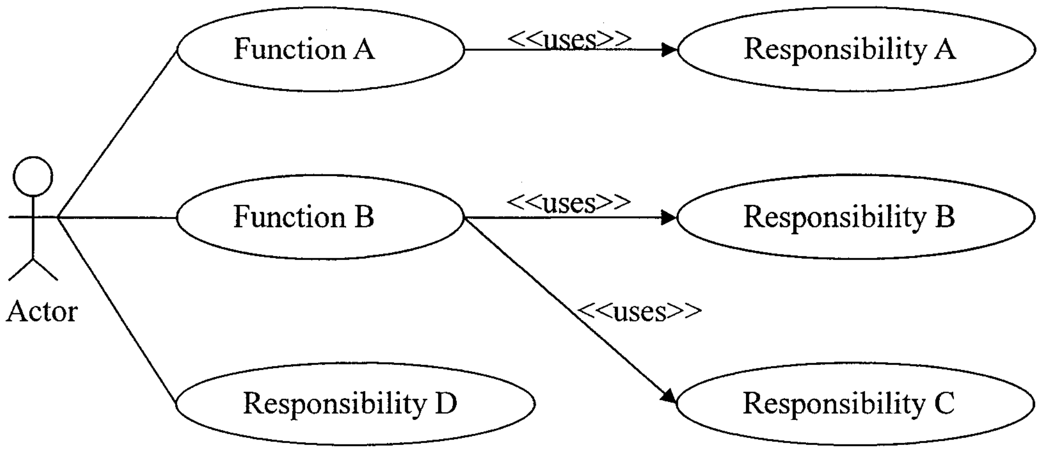

Figure 3-6 A use case view sample

(2) Logic view. The model starts from the entire system, to the subsystems, and to the components. Relations describe the connections between classes or objects. The logic view represents the structure view of a website. An example is shown below (see Figure 3-7 and Figure 3-8).

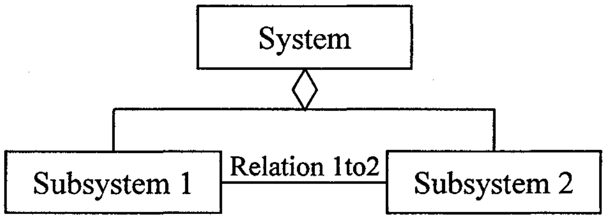

Figure 3-7 Decomposition of a system

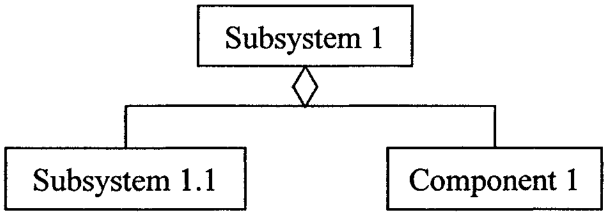

Figure 3-8 Further decomposition of the subsystem 1

Each system, subsystem, and component is described by a class or an object. To make the diagram simple and clear, we used names to indicate the classes and objects. The attributes represent the states of the FBS-WEB model. Together with the responsibilities, each class is shown separately as a system meta model (see Figure 3-9), in which the operations are skipped because they carry the behavior information. In short, the logic views are responsible for the structure layer of the FBS-WEB model.

Subsystem 1	Subsystem 2	Subsystem 1.1	Component 1
Attribute set A	Attribute set B	Attribute set C	Attribute set D
Responsibility A	Responsibility B	Responsibility C	Responsibility D

Figure 3-9 A system meta model

3.4.4 Layout design phase

The layout design phase deals with the issue of the layout or the placement of various components on the website. In other word, the layout design is a more concrete design. Problems to be solved in this phase include: What kind of style would be used to represent the interface, such as single window or multi-window? What components would be settled down in each window, e.g., for a website, is a navigation bar shown in this page? Where to put these components, e.g., the position of a logo on a website? Does the position of components represent the relation and the structure of the conceptual model? A website layout in consistency with the FBS model is shown in the Figure 3-10. Note that the function view and the structure view are both shown in the same level.

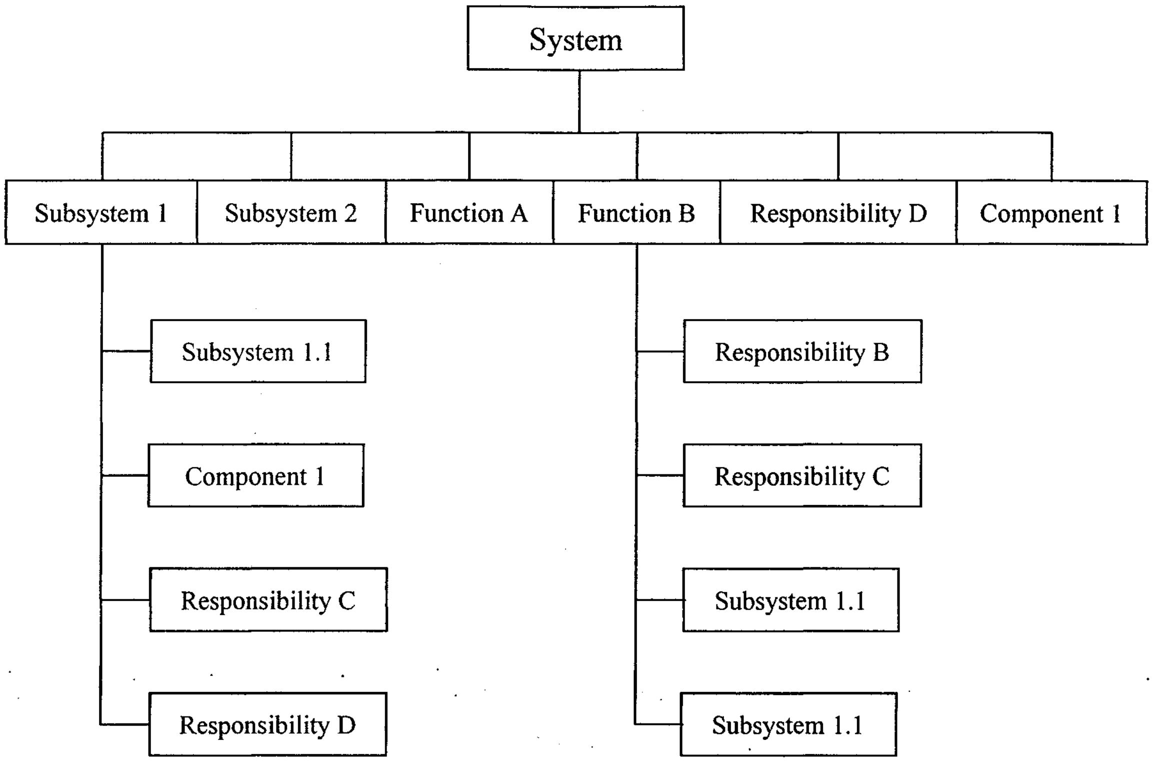

Figure 3-10 The website layout

There are quite a few layouts of a website that can be used when designers consider for determining how to place those components, e.g., logo, menu, navigation bar, etc. But this is not the main concern in the present study. A simple layout is shown in the Figure 3-11.

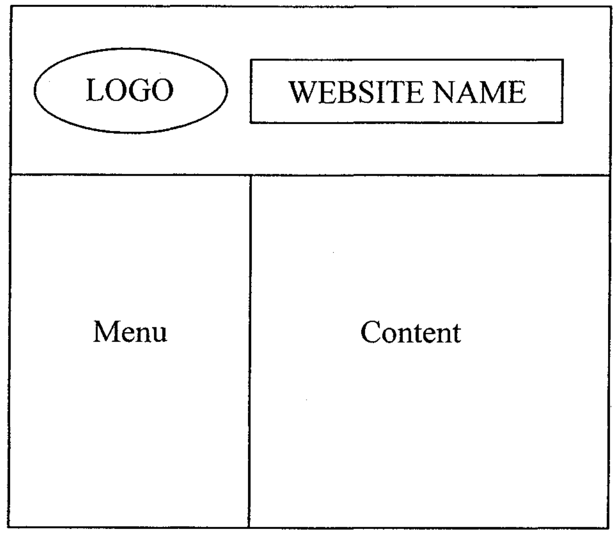

Figure 3-11 A layout of a website

3.4.5 Detail design phase

The detail design phase follows the layout design phase, and it is the final design phase. The website interface finally results in a display of a set of widgets in the detail phase. *Widgets are windows through which humans and machines can communicate* [Lin and Zhang, 2004]. In this design phase, a navigation scheme is created based on the layout design phase. For instance, menus or labels can be used to represent the main architecture. A sample menu to implement the above website map is shown in Figure 3-12.

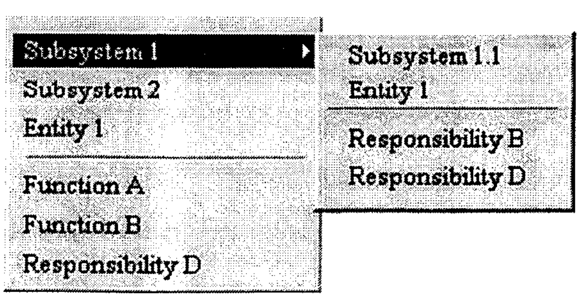

Figure 3-12 A menu of the system

With consideration of the aesthetic design (which is out of the scope of this study), the website of the system finally can be shown in Figure 3-13.

