Study of menu selection based on human information processing: spreading activation approach

Jong Myong Choi

Iowa State University
Study of menu selection based on human information processing:

Spreading activation approach

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Jong Myong Choi

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Adrian Sannier
Judy M. Vance

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This is to certify that the master’s thesis of

Jong Myong Choi

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
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ACKNOWLEDGMENTS
ABSTRACT

The determination of the appropriate interface texts for efficient menu selection, based on information retrieval from long term memory, is important to web site design. A psychological theory, the spreading activation model, is used to explain the users' information searching behavior in menu selection tasks. Two experiments were performed: a spreading activation test and an actual performance test with a real menu. In the first experiment, the degree of relatedness between two text labels in a menu was evaluated. By using two levels of menu structure, we investigated the user's search for semantically related targets and for a known target respectively. The latter was determined by target locations and the number of menu items, allowing selection time to be predicted by Fitts' law. On the other hand, the former was strongly dependent on each subject's memory, and required a significant cognitive load. As seen in the total performance measure, semantic relations of text information played an important role in menu selection. Consequently, the semantic distance for related information was strongly correlated with error rate ($r^2=0.740$) and total menu selection time ($r^2=0.751$). In comparing the spreading activation test with actual performance, response time in the spreading activation test also showed a strong correlation with error rate ($r^2=0.736$) which significantly affected menu selection. This study supports the use of interface languages for certain information structures and provides a semantic approach to the design of menus.
CHAPTER 1. INTRODUCTION

Menu Selection for Information Searching

Menu systems provide for the displaying and organizing of information by use of a specific physical format. Menu systems allow users to search and accomplish their goal by choosing amongst displayed options. Various types of visual interactive content such as text based, graphic interaction, and a multitude of other structures are included in menu systems. Mullet (1995) suggested the use of visual language, which is a design that attempts to reduce search time and also fundamentally provides users with an effective goal seeking behavior. Visual characteristics, such as graphic elements (shape, size, color, etc.) or texts (words, signs, etc.) provide the desired behavior outcome through the users’ understanding of the element. Although “a picture says a thousand words”, text-based information has universally been used for representing options in a menu, since text is not only straightforward but can also be identified quickly.

As an area of Human Computer Interaction (HCI), menu selection usability has become an important aspect in designing menus to solve communication problems and so improve the interface between users and software systems. During the past few years, several empirical studies have evaluated the interaction usability in menu systems. One approach to more
efficient menu design is the trade-off between breadth and depth when navigating through a hierarchical menu system (Miller, 1981; Kiger, 1984; Jacko & Slavendy, 1996; Larson and Czerwinski, 1998; and Zaphiris, 2000). The studies showed that an increase of breadth (number of items at each level) is better than that of depth (number of menu levels) for performance and accuracy in menu selection. In addition, some approaches that considered how to best display menus have been used to present empirical usability of menu selection, for example, different menu display types (Nygren, 1996 and Cheng & Patterson, 2002) and menu item arrangements, both alphabetically or numerically (Perlman, 1984 and Somberg, 1987). Furthermore, 3D menu systems have been studied in Virtual Environments (VE) for particular situations or as a composite generic task. Jacoby and Ellis (1992) reported on the use of virtual menus as a method of interacting with in virtual environments and provided a frame work for the design of these menus.

Previous studies of efficient menu selection have provided usual guidelines by focusing on structural approaches whose results have helped to drive technological improvements such as high-resolution displays which improve readability. In spite of those approaches, a fundamental question still exists in menu selection. A characteristic of menus is that they commonly require text based processing and are composed of sequences of related information. They use a variety of psychological processes such that a selection choice affects subsequent
options. When a menu displays information about the identity of each menu item, user actions are carried out by understanding the text meaning and interrelated networks between successive texts. Depending on whether it conveys information well, menus may either facilitate or retard performance. Therefore, a menu should be designed to organize and help in visual search, as well as in the efficient extraction of semantic information from a text. A menu should help users in following the flow of information through it, and so aid the users in the decision process. For example, when searching for something needed on the web, we intend to click on the items or hyperlinks that are relevant to achievement of a particular goal.

Menu selection is involved with aspects of human information processing: perception, comprehension, judgment and decision-making, and response (Norman, 1991). That is, the perception of an object and its corresponding execution is done based on the knowledge and experiences stored in our memory. Nevertheless, many screen and information layouts often do not provide a well-suited interface for their users based on the concept of human information processing.

To determine searching behavior in a menu, this study was focused on psychological process, particularly, those related to information searching during menu selection. We conducted successive menu selection experiments using a two-level of pull-down menu structure and observed how related information (menu headings) affected target search using a
methodology based on the spreading activation mechanism.

Statement of Problem

Choosing incorrect menu headings causes users to be unable to acquire a desired goal in menu select tasks. Menu headings allow users to first find the group that likely contains the desired item, and then to search with that group. Information Foraging Theory has been developed as a method to explain human information-seeking behavior (Pirolli & Card, 1999). The menu heading plays a role of information scent as proposed in this theory in our two level of the pull-down menu selection task.

Many studies have researched the effects of grouping items in a screen layout. Card (1982) and McDonald, Stone & Liebelt (1983) found that menu items categorized by labels (headings) can initially be searched more quickly than randomly arranged menus. However, users make errors during searches of semantically inappropriate labels. Although it is strongly recommended that good category names help in organizing information, empirical evidence has not been provided to explain how a heading is relevant to its holding group and the effect of adding appropriate labels has not been studied independently in visual information searching task.

Performance time for known targets has been considered in visual search tasks or
diverse menu structures. Although attempts to improve menu structure have brought usable recommendations for organizing information structure, semantic questions still remained. Tullis' (1988) Display Analysis Program (DAP) predicts search times based on grouping, density and layout complexity, but ignores visual semantic cues. For this study, we evaluated how menu headings can help users better approach the target. In more than two level menu selection tasks, such cues are needed to examine relatedness between levels.