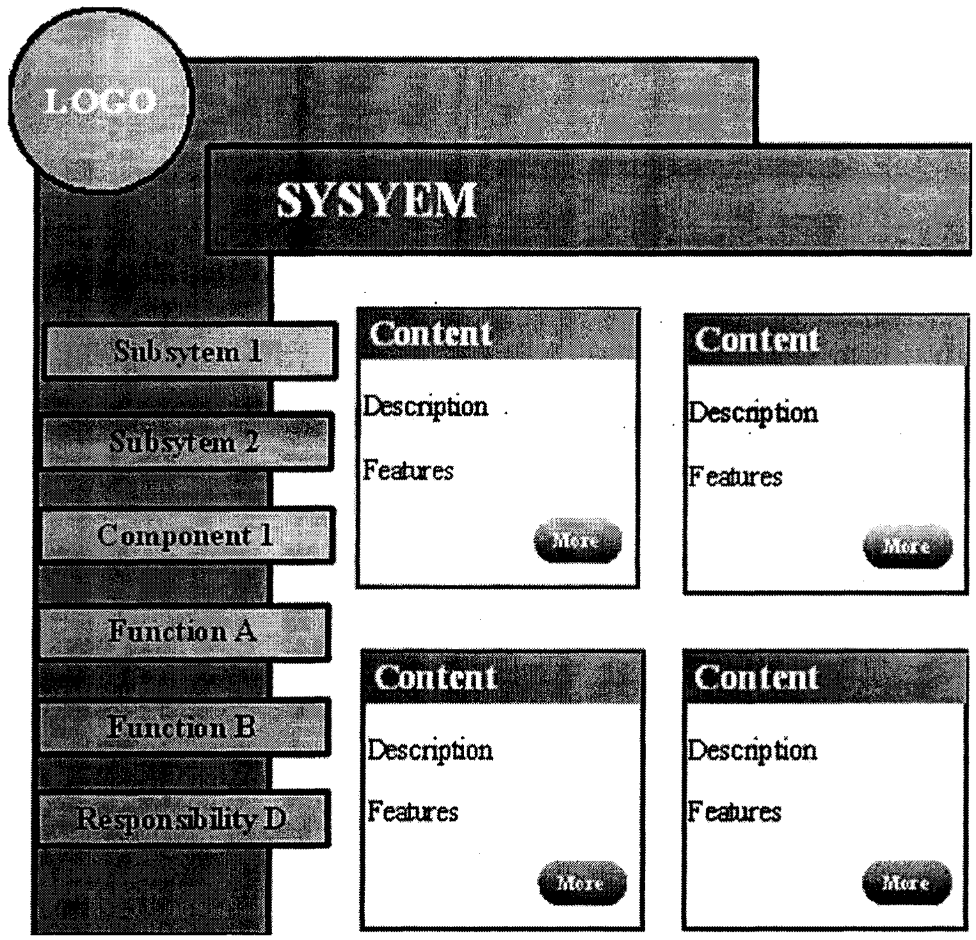

Figure 3-13 A final design of the system website

3.5 A Case Study

The university website, as an interface opened for students, faculty members and scholars, with tons of information provided, has a very complicated organization structure. This case study, thus, takes a university as a prototype to show the development procedure of the proposed approach.

3.5.1 The FBS model of a university

The structure of a university website can be extremely complex. Thus, this study does not intent to design an entire university website. We take students as an example to show how to model the function view of a university, and we consider that students have the following "tasks" to finish when studying in a program: application, enrollment, and attending activities (see Figure 3-14).

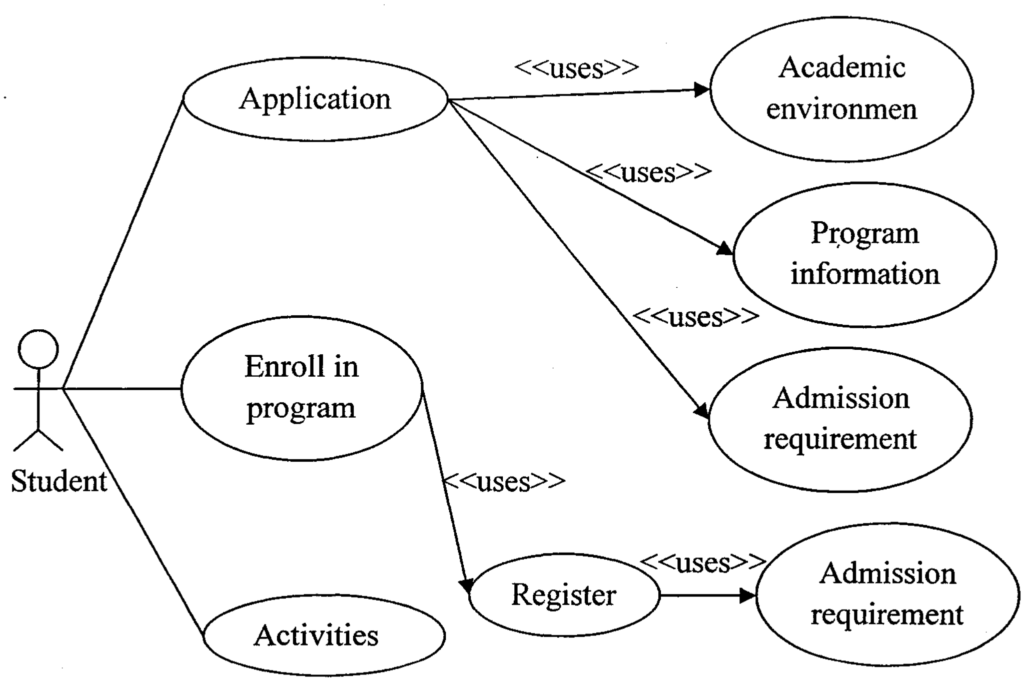

Figure 3-14 The use case diagram of a student

In this case study, we are interested in the following departments and colleges: admission office which is in charge of the admission for all perspective students' applications (including undergraduate students as well as graduate students); administration unit which governs the other departments and also has some responsibilities, e.g., hiring faculties and staffs; library which is an indispensable department of a university; registrar office which takes care of study and course registration; school which offers courses and grants degrees in a particular field; student club, also known as student community, which is an organization in a university that provides student facilities for recreation. Thus, the university is decomposed as follows; see Figure 3-15.

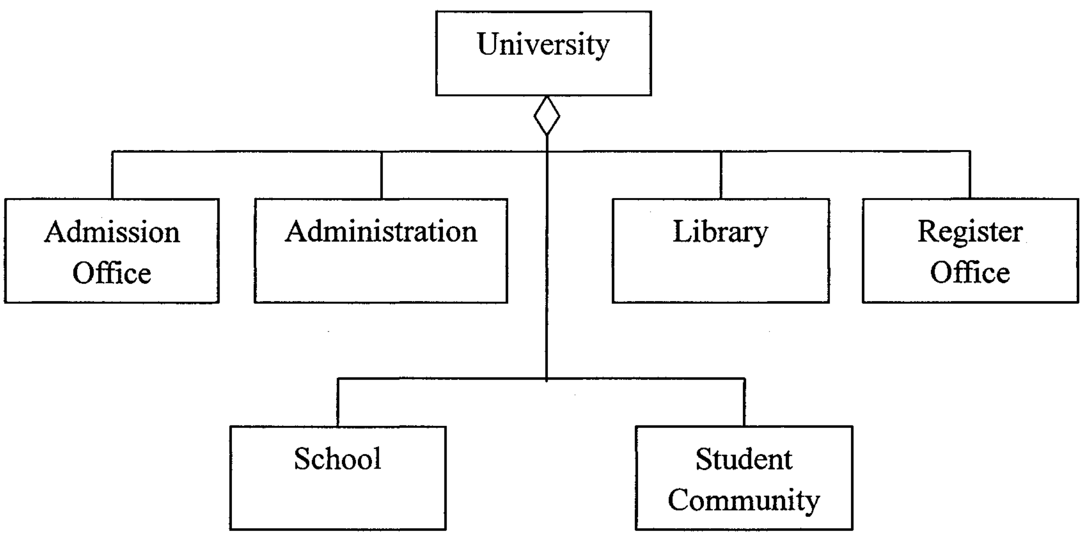

Figure 3-15 The main structure of a university

Each office or unit can be further decomposed. We take the school as an example to show the further decomposition. First, the school has several departments: academic departments, Dean's office, etc. Second, the department, as a basic academic department, has some components: faculty members, staffs, students, courses, and laboratories. Some relations exist between the components (as shown in Figure 3-16). With respect to the use case diagram, the meta model is shown in Figure 3-17.

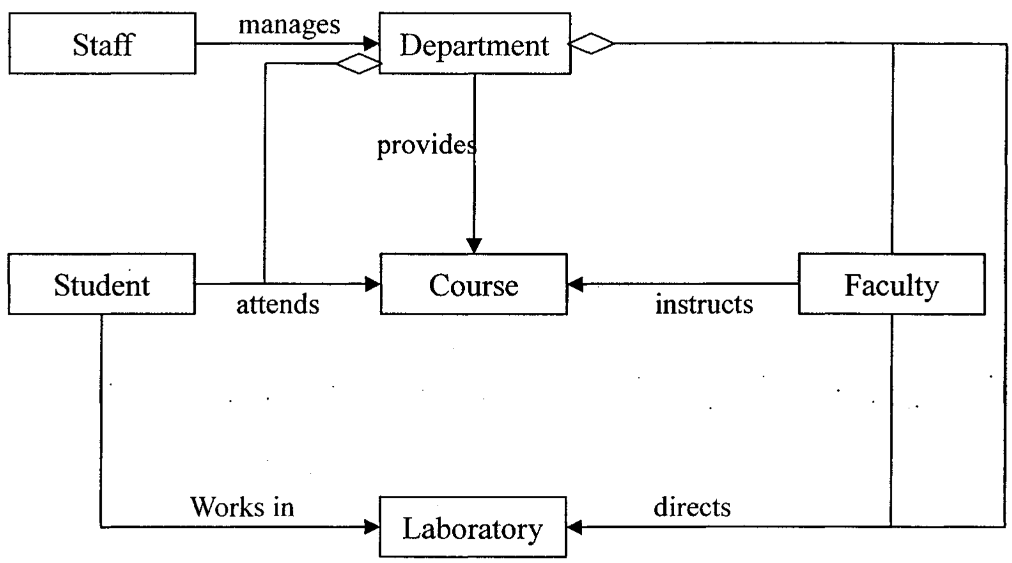

Figure 3-16 The structure of a department in a university

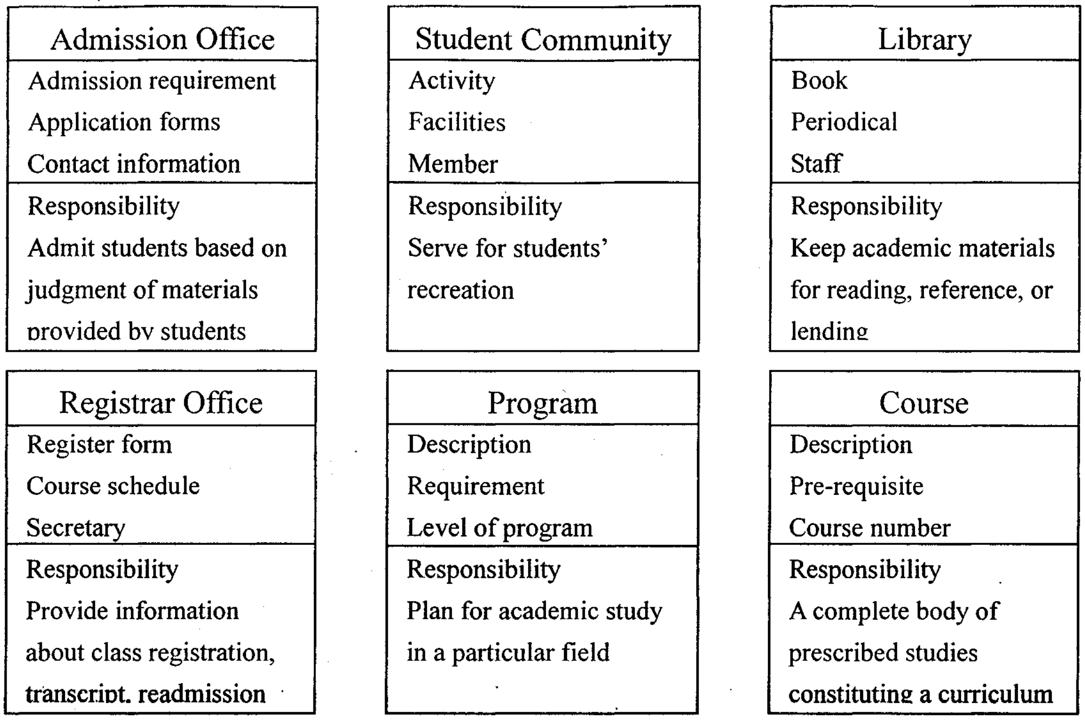

Figure 3-17 The meta model of a university

3.5.2 Layout design phase

First of all, we conduct the website layout of this university, which inherits directly from the conceptual design phase. Based on the FBS model of this university, the website layout of the university is shown in Figure 3-18. This website layout only shows the part of a university website as we mentioned. Note that Figure 3-18 follows Figure 3-11.

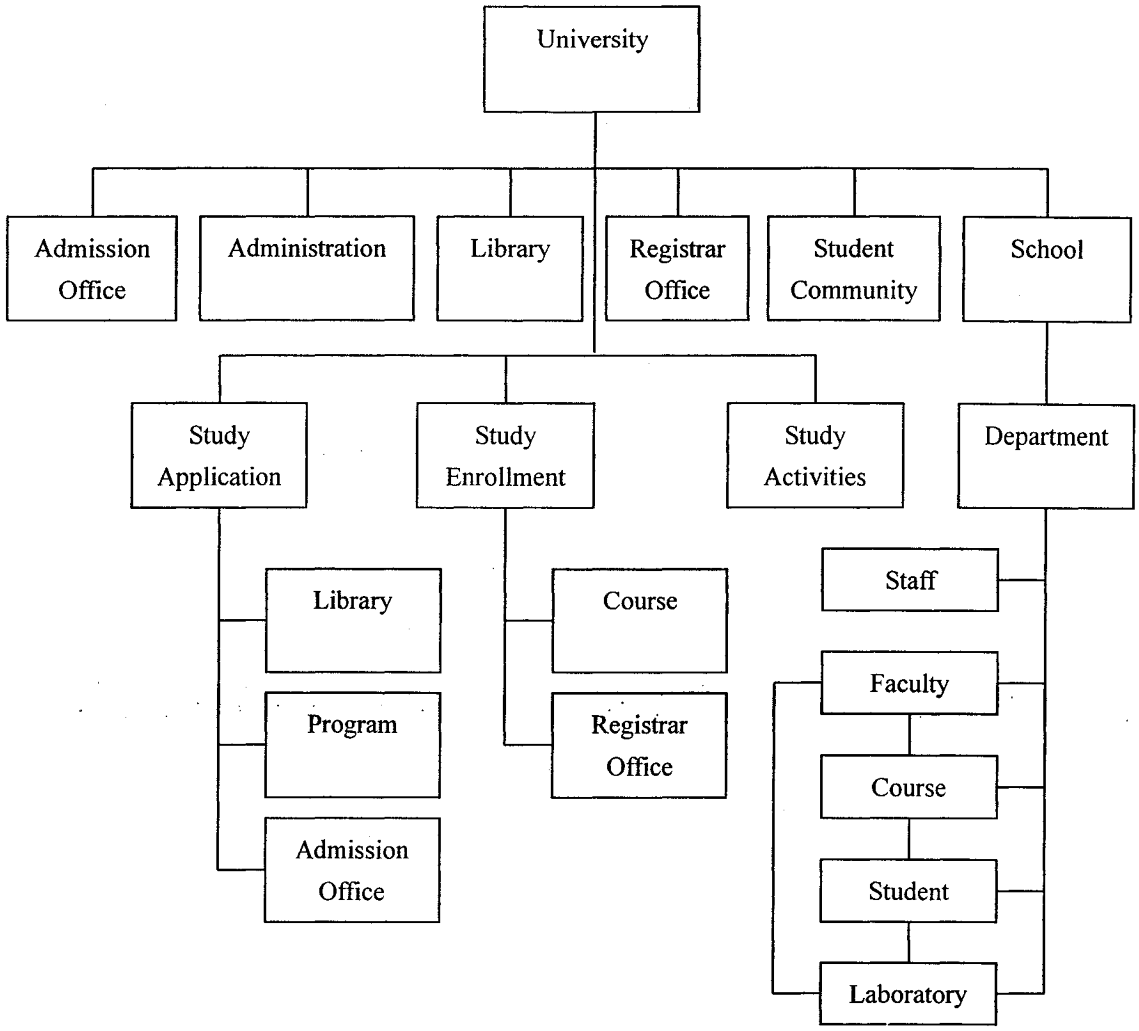

Figure 3-18 The website layout of the university

3.5.3 Detail design phase

The homepage, which is the result of the detail design, is shown in Figure 3-19. The menus of the university and the department are shown, respectively, in Figure 3-20(a) and Figure 3-20(b).

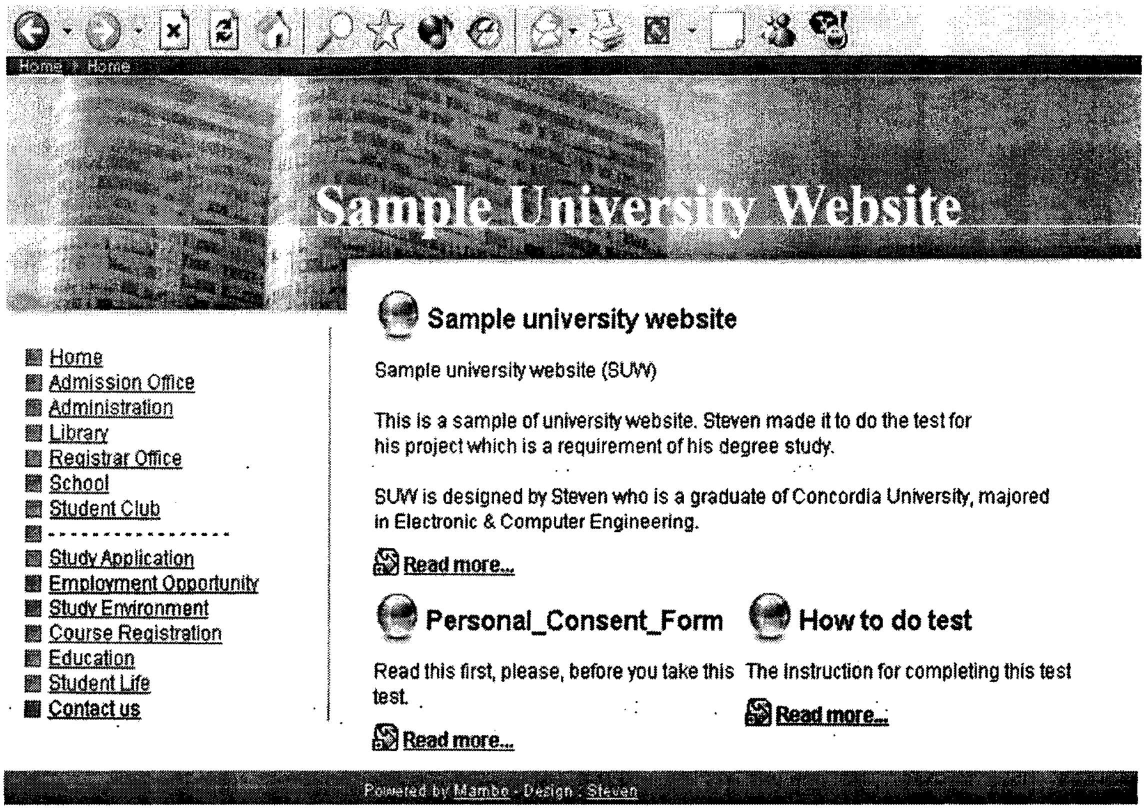

Figure 3-19 The homepage of the university

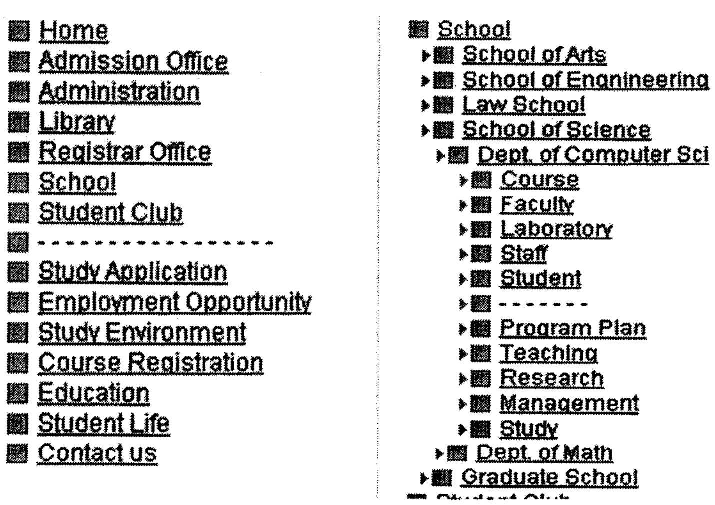

Figure 3-20 The menus of the university and the department

(a. the university; b. the department)

3.6 Summary

In this chapter, we introduced the FBS model and proposed the FBS-WEB website interface design approach. We started with the fundamental notion of the general FBS model and explained the possibility of applying the FBS model to the website interface design. We also discussed about the adaptation of the FBS model to the website interface design. Using the UML language, a powerful and popular modeling tool, we demonstrated how to represent the FBS model. We illustrated how the FBS-WEB approach works with an example.

CHAPTER 4

EXPERIMENTAL VERIFICATION

4.1 Introduction

In this chapter, we present an experiment to verify the FBS-WEB approach proposed in Chapter 3. We chose the university website as a case for the experiment because the university has a wider audience with an excellent generality. Specifically, we chose the York University website to develop our test bed using two approaches, namely the FBS-WEB approach and the F-A approach. In the development of this test bed, a great attention is to make the two interfaces have the same basic and detail designs (i.e., the same look-and-feels) in order to make the comparison exclusively for the evaluation of the conceptual design of the website interface. Section 4.2 presents the task design. Section 4.3 presents the hypotheses that are relevant to our goal of the experiment. Section 4.4 presents the measures used to evaluate the performance of human subjects (or participants). Section 4.5 presents details of the experimental design. Section 4.6 gives the analysis results. Section 4.7 concludes the chapter.