In searching for visual information beyond the simple mouse movement explained by Fitts' experiments, people perform actions through understanding their perceptions and an object's characteristics. In particular, menu selection should incorporate semantic relationships among menu items along with perceptive and cognitive factors, as well as physical movement.

**Objectives of the Thesis**

As mentioned earlier, menu systems are connections of text information. Hence, an investigation is needed using menu selection tasks in at least two levels of menu structure by considering the semantic meanings of the text. Through this study we emphasize the important role of menu representatives and determination of interface languages by menu designers using a semantic approach to menu selection tasks. The relatedness observed is based on the spreading activation model and is measured by response time. We then determined how the
spreading activation model was reflected in actual performance test.

Summary of Subsequent Chapters

The remainder of the thesis is organized as follows: A review of existing studies for menu selection and a psychological theory, the spreading activation model, are given in chapter two. In chapter three, two experiments dealing with the spreading activation test and menu selection performance are conducted. In chapter four, the results from the experiments are analyzed. The results are discussed and conclusion about this work with chapter 5.
CHAPTER 2. BACKGROUND

During menu selection users scan the alternatives, select some desired options in terms of proximity to their goal and finally arrive at the goal. This menu selection uses both cognitive elements and physical behavior.

Human Memory (Human Information Processing)

Menu selection processing is an information-dependent task as well as a time-dependent task. Choice behavior in menu selection is dependent on user expectations and goals based on their knowledge or experiences. That is, menu selection is based on human information processing. External information is perceived and stored in human memory as information or knowledge.

Memory is a human perceptive process model of users within an information processing system. There are three basic types of memory stages: sensory memory, short-term memory and long-term memory (see Figure 1).

Sensory memory acts as a buffer receiving stimuli through the senses: iconic memory for visual stimuli, echoic memory for aural stimuli, and haptic memory for touch. Information is passed through sensory memory into short-term memory. Short-term memory, often called working memory, acts for the temporary recall of the information under process. Short-term
memory has rapid decay (200ms) and limited capacity. Long-term memory, in contrast, is intended to store information over a long time. According to incoming information, there are two types of long-term memory: episodic memory and semantic memory. Episodic memory is the remembering of certain images related to certain events and experiences. In other words, the essence of an episodic memory is that it recaptures the temporal and spatial context of a person's past experience. Semantic memory, on the other hand, is a structured record of facts, concepts and skills acquired. It involves a person’s general knowledge of words and symbols, their meanings and knowledge of the relations among words (Lachman, R. Lachman, J & Butterfield, E, 1979). In searching for information in both familiar and unfamiliar situations, both episodic and semantic provide critical guidelines.

Figure 1. Human memory
Spreading Activation Model

The spreading activation model explains a psychological process that represents human knowledge by use of associative networks. A network consists of a set of nodes, together with the links connecting them. In the case of "associative" or "semantic" networks, the nodes represent concepts and the links the relationships among them (Findler, 1979).

A plausible model for how people organize knowledge was proposed by Collins and Quillian (1969), who simulated language understanding using a network based on dictionary-like definition of English words. The model by Collins and Quillian permitted the efficient retrieval of relevant information through hierarchical associative networks. Collins and Loftus (1975) offered a revision of the Collins and Quillian’s model, which is the spreading activation model. The principle notion is that memory is represented by a semantic network of interconnected concepts, or nodes, with more closely related concepts located closer together within the network. Retrieval consists of activating the relevant node in the network. In a lexical decision task, for example, the processing of a word, such as lion, would send activation to connected concepts, such as tiger. Psychologists concerned with word recognition often refer to a word’s lexical entry by assuming that we possess a mental lexicon— a dictionary-like structure in which there is a representation of each word including its visual characteristics, pronunciation, and meaning (Parkin, 2000). Thus, its internal representation and the process of
word recognition are termed lexical processes. One of the most influential models of word recognition is that of Morton (1969), the logogen model. In this model each word is represented by a logogen that contains information about a given word. When a word is presented, each logogen is compared in parallel with the input and the one with the most overlap "fires", allowing the meaning of that word to become available via semantic memory. The logogen model is a threshold model as the degree of activation needed for a logogen to fire varies depending on the top-down information. Thus, for the word, lion, all words related to lion will have a lower threshold and be identified more quickly (Parkin, 2000). Each logogen possessed in words is interconnected via such a semantic network so that activation of that word can lower the threshold of related words.

As mentioned earlier, one of the distinctive features of spreading activation models is that concepts are represented as nodes, and the semantic relationships between concepts as connections. Originally the idea of semantic network representation was developed for modeling human associative memory as a network that is associated with different many factors (Crestani and Lee, 1999). Since the idea of spreading activation is drawn from the cognitive processes of human associative memory, it could serve as a theoretical background for modeling human information searching process.

Recently this idea has been used as a Human Computer Interaction theory, in particular,
determining how it is applicable to designing web site navigation, content structures and web searching strategies. For example, Information Foraging Theory predicts the information gathering behavior of users in an information environment (Pirolli & Card, 1999). During information seeking, such as choosing hyperlinks on a web page, a user scans some of links and compares the proximal cues with information goals. Web User Flow by Information Scent (WUFIS), for example, is a predictive simulation technique based on a combination of information retrieval techniques and spreading activation.