4.2 Tasks Design

As we mentioned earlier, the task affects the performance of the website interface. In designing tasks, we have two considerations. First, we consider that some tasks may be more structure-oriented; while others are more function-oriented. For instance, on a university website, the task of "finding Dr. Smith's contact number" may be viewed to be more function-oriented. The possible action or action sequence the user may take would be looking up for a function like "finding people" or "finding directory". The task of "finding the contact number of Dr. Smith (who is a professor at the Computer Science Department of the Faculty of Science and Engineering)" would be considered more to be structure-oriented than function-oriented. In this case, the possible action or action sequence the user may take would be: Faculty of Science and Engineering → Computer Science Department → Faculty member → Dr. Smith → Contact number.

Another consideration is the difficulty level of task. In the present study, the difficulty level of task is determined by the length of the access-path of the website. The term access-path in this study is defined as the shortest path of all possible paths between two information nodes (see Figure 4-1). The path *A-B-E-K* has the minimum hops among all possible paths from A to K; therefore, the *A-B-E-K* is considered as the access-path from A to K. A longer access-path physically means that users need to click more hyperlinks to reach the correct information. For instance, users need to click *m* hyperlinks to reach information X and *n* hyperlinks to reach information Y. If *m* is larger than *n*, this means X is more unreachable than Y. As such, the task leading to X has a higher difficulty level than the task leading to Y does.

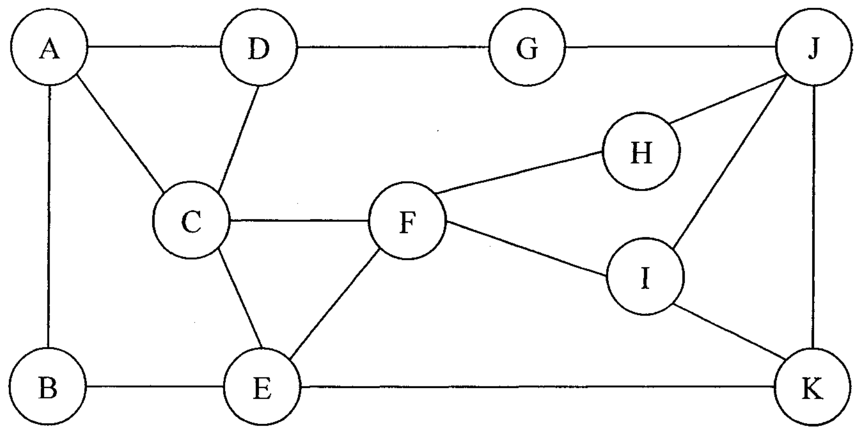

Figure 4-1 The structure of a website

In this experiment, two function-oriented and two structure-oriented tasks were designed. With the consideration of the difficulty level of tasks, four tasks were designed in the following:

F01: assuming you are going to apply for a PhD study in Computer Science, you want to find whether a GRE is required? If so, what is the minimum score requirement?

F02: assuming you are a PhD graduate and looking for an academic position in the HCI (Human-Computer Interaction) research area, you want to know whether there is an academic position opening in this research area? If so, who should be contacted to?

S01: assuming you are going to send an email to Dr. Yves Lesperance to ask for an opportunity to study under his supervision. Dr. Lesperance is an assistant professor of the Department of Computer Science of the Faculty of Science and Engineering. Find out his email address.

S02: assuming you are doing a statistic research in HCI laboratories all over Canada,

HCI Lab,

Department of Computer Science,

Faculty of Science and Engineering,

is one of your samples. Find out how many graduate students work in this lab?

F01 and F02 represent the function-oriented tasks, while S01 and S02 represent the structure-oriented tasks. In particular, task F01 is more difficult than F02; while task S01 is more difficult than S02. That is to say, in our test bed, the task F01 has a longer access-path than the task F02; while the task S01 has a longer access-path than the task S02.

4.3 Hypotheses

We compare the two approaches: the F-A and the FBS-WEB. This is because the F-A approach appears to be a promising one based on the review (see discussions in Chapter 2). The general methodology to compare these two approaches is to develop two websites: one following the FBS-WEB approach (called FS-website for short), and the other following the F-A approach (called F-website for short). We propose the following hypotheses:

Hypothesis 1 (H1). For the function-oriented tasks, the FS-website and the F-website do not have a significant difference in terms of the performance and the mental workload.

The basis for this hypothesis is that both approaches offer somewhat a gateway for the user to think about the information organization from a functional view.

Hypothesis 2 (H2). For the structure-oriented tasks, the FS-website provides a higher performance with less mental workload than the F-website.

The basis for this hypothesis is that the F-website does not provide a gateway for users who would regard such a task from a structural point of view (in this case, they have to first convert the structural view into the functional view, which takes extra effort).

Hypothesis 3 (H3). For the overall performance, the FS-website should be better than the F-website.

The basis for this hypothesis is that the FS-website includes more views than the F-website does. Therefore, it provides more means to search the information; the more views cause a better search result. This might be represented by: for all tasks, the FS-website has a faster access speed than the F-website method; or the F-website has a more mental workload than the FS-website.

Hypothesis 4 (H4). For the difficulty level of tasks, the tasks with a higher difficulty level should have a poorer performance with a more mental workload than the tasks with a lower difficulty level.

The basis for this hypothesis is self-explanatory. In the present experiment, the tasks were designed such that the task F01 is more difficult than the task F02, and the task S01 is more difficult than the task S02. Specifically, with respect to the test bed implementation described in Chapter 3, the length of the access-path for the four tasks are, respectively, 5 for F01, 4 for F02, 8 for S01, and 6 for S02. For instance, to finish F01, the shorted access-path is University Homepage → Admission Office → Graduate Program → PhD in Computer Science → Admission Requirement. From the entrance page (Homepage) to the resulting page (Admission Requirement), users need to access at least 5 pages and thus the number of the access-path for F01 is 5.

Such a length of the access-path can be defined over the three interface design phases (i.e., the conceptual, basic, and detail design phases), respectively. However, in the present study, we used the detail interface in order to be consistent with some other measures such as the number of trials (see the next section for details). This treatment will not affect our purpose of this experiment which is to evaluate the conceptual design of the website interface. This is because the same basic and detail design is employed to the both interfaces.

4.4 Measures

Several measures were selected in this experiment. In terms of the measurement technique, measures can be classified into three categories: (1) the performance measure, (2) the subjective measure and (3) the physiological measure.

Performance measures

Performance measures are those measurable indicators that tell us the quality of executing tasks. In particular, the following variables were defined and used in the present study.

Access time (AT): It refers to time needed for the user to complete a task that is predefined and known to the user. The shorter the AT the higher performance in the present study.

The number of trials (NT): It refers to the number of trials that users need to achieve a task which is predefined and known to the user. Obviously, the smaller the NT the higher performance.

Access failure rate (AFR): It refers to the failure rate (the number of failed tasks over the total number of tasks performed). The higher the AFR the poorer performance.

Subjective measures

Subjective measures are based on the user's comment on an interface after having performed a certain task. Rating Scale Mental Effort (RSME) [Zijlstra, 1985] was selected in the present study. RSME was developed by the Delft University of Technology in 1985 and reported as a relatively good indicator for self-report workload assessment [De Waard, 1996]. RSME uses a set of crosses on a continuous line to indicate the rating of invested effort. This line ran from 0 to 150 mm, and every 10 mm was indicated. There are several anchor points that represent the statements related to effort, e.g., "absolutely no effort" or "extreme effort", along this line. The scale was scored by the measurement of the distance from the origin to the mark in mm. A higher score represented a higher mental workload. The template of RSME used in the present study can be found in Appendix C.

Physiological measures

Physiological measures are indicators of human physiological behaviors or properties, such as heart rate, skin condition, eye movement, hand movement, and so on. These indicators can reflect the mental workload.

Because of lack of necessary equipment, physiological measures were not considered in the present study. The present study only considered the performance measures and subjective measures. The performance measure is used to understand the task performance of the user, and the subjective measure is used to understand the mental workload in the present study.

4.5 Experimental Design

4.5.1 Basic design

The experiment design used a statistic-oriented, 2^k factorial design combined with the blocking technique [Montgomery, 2001]. In any experiment, there will be some nuisance factors which should be eliminated as much as possible. For those known and controllable nuisance factors, the design technique "blocking" was used to systematically eliminate their effect; for those unknown and uncontrollable nuisance factors, "randomization" was designed to guard against them (see Appendix A for more details).

There were three factors in this experiment: the website design methodology, the type of task, and the difficulty level of task. Two levels associated with each factor are, respectively, the F-website and the FS-website for the website design methodology factor, the function-oriented task and the structure-oriented task for the type of the task factor, and the high and the low difficulty levels for the difficulty level of task factor. So, overall, this experiment is a 2^3 factorial design. The total number of treatments is 8 (2^3). The repeating trail for each subject is one. This makes the present experiment differ from most of other experiments [Lin, 2003]. One reason for the one repeating by each subject is that human has a learning ability, so the repeating does not meet the condition called the independent trail (see Chapter 2 for more discussions about the learning and mental model).

The participant factor is out of our interest in this experiment, and so it is treated as a confounding factor. The confounding factor is eliminated by using the blocking technique.

The within-subjects design was employed in this experiment design, which means runs for every level of the factors. In order to eliminate the effect of the order taken in the experiment, participants were divided into two groups: one group processed the F-website first, and the other processed the FS-website first. Each group has the same number of participants.

4.5.2 Sample size

Choosing the number of participants is considered as an important issue, which is related to the sample size. The sample size is the number of elements in a sample. In all cases, a larger sample size makes results more accurate. In the case of statistical generalizations, as the sample size increases, the sample error decreases. Choosing the sample size depends on many factors (1) accuracy required, and (2) resources available to run the sample. The accuracy required is related to the so-called the confidence level or significant level, denoted by p or α. In the human factors engineering, we usually take p or $\alpha = 0.05$. In the human factor engineering, because of the problem with repeating trial, the conventional approach to the determination of the sample size may not apply. Kotval [1998] surveyed 181 published papers in human factors study, finding that the sample size of 13 is the best. In this experiment, we chose 24 participants.

Another issue in the design of experiment is the order of tasks. The effect of the order of tasks is eliminated with the randomization technique. Randomization can be divided into two categories: the complete randomization and the partial randomization. The complete randomization is also considered "pure" randomization, which randomizes without any human's interference. The partial randomization is based on some statistical design methods. In the present study, in order to randomize the order of four tasks, 24 (P [4] = 24) trails were needed. It is noticed that earlier we mentioned 24 subjects. Choosing 24 subjects was also related to the total number of trials needed (24).

4.5.3 Participants

Participants are subjects in human factor experiments. The highly unpredictable feature of human beings makes it play an even more critical role in human factor experiments than the other kinds of experiments.

To eliminate any factor related to the background of the subjects, the participants were chosen from those who at least were either undergraduate or graduate students. Participants received a training which took a couple of minutes. The content of the training includes a short instruction of the website (F-website and FS-website) and how to use browsers.

The number of male and female participants should be even under an ideal circumstance. The age factor is not considered in this experiment, but we still recorded this factor in the experiment.

4.5.4 Procedure

All the participants were required to sign a consent form at the beginning of the experiment. An introduction was given to make all participants clear about the purpose of the experiment and several basic terms related to this experiment. After that, the participants had a short training (3-5 minutes) to get familiar with the browser and solve one sample task (which was not taken into account when analyzing the results). The next step is the formal trial. In the formal trial, four scenarios (i.e., F01, F02, S01 and S02) were employed in a random sequence. The participants were not told which scenario was during the trial. The four scenarios were finished one after another. Each scenario ended up on a success, which means every trial was finished no matter how long it took. The system recorded the AT and the NT that the participants took to finish every task. In the end of each trail, the participants were asked to complete a subjective evaluation by filling out of a RSME rating form (see Appendix C).

It is noted that although there was no failure status during the trail, 200-second was considered a maximum trial time when analyzing the failure rate after the trail. That is to say, the case that a participant finished any scenario more than this time duration was considered as a failure of the task. The basis for the choice of the 200-seceond is that 80% of the trials were found completed within less than 200 seconds.

4.5.5 Data analysis method

Analysis of variance (ANOVA) was used for finding any significant difference among different factors. Once the ANOVA F-test detects a significant difference, the Fisher's Least Significant Difference (Fisher's LSD) analysis method was employed to give more detailed causes for the difference identified in the present experiment (see Appendix A for more details).

4.6 Results

4.6.1 Performance measures

Access time (AT)

The access time was recorded in the unit of second, and the results are shown in Table 4-1, Table 4-2, and Table 4-3 (For the factor of website design methodology, F means the F-website and FS means the FS-website; for the factor of task, F means function-oriented tasks and S means structure-oriented tasks; for the factor of the difficulty level, H means high difficulty level and L means low difficulty level).

With respect to the overall performance, from Table 4-1 we can see that the overall effect of the website design methodology factor is significantly different ($p < 0.05$) with the mean value 174.59^{A} for the F-website and 99.34^{B} for the FS-website (Fisher's LSD test, $\alpha = 0.05$).

Table 4-1 AT means

Total Pr>F* <.0001						
Factor	Website**		Task**		Difficulty**	
Pr>F*	<.0001		<.0001		0.1635	
Level	F	FS	F	S	H	L
Mean	174.59^{A}	99.34^{B}	171.17^{A}	102.77^{B}	N/A	N/A

*: Significance level $p < 0.05$

**: Means with different letters (comparison within column) are significantly different (Fisher's LSD test, $\alpha = 0.05$)

With respect to the difficulty level of task, Table 4-1 shows that there is no significant difference between two difficulty levels ($p > 0.05$).

Table 4-2 AT means when function-oriented tasks were tested

Total Pr>F* = 0.5173				
Factor	Website**		Difficulty**	
Pr>F*	0.0267		0.3887	
Level	F	FS	H	L
Mean	116.58^{A}	88.96^{B}	N/A	N/A

*: Significance level $p < 0.05$

**: Means with different letters (comparison within column) are significantly different (Fisher's LSD test, $\alpha = 0.05$)

With respect to the function-oriented tasks, from Table 4-2 we can see that the effect of the website design methodology factor is significantly different ($p < 0.05$) with the mean value 116.58^A for the F-website and 88.96^B for the FS-website (Fisher's LSD test, α = 0.05).

Table 4-3 AT means when structure-oriented tasks were tested

Total Pr>F* <.0001				
Factor	Website**		Difficulty**	
Pr>F*	<.0001		0.2811	
Level	F	FS	H	L
Mean	232.60^A	109.73^B	N/A	N/A

*: Significance level $p < 0.05$

**: Means with different letters (comparison within column) are significantly different (Fisher's LSD test, $\alpha = 0.05$)

With respect to the structure-oriented tasks, from Table 4-3 we can see that the effect of the website design methodology factor is significantly different ($p < 0.05$), with the mean value 232.60^A for the F-website and 109.73^B for the FS-website (Fisher's LSD test, α = 0.05).

Access failure rate (AFR)

Table 4-4 AFR for the factor of website design methodology

Website	Number of failure
F-website	29 (out of 96)
FS-website	6 (out of 96)

Note that the duration of 200-second was chosen to be a threshold beyond which the task was considered a failure. This choice results in that 82% (157 out 192) tasks are in completion according to the information presented in Table 4-4. Table 4-4 shows the result of the failure rate of two website design methodologies. As we can see the failure rate is 6.25% (6 out of 96) for the FS-website and 30.2% (29 out of 96) for the F-website.

The number of trials (NT)

The results of NT are shown in Table 4-5, Table 4-6, and Table 4-7.

With respect to the overall performance, from Table 4-5 we can see that the overall effect of the website design methodology factor is significantly different ($p < 0.05$) with the mean value 15.5313^{A} for the F-website and 9.0625^{B} for the FS-website (Fisher's LSD test, $\alpha = 0.05$).

Table 4-5 NT means

Total Pr>F* <.0001						
Factor	Website**		Task**		Difficulty**	
Pr>F*	<.0001		<.0001		0.0182	
Level	F	FS	F	S	H	L
Mean	15.5313^{A}	9.0625^{B}	15.3750^{A}	9.2188^{B}	13.2396^{A}	11.3542^{B}

*: Significance level $p < 0.05$

**: Means with different letters (comparison within column) are significantly different (Fisher's LSD test, $\alpha = 0.05$)

With respect to the difficulty level of task, from Table 4-5 we can see that the effect of the difficulty level factor is significantly different ($p < 0.05$) with the mean value 13.2396^{A} for higher difficulty level tasks and 11.3542^{B} for lower difficulty level tasks (Fisher's LSD test, $\alpha = 0.05$).

Table 4-6 NT means when function-oriented tasks were tested

Total Pr>F* = 0.0627				
Factor	Website**		Difficulty**	
Pr>F*	0.0003		0.2582	
Level	F	FS	H	L
Mean	10.8750^{A}	7.5625^{B}	N/A	N/A

*: Significance level $p < 0.05$

**: Means with different letters (comparison within column) are significantly different (Fisher's LSD test, $\alpha = 0.05$)

With respect to the function-oriented tasks, from Table 4-6 we can see that the effect of the website design methodology factor is significantly different ($p < 0.05$) with the mean value 10.8750^{A} for the F-website and 7.5625^{B} for the FS-website (Fisher's LSD test, $\alpha = 0.05$).

Table 4-7 NT means when structure-oriented tasks were tested

Total Pr>F* <.0001				
Factor	Website**		Difficulty**	
Pr>F*	<.0001		0.0377	
Level	F	FS	H	L
Mean	20.188^{A}	10.563^{B}	16.771^{A}	13.979^{B}

*: Significance level $p < 0.05$

**: Means with different letters (comparison within column) are significantly different (Fisher's LSD test, $\alpha = 0.05$)

With respect to the structure-oriented tasks, from Table 4-7 we can see that the effect of the website design methodology factor is significantly different ($p < 0.05$) with the mean value 20.188^{A} for the F-website and 10.563^{B} for the FS-website (Fisher's LSD test, $\alpha = 0.05$).

4.6.2 Subjective measures

The result of the RSME score is put in Table 4-8, Table 4-9, and Table 4-10.

With respect to the overall performance, from Table 4-8 we can see that the overall effect of the website design methodology factor is significantly different ($p < 0.05$) with the mean value 15.5313^{A} for the F-website and 9.0625^{B} for the FS-website (Fisher's LSD test, $\alpha = 0.05$).

With respect to the difficulty level of task, Table 4-8 shows that there is no significant difference between two difficulty levels ($p > 0.05$).

Table 4-8 RSME means

Total Pr>F* <.0001						
Factor	Website**		Task**		Difficulty**	
Pr>F*	<.0001		<.0001		0.5221	
Level	F	FS	F	S	H	L
Mean	54.083^{A}	25.281^{B}	34.094^{B}	45.271^{A}	N/A	N/A

*: Significance level $p < 0.05$

**: Means with different letters (comparison within column) are significantly different (Fisher's LSD test, $\alpha = 0.05$)

Table 4-9 RSME means when function-oriented tasks were tested

Total Pr>F* <.0001				
Factor	Website**		Difficulty**	
Pr>F*	<.0001		0.7223	
Level	F	FS	H	L
Mean	45.104^{A}	23.083^{B}	N/A	N/A

*: Significance level $p < 0.05$

**: Means with different letters (comparison within column) are significantly different (Fisher's LSD test, $\alpha = 0.05$)

With respect to the function-oriented tasks, from Table 4-9 we can see that the effect of the website design methodology factor is significantly different ($p < 0.05$) with the mean value 45.104^A for the F-website and 23.083^B for the FS-website (Fisher's LSD test, α = 0.05).

Table 4-10 RSME means when structure-oriented tasks were tested

Total Pr>F* <.0001				
Factor	Website**		Difficulty**	
Pr>F*	<.0001		0.5724	
Level	F	FS	H	L
Mean	63.063^A	27.479^B	N/A	N/A

*: Significance level $p < 0.05$

**: Means with different letters (comparison within column) are significantly different (Fisher's LSD test, $\alpha = 0.05$)

With respect to the structure-oriented tasks, from Table 4-10 we can see that the effect of the website design methodology factor is significantly different ($p < 0.05$) with the mean value 63.063^A for the F-website and 27.479^B for the FS-website (Fisher's LSD test, α = 0.05).

4.7 Discussions and Conclusions

The Table 4-11 shows the overview of comparison results of each measure with respect to each hypothesis ("y" means the result supports the corresponding hypothesis; "n" means the result fails to support the corresponding hypothesis; "n/a" means this measure is not applicable to the corresponding hypothesis). In the following, we explain the results with respect to each hypothesis.

Table 4-11 Summary of all analysis results

	AT	AFR	NT	RSME
H1	n	n/a	n	n
H2	y	n/a	y	y
H3	y	y	y	y
H4	N	n/a	y	n

H1. The result does not positively test this hypothesis. But it is interesting to observe that for all the measures, the FS-website is better than the F-website. For instance, both the AT and NT of the FS-website are smaller than those of the F-website. The possible reason for this situation could be that some users may view a function-oriented task from a structural view as well. As a matter of fact, they may have such a view relatively readily; in this case the FS-website provides them with the most facilitated way to reach the goal.

H2. All results positively test this hypothesis. Note that the F-website lacks support to access information from the viewpoint of structure. So they need to convert the structure-oriented task into the functional view, which causes extra mental workload and time.

H3. All results positively test this hypothesis. This is because the FS-website has both functional and structural views for reaching the target information. In a way, the FS-website has captured not only the average mental model but also accommodated mental model deviations at large.

H4. The NT measure positively tests this hypothesis; while other measures do not. This might be because the difference in the difficulty level of task is not sufficiently large; for example for only 1 unit length difference in the function-oriented task category, and 2 unit lengths difference in the structure-oriented task category. A future study is needed on the definition of the difficulty level of task.