Sharifian and Samani (1997) investigated the spreading activation model in a hierarchical memory network. They showed a significant difference in subject reaction time using pairs of words having hierarchical relations and found that reaction time for subjects to detect the relation between words that were ambiguous in a hierarchical structure was greater than between the words that had obvious hierarchical relations. This showed that activation to detect words spreads quickly when words are well organized hierarchically.
Action Cycle Model (A Display-Based Cognitive Model)

The Action Cycle Model shows how users perceive objects on a real display and the selection behavior using a cognitive process. Kitajima and Polson (1992) developed a cognitive model of display based, human computer interaction. They proposed that a display based HCI is analogous to text comprehension, as users need a large amount of knowledge to understand the meaning of texts. The model explains processes that focus on task-relevant information in the display and that stored in long term memory, and consists of four basic components:

1) goals which represent what the user wishes to achieve,
2) *a task environment* which is the world that reacts to the user’s actions and responds by altering the display,

3) *the stage of evaluation* which is the processes that evaluate and comprehend the display, and

4) *the stage of execution* which is the processes that select and execute actions that influence the world.

![Diagram of the Action Cycle Model](image)

*Figure 3. The Action Cycle Model (Kitajima and Polson, 1995)*

In particular, the evaluation stage includes *the display representations* and *the elaboration process*. After goal formation, only information about the identity of each object on the display
and visual status is involved in the display representation. That is, users notice objects on the
display, their appearance, shape, locations and so on. No information about meaning or
relationship is included. In elaboration, information about a given task and objects on the
display is generated by a random sampling process to retrieve information from long term
memory. Again, the retrieved information elaborates the display representations in terms of the
strengths of links between representations of objects, a given task, and information in long
term memory.

And the stage of execution includes the selection of candidates on the display and the selection
action. First based on the evaluation, object selection for the next action is performed by the
spreading activation mechanism. After the process of selecting objects, possible actions are
selected such as moving a mouse or pressing a keyboard.

**Estimation of Physical-motor Time (Fitts’ law)**

Researches related to human performance on computing systems have used many
traditional techniques and models from human factors. To understand and evaluate models or
systems, related theories have concentrated on user performance time. An example is Fitts’ law,
which predicts movement time:
MT = a + b \log_2 \left( \frac{A}{W} + c \right)

(1)

where MT is movement time, a and b are constants determined through linear regression, A is distance to a target, W is the width of a target, c is 0, 0.5 or 1, and the log term is called index of difficulty (ID). Based on values of c, two variations of the law were proposed by Welford (1968),

MT = a + b \log_2 \left( \frac{A}{W} + 0.5 \right)

(2)

and Mackenzie (1989).

MT = a + b \log_2 \left( \frac{A}{W} + 1 \right)

(3)

Equation (3) is known as the Shannon formulation.

Fitts’ law basically provides a one-dimensional model of human movement. However, it has been applied to two-dimensional target acquisition tasks, for example words or icons. Mackenzie and Buxton (1992) extended Fitts’ law to two-dimensional target acquisition task using Shannon formulation, which always yields a positive ID.
Visual Search Strategy

Determining search strategies is important in visual search tasks as they involve perceptual, cognitive, and motor processes. Hornof (2000) argued that aspects of visual search strategies could be determined by modeling cognitive processes in relatively simple tasks such as searching for an item in pull-down menu. Nilsen (1991) conducted menu selection experiments in a single physical dimension. He examined users’ search styles by using numerical digits (1 through 9) as visual targets and distractors to help to facilitate cognitive modeling of the visual search tasks. Hornof & Kieras (1997) developed the EPIC model that predicts users’ search strategies in menu tasks. According to EPIC, 1) users combine both random and systematic strategy for searching for menu items, 2) users consider more than one item at a time, and 3) a mouse does not move until visual search is completed. The ACT-R model by Anderson (1997) showed that 1) visual search strategy is motivated by the characteristics in menu items, 2) menu items are scanned item by item, and 3) a mouse moves with eye movements while searching for a target item.

Norman (1991) suggested three search models in menu selection: (a) serial inspection, (b) random inspection without repetition, or (c) random inspection with replacement (see Figure 4). Serial search requires that the user scan item by item without skipping. In random inspection without repetition, the user scans some items randomly but items already scanned.
Lastly, random inspection with replacement menu items is scanned repeatedly with random order.

![Diagram showing three models of visual search of menu selection: (a) Serial Inspection, (b) Random Without Repetition, (c) Random With Replacement.](image)

Figure 4. Three models of visual search of menu selection

**Number of Alternatives in a Menu**

Menu selection time to choose an item also depends on the number of alternatives. The number of menu items has been investigated in building efficient hierarchical menu structures. One approach to menu design is the trade-off between depth and breadth of menu structures. From experimental results menu designers have been advised to provide more breadth than
depth (Miller, 1981; Larson and Czerwinski, 1998; Zaphiris 2000, Kiger, 1984; Jacko & Slavendy 1996; Zaphiris 2000). Consequently, response time in terms of the number of items in each menu is also an important consideration. Human’ response time related to the number of alternatives was suggested by Hick (1952) and Hyman (1953):

\[ CT = a + b \log_2(n) \]  

(4)

where \( CT \) is choice time, \( a \) and \( b \) are constants, and \( n \) is the number of alternatives.

Lee and MacGregor (1985) also presented a general approach to predicting a menu selection time that depended on search strategies, either a self-terminating or exhaustive, within each menu:

\[ S = E(A)t + k + c \]  

(5)

where \( S \) is the search time, \( E(A) \) is the total number of items, \( t \) is the time required to read one item, \( k \) is key-press time and \( c \) is computer response time. They suggested that a menu-based retrieval system should be organized with about 4 to 8 items per page to minimize search time.
CHAPTER 3. MATERIALS AND METHODS

Experiment 1. Spreading Activation Test

Objective

This experiment investigated the relationship between a menu heading and its hold items by use of response times and accuracies. Some target items were selected for the actual performance experiment based on the results from this first experiment.