Overall, this experiment has shown that the FS-website is far better than the F-website. Such a difference can be due to the structure of the website interface; in other words, the conceptual design of the website interface is very important.

CHAPTER 5

CONTRIBUTIONS AND FUTURE WORK

5.1 Overview of the Thesis

We experience a common situation where we feel more comfortable with one website than with another website of a business or organization when performing the same task. One of the best examples is the university website. A pilot study was conducted, leading to the general hypothesis: the structure of the website has a significant impact to the website interface design. The structure of the interface of a domain is about what information needs to be put on an interface medium. In the general interface design methodology, this question may be answered by the approaches such as the EID or FBS framework. However, this may not be the case in the website interface. This thesis study thus focused on the investigation of a methodology for the website interface design. Based on a preliminary study of literature, the two specific objectives were proposed:

- *Objective 1: To develop a new website interface design methodology which is based on the FBS model for the conceptual design of the website interface. The goal of the conceptual design is to determine the structure of an interface, i.e., information contents and their relationships. The new approach was called the FBS-WEB approach.*

- *Objective 2: To conduct a comparative evaluation on both the function and usability of two website interfaces designed by following the FBS-WEB approach and the approach which combines the audience based approach and function-based approach (called the F-A approach for short) which is a popular website interface design methodology, respectively.*

In Chapter 2, we presented a discussion on some useful concepts related to website interface design and web usability. Specifically, we elaborated on the concept of mental model and its role in the interface design. As a general understanding of interface design, the design model of an interface should be the same as the users' mental model. However, we have found a design paradox: on one hand, website interface design is based on a design model, and the design model of a website interface should be equal to users' mental model; on the other hand, an interface should tailor to individuals. Mental model is a subjective representation of an artifact in human's mental world. Different users apparently have a different understanding of an artifact (i.e., one mental model per user). The paradox of website interface design can be described as this: the interface has *one* design model which is the mental model of users, but users have different mental models (i.e., there are a *multiple* number of mental models). We proposed the solution to the paradox: the design model of website should depend on an "average" mental model and should have an adaptive capability. Nevertheless, in this thesis, the adaptive interface is out of the scope.

In Chapter 2, we further reviewed several existing interface design methodologies to confirm whether they were suitable to the website interface. We reviewed those web application software design methodologies with a finding that they were focused on the control of data not on the user's mental model. We also reviewed those methodologies that were claimed to be used for the website interface design. We concluded that the combination of the function-based and the audience-based approaches was a most promising one so far. However, it was still not most suitable to the website interface. The discussion provided justification to our research objectives.

In Chapter 3, we proposed a new approach to the website interface design. The new approach was based on the FBS framework proposed by Lin [2003] for the general interface design. In the FBS framework, there were five layers of concepts, namely, structure, state, principle, behavior, and function. We illustrated that for the website interface five layers of concepts should be reduced to three only: structure, state, function.

In Chapter 4, an experiment was developed for verifying the proposed website interface design approach. We first defined tasks and then proposed four hypotheses. We used two categories of measures, i.e., performance measure and subjective measure. The experiment results successfully proved the two hypotheses: (1) the FS-website has a better overall performance and a less mental workload than the F-website, and (2) for the structure-oriented task, the FS-website is far better than the F-website. Besides, for the function-oriented task, the experiment showed that the FS-website has a better performance and a less mental workload than the F-website.

There are following conclusions which can be drawn from this research. (1) Mental model plays an important role in website interface design. To achieve the goal that users can retrieve information easily and quickly, a website interface design should start with a well-defined mental model. (2) The proposed FBS-WEB approach should replace the popular one called F-A approach to website interface design.

5.2 Contributions of the Thesis

This thesis work focused on the development of the website interface design and the experiment to evaluate design approaches including the one proposed in this thesis. The following contributions have been made from this study.

First, this study provided a comprehensive elaboration on the concept of mental model. Mental model is the image of an artifact in human's mind. It represents the individual understanding of the system. Thus, the mental model of an artifact is important when designing an interface. Two types of mental model were identified: the functional and the structural mental models. Both mental models should be supported within an interface design model.

Second, this study developed a new website interface design approach called FBS-WEB approach. The proposed design approach is parallel to the FBS design model. That is to say the core concepts of the FBS-WEB approach are the core concepts of the FBS model. The proposed approach has both the functional and structural views of a website, so it supports the mental model in the concept of the website interface.

Last, this study developed an experiment with rigorous considerations on the task design for evaluating the website interface. The difficulty level of tasks is an area not well studied. This thesis study defined the difficulty level of tasks according to the number of steps to complete a task over the structure of an interface. This definition is more objective in two senses: (1) the structure of a website is relatively "stable" as it is about the domain of an organization; (2) the structure of website is independent of the layout and form of display elements.

5.3 Limitations and Future Work

There exist several limitations which lead to the future work. When the human factor experiment is designed, physiological measures are good indicators to measure the mental workload. One of the physiological measures is based on the eye movement behavior [Lin et al, 2003]. The eye movement behavior would be introduced here to particularly evaluate the detailed design of the website interface.

During our experiment, we failed to verify two of four hypotheses, which were related to function-oriented tasks and difficulty levels of task. Although these two hypotheses are relatively not critical to our conclusion, further studies on them are worthwhile.

Last future work is the adaptive interface. As we discussed in Chapter 2, the adaptive interface concept is a good complement to the average mental model concept. It is very important to note that the adaptive to human behaviors or preferences should be based on the specification of the average or nominal behaviors or preferences, i.e., the average mental model of the system which is behind the interface. While the average mental model may be easily captured, the deviation from the average mental model is relatively difficult to be captured. Capturing of the deviation mental model may be done through the experiment. A further challenge lies in how to detect and quantify the deviation for an individual user. This may be done intelligently through some pre-operation tests or through several interactions between the user and the interface. The last issue related to the adaptive interface is that the adaptive makes sense on all the three levels of interface design: conceptual, basic, and detail. The commonly known deviation or difference in terminology, e.g., college and faculty (both meant for the same thing in the context of university), may be captured at the detail interface design phase (i.e., the matter of choosing different syntactical forms).

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APPENDIX A

Statistical Design of Experiment

Nowadays, statistical experiments play an important role in scientific research, engineering design, manufacture management, decision-making, and human factor research as well. Because of high variance from people to people, statistical experiment design is extremely important for validating a human factor design. Basically, the statistical experiment is composed of two parts: (1) the design of experiment for a statistical purpose and (2) the statistical analysis of the experiment result.

The design of experiments

(I) Elementary Concepts in Statistical Experiment

There are three components in an experiment: (1) the factors or variables, (2) the subjects (the samples in non-human related research, or the participants in the human factors research), and (3) the number of runs.

Factors or Variables

A variable is any measured characteristic or attribute that makes subjects differ from each other, also known as a factor. For example, if the length of several subjects were measured, the length would be a factor. When an experiment is conducted, some factors that are manipulated by the experimenter are called independent factors; while other factors that are measured or recorded only are called dependent factors. For example, consider an experiment on the effect of voltage on current. The voltage is manipulated as 0.1v, 0.5v, 1v, or 2v and then has the current measured in order to observe the correlation between the voltage and the current. The independent factor would be the voltage and the dependent factor would be the current. All other factors that are not observed in data are known as extraneous factors. Some of extraneous factors or variables are uncontrollable, known as confounding variables or confounds. Confounds could affect the measures observed and interpretation of the measures. In the design of experiments, therefore, we should try to eliminate confounds as possible as we can to make the results more reliable. The principle of eliminating confounds in the design of experiments will be discussed later in this section.

Levels of factors

Levels are indicators refer to the different values of the characteristic or attribute of subjects in an experiment. In other words, levels indicate how different of factors from one subject to another. Two kinds of levels: quantitative level and qualitative level can represent this difference. If different design method of a system were a measure in an experiment, the levels would be qualitative ones as design method No.1 and design method No.2. It is measured on nominal scale. But if the voltage were a factor, the levels could be 0.1v or 10v and these represented quantitative levels. Also, quantitative levels can be measured on (1) ordinal, (2) interval or (3) ratio scale.

Subjects

In the design of human factor engineering experiments, two issues are involved in the selection of subjects. The first issue is regarding the category of subjects. Knowledge level, experience level, age difference, gender difference and cultural difference should all be considered in the design. These factors might affect the experiment results in a very large range. For example, considering a hypothetical experiment on the effect of a software interface on operation time, the experience level (expert versus novice) might be of interest. When any difference of category is not of interest, as an extraneous factor, we should try to eliminate it as possible as we can in order to make the experiment more reliable.

As we discussed before, participants are the subjects in human factors research. Choosing the number of participants is considered as the second issue, which is related to the sample size. The sample size is the number of units in a sample. In all cases, larger sample size makes conclusions more accurate. In the case of statistical generalizations, as the sample size increases, sample error decreases. Choosing a sample size depends on several principles: (1) Accuracy required. More accuracy (means less errors) needs a larger sample size, vice versa. (2) Under the certain accuracy required, a larger population needs a larger sample size. However, an even larger sample size will not be necessary once this sample size is already larger than a certain number, because this certain number of the sample size is good enough to achieve the required accuracy. (3) To determine a sample size, human resource, material resource, financial resource, and time restriction should also be taken into account. Because of the fact of complexity in human factors experiment, the number of subjects is difficult to determine using standard principles in statistics [Montgomery, 2001]. A replaced method [Kotval, 1998] was used to determine the number of subjects in human factor study. He simply surveyed 181 published papers in the area of human factor study, and found 13 subjects was the best number. This method was taken into the present experiment.

Number of runs

Combinations of all levels of factors are known as trials or replicates. The number of trials also depends on the design of experiments. For an experiment with m factors (each factor with $l_1 \ldots l_m$ levels), the total number of runs will be (l_1 x l_2 x...x l_m). The experiment with all possible trials is called complete experiment. For some reason, taking part of trials to do the study is called partial experiment.

(II) Type of Experiments

According to the purposes of experiments, experiments can be divided into two categories: (1) confirmatory experiments and (2) exploratory experiments. In confirmatory experiments, the correlations between factors and subjects are already known. The purpose of confirmatory experiments is to verify or confirm these correlations. In this case, a researcher might manipulate the factors or variables. Data analysis in confirmatory experiments comes down to calculate correlations between variables, specifically, those manipulated and those affected by the manipulation. On the other side, during exploratory experiments, the correlations between factors or variables are normally unknown. What we need to do is going to find out the correlations. In exploratory experiments, we do not (at least try not to) manipulate factors but only measure them and try to figure out the correlations between some set of factors.

(III) Principles of the design of experiments

Blocking, replication, and randomization are the three principles of the design of experiments. These principles provide an ability to eliminate the effect of confounding factors will become possible.

Blocking

Blocking is the most import principle to design an experiment. Because there always have some confounding factors in any experiment that are uncontrollable, blocking technique, therefore make it possible to eliminate the effect of those confounding factors.

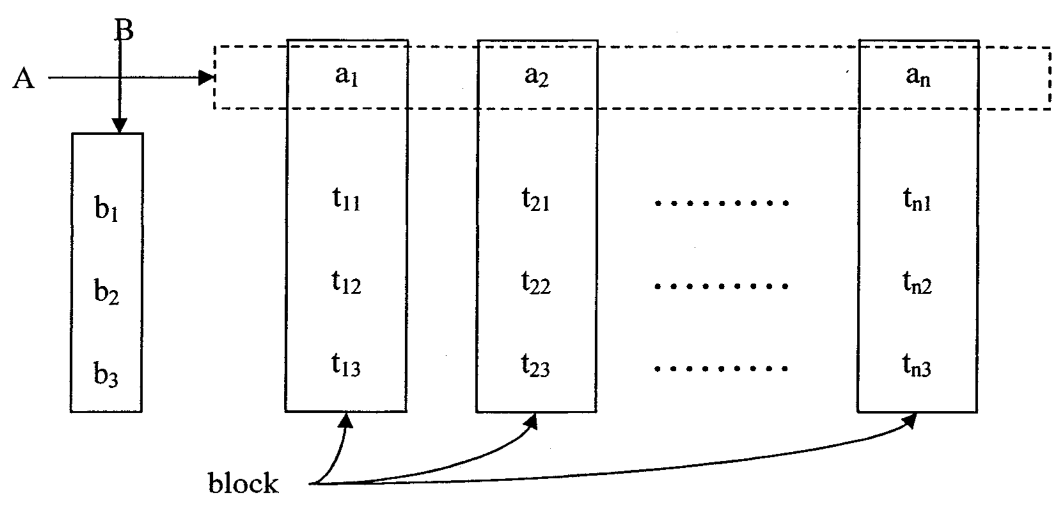


Figure A-1 The randomized complete block design technique

The general idea of blocking technique is as follows. Suppose A is a confounding factor with n levels from a_1 to a_n. B is an independent factor with level b_1, b_2 and b_3. The trails are ordered as t_{11}, t_{21} ... t_{n1} ... t_{12}, t_{22} ... t_{n2} ... t_{13}, t_{23} ... t_{n3}. The total arrangement is shown in Figure A-1. In each block, the level of confounding factor A is holding constant. In this way the effect of factor A is eliminated. This particular blocking technique is called the randomized complete block design technique [Montgomery, 2001].

Replication

Replication means a repetition of trials. Trials refer to the combinations of the levels of factors. The purpose of the replication is to evaluate the variance of measurements, improve the precision and reliability of the experiment. Usually, if the variance were lager, more replications would be required; if the variance were small, there would be no need to do too many replications.

Randomization

Randomization is a further experiment design technique that provides designers an ability to eliminate uncontrolled or unknown confounding factors. In fact, the randomization technique arranges the allocation of blocks, the order of trials, and the order of levels randomly to make the experiment unbiased and reliable. For example, if the order of two levels A and B might affect the experiment, to eliminate this interference, the experiment should be designed as the even order of two levels: AB and BA both take 50 percent in all trials.

(IV) Within- or between-subjects design

Within-subjects design is a design of experiment in which the independent variables are manipulated by testing each subject at each level of the variables; while between-subjects design is a design of experiment in which a different group of subjects is used for each level of the variables. For example, in an experiment, the independent factor M has two levels: A and B. If each of the subjects tests both level A and level B, it is a within-subjects design; if one group of subjects runs level A and another group of subjects runs level B, it is a between-subjects design.

Within-subjects design and between-subjects design both have their advantages and disadvantages. Because subjects differ from each other, to make the experiment even, each subject runs each level (within-subjects design) seems to be reasonable. But sometimes the order of testing levels might affect the result. If testing level B after testing level A can make level B more "simple" or "difficult", within-subjects design will make the study results unreliable. In this case, between-subjects design should be used to solve this problem. But also because subjects are always different from each other, the difference might happen between each group of subjects if a between-subjects design is applied. Three issues should be considered when choosing a within-subjects design or a between-subjects design [Eberts, 1994]: (1) Equality between the subjects. For between-subjects design, equality of each group of subjects should be considered. Randomization might be one of solutions to assure the equality. The within-subjects design does not have this problem, simply because each subject runs each level. (2) Given a certain order, one level might affect another level. This makes the within-subjects design not reliable. Note that the between-subjects design does not have this problem, simply because each group of subjects will only run one level. (3) The order that subjects test different levels must be even. This could solve the entire problems above: occupying within-subjects design method to make the equality of the subjects, making the order of testing even to ensure the order does not affect the results.

(V) Measure

Measurement is the process of assigning dimensions, quantity, or capacity to subjects in such a way as to describe them according to a clearly defined standard, by which differences between subjects can be told. Measurement exists all over in our daily life. Price acts as a measure of value of an item, so we can compare the price of one item with another. Size is used as a measure of clothing so that we contrast size in a clothing store to make sure our clothing will fit us properly. An experiment without measurement cannot be realistic, simply because the difference of subjects cannot be told without measurement. Choosing measures is directly linked to the utility of a human factors research project [Kantowitz, 1992]. Measures in human factor experiment can be basically classified into three categories: (1) performance measures, (2) subjective measures, and (3) physiological measures.

Performance measures

Performance measures are those measurable indicators that can be systematically tracked to access progress made in achieving predetermined goals. Time, quality, and quantity can be used in an experiment as performance measures. Two categories of performance measures can be classified in terms of in which stage the measures lie in the whole experiment. They are (1) product measures and (2) process measures. The product measures only care about the final result, such as how long it takes subjects to finish the trials; while the process measures are interested in the steps that followed to complete the trials. If each step of experiment were measured following a time line, this would be a process measure, because this would make it possible to observe the steps in the whole trial.

Subjective measures

Subjective measures refer to measures that involve self-reports based on implicit criteria. And these self-reports collected based on some criteria can be mapped into the quantity of measures for making measurement possible. These criteria are known as verbal protocols [Kirwan et al., 1995] and classified into three categories in terms of the order the protocol is given: (1) concurrent verbal protocol, which is given during the trail, (2) retrospective verbal protocol, which is given after the trail, and (3) interruptive verbal protocol, which is given alternately during the trail.

Subjective measures normally are used to directly indicate the subjects' mental workload despite some bias exists somehow [Lansdale and Ormerod, 1994]. Several subjective mental workload measures have been developed and used in human factor experiments. In terms of the number of dimensional scales used, basically, these methods can be classified into two categories: one-dimensional and multi-dimensional scales. Modified Cooper-Harper (MCH) [Wierwille and Casali, 1983], Rating Scale Mental Effort (RSME) [Zijlstra and van Doorn, 1985], and Overall Workload (OW) [Vidulich and Tsang, 1987] are several frequently used one-dimensional scale measure. Respectively, 10-point, 100-point and 150-point scales were used in each measure method. And Subjective Workload Assessment Technique (SWAT) [Reid, et al., 1981] and the National Aeronautics and Space Administration Task Load Index (NASA TLX) [Hart and Staveland, 1988] are multi-dimensional scales measures. Mental demands, physical demands, temporal demands etc. scales were used during multi-dimensional scales measures method. It is reported the RSME had a more sensitive measure and so provided us a better performance when using the RSME in the experiment [De Waard, 1996].

Physiological measures

Physiological measures are also good indicators to measure the human mental workload, which includes heart rate, skin condition, eye movement, hand movement, and so on. Psychologists realized these measures have strong connections with the human mental workload and thus can be used to do the human mental workload measurement. Lin [2003] reported eye movement was a good indicator to do the mental workload measurement when doing a human factor experiment. Fixation and pupil diameter were measured during Lin's experiment and a reliable result was reported based on the measures. But in the present experiment, because of lacking of some necessary equipment, physiological measures will not be considered in the experiment.

The data analysis methods

Comparison is the basic idea of the data analysis. This comparison might happen between the simulated result and experimental result or two experimental data samples from different experiment configurations. Two subjects of the comparison having a consistent difference, e.g. subject A is always greater or smaller than subject B, can be used as the proof of our conclusion. By the nature of the probability, in any trail, subject might be affected by extraneous factors. So to declare the difference of a comparison is consistent is always the very first concern during any experiment. In human factor experiments, because of high uncertainty of human being, to ensure the difference of a comparison is consistent is even harder than the other kinds of experiments.

To evaluate a result is really consistent or significant, two terms were introduced: significance level (p-value) and confidence level (α-value). Significance level is the level at which it is seen as a possibility of accepting statistical results as significant. Using less technical terms, the significance level tells us in what degree (represented by probability) we can believe the significance is true. More technically, p-value is assigned as an indicator to represent this degree. The higher the p-value, the less we can believe that the observed result is reliable. For example, a p-value of 0.01 (1/100) indicates that there is 1% probability of error involved in accepting the observed result is valid, which seems a very small chance of making a mistake to accept the observed result. In a spaceship experiment, 1% error could be thought not-rigorous; while in a human factor experiment, because of uncertainty of people, 1% error would be believed too restricted. So in the real world, we have to artificially define a level, called confidence level (indicated by α-value), by which once p-value is equal or smaller than α-value we will accept the observed result, otherwise, we will reject the result. As we discussed above, the selection of α-value all depends on the application. Some experiments have a larger α-value and some have a smaller one. There are innumerous α-values we can choose. Traditionally, only three of them are recommended. Respectively, these three α-values are 0.01, 0.05 and 0.10. Because of the uncertainty feature of human beings, a α-value=0.05 is going to be used in our experiment.

Because the data samples are all random variables, during the data analyzing, comparison cannot handle with one data element with another. So some statistical properties are used to do the data analysis of random data samples. Mean, standard deviation, and variance are some of the most common statistical properties selected to make the data analysis possible. In deed, when doing data analysis, people always merger some statistical properties into a single value by the probability theory to do the data analysis. This value is called "test statistic". And each analysis method (so-called "test") uses one or more test statistics to do the data analysis. The choice of the test statistic depends on the different analysis methods. For example, F-statistic is for F-test and χ^2-statistic is for chi-square contingency table analysis. Two very basic tests are: (1) the T-test is for the comparison of means of two samples and (2) the F-test shows the ratio of two variances for the comparison of means. Several common methods are used for the multiple comparisons. (1) Least Significant Difference (LSD) is the one of simplest comparison methods for detecting the difference of pairs of means. Each comparison is a T-test in LSD. A LSD method that is applied only if a F-test is significant is called Fisher's LSD or restricted LSD [Fisher, 1935]. Otherwise it is an unrestricted LSD method. (2) Tukey Comparisons work on the comparison of means with the same number of observations. But an approximation test can also be used when the observations are not so unequal. Tukey's test also gives a control of overall error rate [Goldberg and Probart, 1999], which makes it more restricted. (3) Duncan's Multiple Range Test is one of the most popular comparison methods for comparing all pairs of means [Montgomery, 2001]. This test method also requires the even number of observations for each mean. Analysis of variance (ANOVA) is used for detecting of significance. Once ANOVA F-test detects a significant difference, Fisher's Least Significant Difference analysis method would be employed to give more detailed causes for the difference identified in the present experiment.