Subjects

25 students at Iowa State University, familiar with Microsoft Word, participated in this study voluntarily (Male: 20 and Female: 5).

Procedure

For this experiment 78 pairs of words that had parent-child relations organized in two levels of structure were prepared as Microsoft Word menus. These words were stored in a Microsoft Access table and shown to each subject in a random order. All actions were done using a mouse. Before starting an actual test, several practice tests were performed until subjects were familiar with this experiment. When the subject pressed a button, a word appeared in a textbox. After another button click, a word corresponding to the previous word appeared in a textbox. For example, Copy from the first button click and Edit from the second
button click. Once both words were shown, a subject responded either Yes or No in terms of the existing of a relationship between the two paired words.

The primary measure in this experiment was the response time taken until the subjects answered about the relationship between each pair. In other words, response time was the gap between the time when both words were presented and the time when subjects answered. During the experiment, subjects took breaks every 20 word pairs to prevent eye fatigue (20-20-20-18).

Experiment 2. Actual Selection with 2-level of a Pull-down Menu

Objective

In this experiment menu selection times in a two-level pull-down menu were measured as a function of not only the locations of target items but also the relatedness between menu headings and a target item. Two subtasks were considered: selecting menu headings and selecting a target item. Search time and mouse movement time have typically been considered as a single value. In this study we investigated menu selection time by separating recognition time and mouse pointing time from selection time in a pull-down menu. Especially since selecting a menu heading is strongly dependent on the recognition of relations between headings and targets, the separation provided the lengths of paths or the strength of link
between a target menu and a menu heading from human memory. This permitted us to examine roles of menu headings quantitatively during search performance and also observe users' search behavior when searching for a final target in the pull-down menu.

Subjects

Twenty-six students (18 male, 8 female) at Iowa State University voluntarily participated in this experiment. They ranged in age from 19 to 27 years (mean=22.48, SD=2.40). All subjects were native English speakers.

Experimental design

For this study a personal notebook (PentiumIV, CPU 1.7 GHz, 320MB of RAM) and a cordless mouse were used. Screen size and resolution were 15 inches and 1400 x 1050 pixels, respectively. The pull-down menu of the experimental platform, programmed in JAVA, was designed using the same structure as Microsoft Word. Menu headings were 5 mm high, 7 to 11 mm wide, and located 111 to 116 distant from the start button. Menu headings contained between 9 and 16 menu items (Figure 5).

Procedure

Twenty-nine target items were prepared using the results from the spreading activation test (Experiment 1) based on response times and locations in a menu (Table 1). Before the
experiment, subjects practiced until they were familiar with this experiment. All executions were carried out using mouse clicks.

Once a subject pressed the *start* button, a target item was randomly shown and then he or she had to select the target in a pull-down menu. All subjects were required to move the mouse only after they were sure which menu heading they would select. In other words, the mouse cursor had to stay on the *start* button while subjects were thinking about which menu heading to hit. Once they made a decision about which menu heading to select, they were required to move a mouse as quickly as they could. This provided us the ability to separate recognition times about text-information in the displayed menu and physical movement times from the menu heading selection time by preventing subjects from hovering among headings on the menu bar. We regarded the time mouse cursor's staying on the start button as subjects' cognition time to choose an appropriate heading for a given target, and the time between when a cursor exits and when it hits a heading as physical movement time, which can be explained by Fitts’ law (1954).

Based on a characteristic of pull-down menus, all sub items under each heading were shown (also see Figure 5). Subjects searched for a target item within them. If there was no target under the heading selected, subjects searched for the target again by selecting another heading, continuing until they found the target. The target selection was also divided into two
parts: visual search time and physical mouse movement. Visual search time was the duration time until the target was detected, which related saccades, the number of alternatives, and search strategies. Visual search time was measured as the gap between when a heading was selected and when a mouse cursor was moved out from the heading to select the target. Physical mouse movement was measured as an interval time from when a mouse cursor left a heading to when it hit the target item.

Figure 5. Experimental pull-down menu platform
Table 1. Target items for performance in an actual pull-down menu

<table>
<thead>
<tr>
<th>Visual area</th>
<th>Response time</th>
<th>Long</th>
<th>Short</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Borders and Shading(3), Print layout(3)</td>
<td>Close(3), Cut(3), Open(2)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>AutoText(4), Drop Cap(6), Paragraph(2), Toolbars(5)</td>
<td>Save As(5), Paste(5), Clear(2)</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Footnote(8), Frame(9), Merge Document(7), Theme(8)</td>
<td>Full Screen(9), Select All(7)</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Cross-reference(10), Envelopes and Labels (10), Letter Wizard(11),</td>
<td>AutoFormat(10), Pictures(11), Print Preview(10)</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Customize(14), Options(15)</td>
<td>Exit(14), Hyperlink(16), Object(14)</td>
</tr>
</tbody>
</table>

Visual area includes 3 items in a menu. ( ) indicates target locations within a menu.
CHAPTER 4. RESULTS

4.1 Results of Spreading Activation Test

Response times were compared in term of the subject’s gender. We applied a paired t-test and no significant differences were found in response times between male and female users. From the spreading activation test, we obtained mean response time, standard deviation and accuracies according to each pair (see APPENDIX B).

4.2 Menu Selection in Two level pull-down menus

There were two sub tasks in the experimental pull-down menu selection: menu heading selection and target selection.