APPENDIX B

Experiment Recording Form

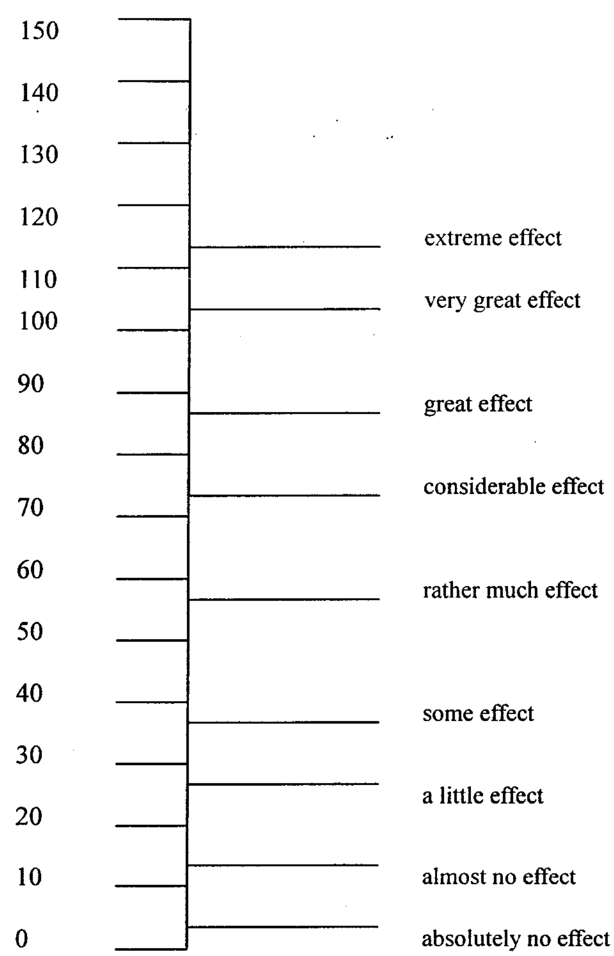
Gender: Male / Female Age: _______ Degree:__________ Major:_____________

Interface + Scenario	Task Order	RSME value	Time to finish the task **(Supervisor Use Only)**	Trials to finish the task **(Supervisor Use Only)**
Sample				
1+01				
1+02				
1+03				
1+04				
2+01				
2+02				
2+03				
2+04				

APPENDIX C

Rating Scale Mental Effort (RSME)

Could you please indicate, by marking the vertical line with a cross, how much effort it cost you to perform the task you've just finished?



APPENDIX D

Statistical Analysis System Code (SAS)

```
data ThreeFinRCBD;
input Subject Interface Task Difficulty RSME Time Trials;
cards;

1   1   1   1   28   149 15
1   1   1   2   38   142 14
1   1   2   1   72   379 30
1   1   2   2   28   173 13
1   2   1   1   3    28  6
1   2   1   2   3    50  6
1   2   2   1   14   100 15
1   2   2   2   14   59  11
2   1   1   1   25   80  6
2   1   1   2   80   180 9
2   1   2   2   90   177 12
2   1   2   1   100  263 32
2   2   1   1   15   52  6
2   2   1   2   15   91  6
2   2   2   2   20   86  9
2   2   2   1   20   70  9
3   1   1   1   40   140 9
3   1   2   1   65   345 29
3   1   1   2   50   62  6
3   1   2   2   50   120 11
3   2   1   1   30   83  7
3   2   2   1   32   82  8
3   2   1   2   25   114 5
3   2   2   2   40   131 10
4   1   1   1   25   76  9
4   1   2   2   85   162 15
4   1   1   2   55   136 12
4   1   2   1   115  604 45
4   2   1   1   55   106 9
4   2   2   2   85   274 18
```

4	2	1	2	85	169	10
4	2	2	1	55	110	13
5	1	1	1	60	128	15
5	1	2	1	70	339	31
5	1	2	2	60	258	19
5	1	1	2	50	139	10
5	2	1	1	20	76	6
5	2	2	1	10	63	10
5	2	2	2	30	149	15
5	2	1	2	10	34	6
6	1	1	1	20	81	11
6	1	2	2	40	180	11
6	1	2	1	40	192	19
6	1	1	2	20	84	7
6	2	1	1	10	102	6
6	2	2	2	50	270	15
6	2	2	1	40	146	12
6	2	1	2	30	178	8
7	1	1	2	40	51	6
7	1	1	1	90	191	20
7	1	2	2	120	325	25
7	1	2	1	110	375	45
7	2	1	2	20	66	6
7	2	1	1	15	54	6
7	2	2	2	50	192	19
7	2	2	1	40	91	10
8	1	1	2	55	95	15
8	1	1	1	50	195	16
8	1	2	1	60	509	46
8	1	2	2	45	71	10
8	2	1	2	50	90	6
8	2	1	1	70	277	16
8	2	2	1	30	147	13
8	2	2	2	50	253	16
9	1	2	1	40	323	23
9	1	1	1	40	220	14
9	1	1	2	30	85	10
9	1	2	2	30	134	12
9	2	2	1	30	88	9
9	2	1	1	40	141	11
9	2	1	2	30	138	15

9	2	2	2	30	242	19
10	1	2	2	60	303	27
10	1	1	1	40	84	11
10	1	1	2	40	80	6
10	1	2	1	50	174	16
10	2	2	2	30	132	9
10	2	1	1	10	108	5
10	2	1	2	10	37	4
10	2	2	1	20	140	12
11	1	2	1	55	325	24
11	1	1	1	45	119	9
11	1	2	2	50	246	15
11	1	1	2	52	209	11
11	2	2	1	15	93	12
11	2	1	1	10	43	4
11	2	2	2	12	98	8
11	2	1	2	5	33	5
12	1	2	2	80	147	18
12	1	1	1	80	154	13
12	1	2	1	80	184	14
12	1	1	2	100	184	20
12	2	2	2	30	110	9
12	2	1	1	30	131	12
12	2	2	1	20	83	8
12	2	1	2	20	132	12
13	1	1	2	40	109	9
13	1	2	1	60	267	22
13	1	1	1	30	145	13
13	1	2	2	50	161	11
13	2	1	2	30	40	6
13	2	2	1	20	30	7
13	2	1	1	20	26	4
13	2	2	2	20	59	8
14	1	1	2	30	107	11
14	1	2	2	60	175	36
14	1	1	1	10	50	6
14	1	2	1	30	87	18
14	2	1	2	10	64	5
14	2	2	2	30	103	10
14	2	1	1	20	121	16
14	2	2	1	10	22	7

15	1	2	1	70	285	22
15	1	1	2	55	107	7
15	1	1	1	70	124	9
15	1	2	2	85	219	16
15	2	2	1	15	66	8
15	2	1	2	15	48	5
15	2	1	1	5	25	4
15	2	2	2	35	141	14
16	1	2	2	60	203	26
16	1	1	2	20	36	6
16	1	1	1	15	36	5
16	1	2	1	45	90	8
16	2	2	2	12	123	7
16	2	1	2	10	25	4
16	2	1	1	30	209	15
16	2	2	1	8	110	8
17	1	2	1	40	330	19
17	1	2	2	40	226	12
17	1	1	1	40	139	9
17	1	1	2	40	119	15
17	2	2	1	20	84	11
17	2	2	2	20	42	7
17	2	1	1	10	109	12
17	2	1	2	10	57	6
18	1	2	2	60	183	16
18	1	2	1	100	293	24
18	1	1	1	100	196	13
18	1	1	2	60	59	5
18	2	2	2	20	87	7
18	2	2	1	30	97	10
18	2	1	1	35	175	10
18	2	1	2	30	169	10
19	1	1	2	50	213	24
19	1	2	1	70	320	28
19	1	2	2	50	67	10
19	1	1	1	20	108	6
19	2	1	2	20	105	7
19	2	2	1	35	102	12
19	2	2	2	40	95	9
19	2	1	1	20	69	6
20	1	1	2	60	26	6

20	1	2	2	90	237	18
20	1	2	1	80	79	8
20	1	1	1	90	299	25
20	2	1	2	20	33	4
20	2	2	2	45	92	8
20	2	2	1	35	54	9
20	2	1	1	25	16	5
21	1	2	1	40	260	21
21	1	1	2	40	193	16
21	1	2	2	30	166	17
21	1	1	1	20	20	4
21	2	2	1	20	90	8
21	2	1	2	30	92	10
21	2	2	2	30	120	13
21	2	1	1	20	24	4
22	1	2	2	90	137	18
22	1	1	2	50	31	6
22	1	2	1	60	78	10
22	1	1	1	50	63	13
22	2	2	2	40	96	13
22	2	1	2	40	107	11
22	2	2	1	30	38	7
22	2	1	1	50	88	11
23	1	2	1	100	346	25
23	1	2	2	90	228	13
23	1	1	2	60	63	6
23	1	1	1	40	56	8
23	2	2	1	15	109	8
23	2	2	2	10	119	11
23	2	1	2	10	72	4
23	2	1	1	5	61	5
24	1	2	2	20	293	16
24	1	2	1	12	127	13
24	1	1	2	12	153	15
24	1	1	1	10	80	11
24	2	2	2	10	134	9
24	2	2	1	2	45	7
24	2	1	2	12	72	6
24	2	1	1	20	130	10

;

```
proc glm;

class Subject Interface Task Difficulty;
model Time=Subject Interface Task Difficulty Interface*Task
Interface*Difficulty Task*Difficulty Interface*Task*Difficulty;
random Subject;

means Interface/lsd;
means Task/lsd;
means Difficulty/lsd;

lsmeans Interface/stderr;
lsmeans Task/stderr;
lsmeans Difficulty/stderr;

run;

proc glm;

class Subject Interface Task Difficulty;
model RSME=Subject Interface Task Difficulty Interface*Task
Interface*Difficulty Task*Difficulty Interface*Task*Difficulty;
random Subject;

means Interface/lsd;
means Task/lsd;
means Difficulty/lsd;

lsmeans Interface/stderr;
lsmeans Task/stderr;
lsmeans Difficulty/stderr;

run;

proc glm;

class Subject Interface Task Difficulty;
model Trials=Subject Interface Task Difficulty Interface*Task
Interface*Difficulty Task*Difficulty Interface*Task*Difficulty;
random Subject;
```

```
means Interface/lsd;
means Task/lsd;
means Difficulty/lsd;

lsmeans Interface/stderr;
lsmeans Task/stderr;
lsmeans Difficulty/stderr;

run;
```