4.2.1 Menu heading selection

Significant difference in the heading selection for the twenty-nine targets was observed using the analysis of variance ($F_{28, 725} = 6.73, p < 0.05$). The menu heading selection time was divided into two parts: cognition time and mouse pointing time. Cognition time was defined as a duration time until the subject determines which menu heading holds the target after a target item was given. Mouse pointing time was defined as the physical movement time used to select a menu heading to display a pull-down menu. By separating cognition time from each heading
and mouse pointing time from heading selection time, we could observe the effects of the two factors. However, since menu headings on the experimental platform had similar distances and target widths from the start button, mouse movement time did not much affect menu heading selection. The cognition time, on the other hand, was significantly related to heading selection ($r^2 = 0.985$, see Figure 6).

![Figure 6. Menu heading selection time corresponding to target items](image-url)
4.2.2 Target Item Selection in One level

Using the same method of heading selection, we also investigated search time and mouse pointing time in a one-level menu. Since menu items were vertically arranged within a single level, unlike the mouse movement time in heading selection, the Welford version of Fitts' law was applied to predict mouse movement time. Considering that a characteristic of pull-down menus is that all sub items are shown by clicking on menu headings and the pull-down menu in the experiment contained at most sixteen items. We assumed that,

- Initial eye position was located at the top of menu,
- Menu items were scanned from top to bottom,
- Three items were scanned at a time, and
- Mouse movement started when visual search was completed.

As the selection time was linear to target positions, a mathematical formulation based on the number of items scanned and target locations was developed:

\[
ST = 1085.23 + 272.04 \log_2(N) + 235.73 \log_2\left(\frac{A}{W} + 0.5\right) \quad \text{with} \quad r^2 = 0.83 \quad (6)
\]

where \(ST\) is selection time, \(N\) is the number of items, \(A\) is the distance to target, and \(W\) is the target width. The model explained the users' menu selection task well for the observed data in a
single level ($r^2 = 0.83$, see Figure 7).

![Figure 7. Target selection time in a single level](image)

As can be seen in Figure 7, in terms of a known target in a single level, the target selection time had a slightly linear relationship with target locations. This shows that, in terms of known targets, location is an important factor in determining menu selection such as found
in previous studies. For instance, Nilsen's task which used single numerical digits as the targets and distractors. Meanwhile, in the case of selecting menu headings, the cognition time to judge the relationship between menu headings and targets was considered to be an important factor for arriving at the targets accurately (Figure 6).

In addition, we measured menu selection time by considering both cognition time and target location. For this, we selected four targets located on the same position in each menu. Depending on the target locations, we were able to determine the performance time corresponding to each target (Figure 8). This shows that there was no significant difference in target selection times in the one-level experiment. However, as related information (menu headings) was added in a menu selection task, performance times were significantly different.

![Figure 8. Menu selection time under the same target location](image-url)
We found statistical significance \((F_{3,100}=3.617, p<0.05)\) for performance times and \((F_{3,100}=5.953, p<0.05)\) in cognition times among targets (Table 3). Furthermore, the difference among target selection time shows that the performance time to search for \textit{Print Preview}, \textit{AutoFormat}, \textit{Cross-reference}, and \textit{Envelopes and Labels} were significant. (Table 4).

Table 3. ANOVA table for performance time based on the same location

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>(F_0)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance time</td>
<td>1,754,129,880</td>
<td>3</td>
<td>584,709,960</td>
<td>3.617</td>
<td>0.016</td>
</tr>
<tr>
<td>Cognition time</td>
<td>88,309,300</td>
<td>3</td>
<td>29,436,433</td>
<td>5.953</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 4. Mean differences between menu selection times

<table>
<thead>
<tr>
<th>Target item(i)</th>
<th>Target item(j)</th>
<th>Mean Difference(i-j)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AutoFormat</td>
<td>Cross-reference</td>
<td>1624.23</td>
<td>0.646</td>
</tr>
<tr>
<td></td>
<td>Envelops and Labels</td>
<td>3438.73</td>
<td>0.332</td>
</tr>
<tr>
<td></td>
<td>Print Preview</td>
<td>10746.58*</td>
<td>0.000</td>
</tr>
<tr>
<td>Cross-reference</td>
<td>Envelops and Labels</td>
<td>1814.5</td>
<td>0.608</td>
</tr>
<tr>
<td></td>
<td>Print Preview</td>
<td>9122.34*</td>
<td>0.011</td>
</tr>
<tr>
<td>Envelops and Labels</td>
<td>Print Preview</td>
<td>7307.84*</td>
<td>0.041</td>
</tr>
</tbody>
</table>

* indicates that the mean difference is significant using Least Significant Difference (LSD)

4.2.3 Errors

Errors were classified into two qualitatively different types. The first mistake is when users failed to immediately discover the correct action. The others are slips which are made
when user fails to successfully execute the correct action despite having the correct intention.

In this experiment, errors from twenty-nine trials with twenty-six subjects in the two-level menu selection task were examined. Initially, we considered two kinds of errors: one that occurs when users click on a menu heading that does not possess the given target item and the other error that unintentionally occurs by selecting a different target from a given one. Since the latter error appeared only 2 of 754 trials, we only considered the former in this study. In the menu selection experiment, errors caused by choosing wrong menu headings were an element that determined performances. The errors were significantly correlated the cognition time ($r^2=0.74$) and target selection time ($r^2=0.852$) (Figure 9).

![Figure 9](image.png)

Figure 9. Scatter plots of cognition time, error rate and selection time corresponding to each target search
CHAPTER 5. DISCUSSION AND CONCLUSIONS

Discussion

In this study we used two levels in a pull-down menu to observe menu selection by adding related targets. These were menu headings for menu selection of identically equal targets (known targets) on a single level. To observe the selection of menu headings, the spreading activation model, showing the degree of relatedness between two words, was used.

First, in the selection of the target menu, as a target was identically equal to a given initial goal, the target selection times were determined by target locations and items scanned within a menu. Therefore, menu selection times for known targets were dependent on users' search strategies and target positions in a menu structure. We predicted target selection time by generating a mathematical equation based on Fitts' law and the number of menu item scanned (Equation 6). Since finding exactly equal menu items compared with a given goal was required for each subject, the subject tried to find target items immediately through visual scanning.

On the other hand, the selection of menu headings required a greater cognitive load based on subjects' judgment of the conceptual construct of information contained in the display. That is, the performance times to select the menu headings were strongly affected by the cognition time needed to determine the relatedness between a given goal and its candidates ($r^2=0.985$), a result explained by the spreading activation model. This cognition time showed a
linear relationship with errors. As cognition time increased, there were less errors in selecting a menu heading holding a given target. Meanwhile, in cases that the users took relatively long times to figure out the semantic relations between menu headings and targets, more errors occurred in selecting menu titles. This implies that the users had more nodes to retrieve information from long term memory, resulting in more extraction time and more errors. As a result, it caused a failure in finding a given target menu, yielding longer times in menu selection (see Figure 11). By comparing target selections located on the same position of each menu, it was found that target selection times were statistically different (Table 4). Hutchins, Hollan and Norman (1986) defined ‘semantic’ by how many processing structures are required for the user to determine if the goal has been obtained. Therefore, when a menu has more than one related-information to obtain a final goal, it is important to recall easily and quickly the relationships between subsequent levels more than the visual positions of targets.

Basically, spreading activation is a process that operates in semantic memory. Activation spreads depending on the semantic meaning that a word originally possesses. We found that although words themselves in the menu do not seem associated semantically, they showed a direct semantic interface. For example, in the case of searching for a target, Exit, a menu heading, File, should be selected to pull down the correct list. During this task, no subjects made errors and its cognition times were relatively faster than those of others. It is
well explained that when a task has frequently been done, it requires little or no conscious attention. Therefore the subjects did not need to build a new semantic structure since it had been used and seen often in certain environment, the Microsoft menu system. In other cases, those that produced many errors and long cognition times required that each subject build semantic structures to determine the relationships between two texts. These results were observed in both the spreading activation test and the actual test.

As discussed earlier, errors were significantly related with the performance time. Table 6 shows the number of errors and menu headings chosen in the actual menu selection experiment corresponding to each target. This suggests that to improve menu usability, some items should be located under different menu headings, for example, 20 of 26 subjects chose *File* to search for *Print Layout*, 14 subjects chose *Format* for *AutoText* and *Customize* respectively.

<table>
<thead>
<tr>
<th>Target</th>
<th>Error rate</th>
<th>Number of errors</th>
<th>Menu headings selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-reference</td>
<td>0.769</td>
<td>20</td>
<td>0 2 0 0 5 13</td>
</tr>
<tr>
<td>Frame</td>
<td>0.769</td>
<td>20</td>
<td>0 2 9 8 0 1</td>
</tr>
<tr>
<td>AutoText</td>
<td>0.808</td>
<td>21</td>
<td>0 0 0 1 14 6</td>
</tr>
<tr>
<td>Customize</td>
<td>0.808</td>
<td>21</td>
<td>1 3 0 3 14 0</td>
</tr>
<tr>
<td>Merge Document</td>
<td>0.808</td>
<td>21</td>
<td>3 10 2 0 6 0</td>
</tr>
<tr>
<td>Print layout</td>
<td>0.846</td>
<td>22</td>
<td>20 1 0 0 1 0</td>
</tr>
</tbody>
</table>
We cannot guarantee that a short time in selecting related information always brings correct answers and a relatively long time does not. This is because in menu selection tasks the users determine the relations, along with those that might interrupt the relationship, if they do not find such a strong semantic connection. Through experiments in this study, however, we observed that a long time in cognition brought high probabilities of errors in the selection of menu headings.

Finally, we compared the results from the spreading activation test with those from the actual pull down menu (Table 7), demonstrating a correlation. In particular, focusing on the selection time in the actual menu, error rates were strongly correlated with total selection time \(r^2=0.852\). We found that when many errors occurred in the selection of a correct menu heading corresponding to a given target, the users spent a long time to find the target menu.

<table>
<thead>
<tr>
<th></th>
<th>Response time (SAT)</th>
<th>Inaccuracy (SAT)</th>
<th>Cognition time</th>
<th>Error rate</th>
<th>Menu selection time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response time (SAT)</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Inaccuracy (SAT)</td>
<td>0.679</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cognition time</td>
<td>0.772</td>
<td>0.713</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Error rate</td>
<td>0.736</td>
<td>0.657</td>
<td>0.740</td>
<td>1.000</td>
<td>-</td>
</tr>
<tr>
<td>Menu selection time</td>
<td>0.672</td>
<td>0.637</td>
<td>0.751</td>
<td>0.852</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Considering two components, responses time and inaccuracies in SAT (Spreading
Activation Test), the error rates in the actual menu selection task were more highly correlated with response times ($r^2=0.736$) than inaccuracies ($r^2=0.657$). This is because only a menu heading corresponding to a target was considered in the spreading activation test. In spite of this constraint in SAT, a long response time represented a long semantic distance between two texts, causing errors in menu heading selection. We can then predict user performance in an actual menu structure by using response time for each pair in the spreading activation test.

Conclusions

This study dealt with the fundamental principles in building a hierarchical menu by evaluating the psychological processes of the user, in particular, focusing on investigating how the relatedness between menu headings and task goals affects menu selection. The cognition time showing semantic distances between menu headings and target menus had strong relationships with error and performance time in menu selection.

In general, there are two basic ways to reduce the semantic distance. One is from the designer’s side and the other is from the users’ side. To reduce the semantic distance users need to be familiar with a menu system or menu designers should consider carefully how to develop interface languages to make it easier for users to reduce semantic distances between the designers’ intention and the users’ expectations. Through frequent exposure to a system, they
build a new mental structure of it. Although basic meanings may be used differently in some information systems, sometimes it would be advantageous to develop a better interface by reducing semantic distance. This was represented by the relatively fast response times and cognition times in both the spreading activation test and the performance test with a real menu.

In conclusion, the goal in system interface design is to minimize cognitive effort. The better the system interfaces, the less cognitive effort is needed. For user centered system design, reducing the semantic distance of objects should be an emphasis. This implies that menu designers should consider how to develop text information for the user to easily create a semantic structure between the design intention and user expectations in menus. Finally, this study demonstrates the value of a semantic approach to the use of text in building menu structures. We provide a methodology to evaluate usability of menu structures and to ultimately design user-centered and comprehension-based menu structures. Even though menu designers may use common sense for organizing menus, their intentions often do not match with real user expectations. The spreading activation approach could serve as one cognitive method to observe which menu item has ambiguity problems and predict the performance of menu selection in real menus.
REFERENCES


Hyman, R. (1953). Stimulus information as a determinant of reaction time. *Journal of
Experimental Psychology, 45, 188-199.


APPENDIX A. INFORMED CONSENT DOCUMENT

Title of Study: Study of Menu Selection based on Human Information Processing: Spreading Activation Approach
Investigators: JongMyong Choi (cim7331@iastate.edu) and Dr. Patrick E. Patterson (ppatters@iastate.edu)

This is a research study. Please take your time and attention in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION
The objective of this study is to evaluate the usability of an existing menu structure using spreading activation model corresponding to human cognitive process. You are encouraged to participate in this study for the purpose of a user-centered menu design.

DESCRIPTION OF PROCEDURES
With your agreement to participate in this study, you will have a pair of words used in Microsoft Word. Once you see the pair, you will be asked if the pair is semantically associated with each other. The pairs will be shown by an experimental platform and your reaction time will be calculated by it.

RISKS
While participating in this study, there is no foreseeable risks you may experience from participating in this study.

BENEFITS
If you make a decision to join in this study there may be no direct benefit to you. Some information from your participation of this study will provide users’ mental process in menu selection and contribute to a basis of menu design corresponding to human cognition.

PARTICIPANT RIGHTS
You are encouraged to participate in this study voluntarily and you may refuse to participate or leave the study at any time.

RESEARCH INJURY
Emergency treatment of any injuries that may occur as a direct result of participation in this research is available at the Iowa State University Thomas B. Thielen Student Health Center, and/or referred to
Mary Greeley Medical Center or another physician or medical facility at the location of the research activity. Compensation for any injuries will be paid if it is determined under the Iowa Tort Claims Act, Chapter 669 Iowa Code. Claims for compensation should be submitted on approved forms to the State Appeals Board and are available from the Iowa State University Office of Risk Management and Insurance.

CONFIDENTIALITY
Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, the following measures will be taken. Subjects will be assigned a unique code and letter and will be used on forms instead of their name. If the results are published, your identity will remain confidential.

QUESTIONS OR PROBLEMS
You are encouraged to ask questions at any time during this study. For further information about the study contact JongMyong Choi (cjm7331@iastate.edu, 515-296-0006) or Dr. Patrick E. Patterson (ppatters@iastate.edu, 515-294-8661). If you have any questions about the rights of research subjects or research-related injury, please contact Ginny Austin, IRB Administrator, (515) 294-4566, austingr@iastate.edu, or Diane Ament, Research Compliance Officer (515) 294-3115, dament@iastate.edu.

SUBJECT SIGNATURE
Your signature indicates that you voluntarily agree to participate in this research, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the signed and dated written informed consent prior to your participation in the study.

Subject’s Name (printed) ____________________________________________

(Subject’s Signature) (Date)
INVESTIGATOR STATEMENT
I certify that the participant has been given adequate time to read and learn about the study and all of their questions have been answered. It is my opinion that the participant understands the purpose, the risks, benefits and the procedures that will be followed in this study and has voluntarily agreed to participate.

__________________________________________  _____________________________
(Signature of Person Obtaining Informed Consent) (Date)
## APPENDIX B. MEAN RESPONSE TIME (RT), STANDARD DEVIATION (SD) AND ACCURACIES IN SPREADING ACTIVATION TEST

( ms : millisecond )

<table>
<thead>
<tr>
<th>Menu heading</th>
<th>Menu item</th>
<th>RT (ms)</th>
<th>SD (ms)</th>
<th>Accuracy</th>
<th>Menu heading</th>
<th>RT (ms)</th>
<th>SD (ms)</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>File</td>
<td>Save</td>
<td>1362</td>
<td>654</td>
<td>0.96</td>
<td>Insert</td>
<td>2045</td>
<td>944</td>
<td>0.84</td>
</tr>
<tr>
<td>File</td>
<td>Exit</td>
<td>1623</td>
<td>573</td>
<td>0.92</td>
<td>Insert</td>
<td>2345</td>
<td>1460</td>
<td>0.84</td>
</tr>
<tr>
<td>File</td>
<td>Open</td>
<td>1651</td>
<td>666</td>
<td>1.00</td>
<td>View</td>
<td>2402</td>
<td>1185</td>
<td>0.76</td>
</tr>
<tr>
<td>File</td>
<td>Save As</td>
<td>1662</td>
<td>1869</td>
<td>1.00</td>
<td>Format</td>
<td>2417</td>
<td>1404</td>
<td>0.96</td>
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<tr>
<td>File</td>
<td>Close</td>
<td>1664</td>
<td>1001</td>
<td>0.96</td>
<td>View</td>
<td>2423</td>
<td>1185</td>
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<tr>
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<td>Paste</td>
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<td>1418</td>
<td>1.00</td>
<td>File</td>
<td>2296</td>
<td>1319</td>
<td>0.88</td>
</tr>
<tr>
<td>File</td>
<td>Print</td>
<td>1822</td>
<td>1043</td>
<td>0.92</td>
<td>Format</td>
<td>2433</td>
<td>2120</td>
<td>0.92</td>
</tr>
<tr>
<td>File</td>
<td>New</td>
<td>1841</td>
<td>1376</td>
<td>0.96</td>
<td>Format</td>
<td>2444</td>
<td>1637</td>
<td>0.92</td>
</tr>
<tr>
<td>Edit</td>
<td>Cut</td>
<td>1947</td>
<td>1404</td>
<td>1.00</td>
<td>Insert</td>
<td>2591</td>
<td>1669</td>
<td>0.84</td>
</tr>
<tr>
<td>View</td>
<td>Full Screen</td>
<td>1957</td>
<td>1207</td>
<td>1.00</td>
<td>View</td>
<td>2598</td>
<td>2224</td>
<td>0.60</td>
</tr>
<tr>
<td>Insert</td>
<td>Pictures</td>
<td>1959</td>
<td>1383</td>
<td>0.92</td>
<td>Insert</td>
<td>2634</td>
<td>2730</td>
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<tr>
<td>Edit</td>
<td>Replace</td>
<td>1986</td>
<td>1092</td>
<td>0.88</td>
<td>View</td>
<td>2641</td>
<td>1787</td>
<td>0.88</td>
</tr>
<tr>
<td>Insert</td>
<td>Page Numbers</td>
<td>2344</td>
<td>1500</td>
<td>0.84</td>
<td>Format</td>
<td>2668</td>
<td>2074</td>
<td>0.64</td>
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<td>TextBox</td>
<td>2074</td>
<td>1186</td>
<td>0.84</td>
<td>Insert</td>
<td>2695</td>
<td>1527</td>
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<td>Edit</td>
<td>Copy</td>
<td>2189</td>
<td>1609</td>
<td>0.96</td>
<td>Tools</td>
<td>2710</td>
<td>1555</td>
<td>0.72</td>
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<tr>
<td>File</td>
<td>Print Preview</td>
<td>2239</td>
<td>1380</td>
<td>0.68</td>
<td>Insert</td>
<td>2723</td>
<td>1784</td>
<td>0.68</td>
</tr>
<tr>
<td>Insert</td>
<td>Date and Time</td>
<td>2268</td>
<td>1003</td>
<td>0.84</td>
<td>Edit</td>
<td>2758</td>
<td>1790</td>
<td>0.96</td>
</tr>
<tr>
<td>Tools</td>
<td>Spelling and Grammar</td>
<td>2274</td>
<td>1134</td>
<td>0.88</td>
<td>Tools</td>
<td>2762</td>
<td>1504</td>
<td>0.72</td>
</tr>
<tr>
<td>Edit</td>
<td>Select All</td>
<td>2270</td>
<td>1278</td>
<td>0.92</td>
<td>Edit</td>
<td>2792</td>
<td>1940</td>
<td>0.44</td>
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<tr>
<td>Tools</td>
<td>Word Count</td>
<td>2428</td>
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<td>Format</td>
<td>2800</td>
<td>2325</td>
<td>0.60</td>
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<tr>
<td>Tools</td>
<td>Options</td>
<td>3061</td>
<td>1905</td>
<td>0.84</td>
<td>Tools</td>
<td>2903</td>
<td>2208</td>
<td>0.88</td>
</tr>
</tbody>
</table>
Assuming that the experimental response times are independently distributed in the normal distribution, there was no significant difference between male and female with pair t-test ($t$ value < $t_{0.05}(77)=1.99$).
APPENDIX C. MEAN COGNITION TIME AND TARGET SELECTION TIME WITH 29 TARGETS IN TWO-LEVEL OF PULL DOWN MENU

( ms : millisecond )

<table>
<thead>
<tr>
<th>Target menu</th>
<th>Cognition time(ms)</th>
<th>Menu selection time(ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AutoFormat</td>
<td>3172</td>
<td>16051</td>
</tr>
<tr>
<td>AutoText</td>
<td>3263</td>
<td>20461</td>
</tr>
<tr>
<td>Borders and Shading</td>
<td>3661</td>
<td>8561</td>
</tr>
<tr>
<td>Clear</td>
<td>2401</td>
<td>7426</td>
</tr>
<tr>
<td>Close</td>
<td>1681</td>
<td>5823</td>
</tr>
<tr>
<td>Cross-reference</td>
<td>4357</td>
<td>14427</td>
</tr>
<tr>
<td>Customize</td>
<td>4234</td>
<td>12852</td>
</tr>
<tr>
<td>Cut</td>
<td>1717</td>
<td>3804</td>
</tr>
<tr>
<td>Drop Cap</td>
<td>3997</td>
<td>13077</td>
</tr>
<tr>
<td>Envelops and Labels</td>
<td>3252</td>
<td>12612</td>
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<td>Exit</td>
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<td>4262</td>
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<td>9581</td>
</tr>
<tr>
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<td>12762</td>
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<td>1974</td>
<td>9259</td>
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</tr>
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<tr>
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<td>Options</td>
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<td>Paragraph</td>
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</tr>
<tr>
<td>Paste</td>
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<td>3884</td>
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<tr>
<td>Pictures</td>
<td>1787</td>
<td>6095</td>
</tr>
<tr>
<td>Print Layout</td>
<td>1996</td>
<td>13398</td>
</tr>
<tr>
<td>Print Preview</td>
<td>1760</td>
<td>5304</td>
</tr>
<tr>
<td>Save As</td>
<td>1121</td>
<td>3386</td>
</tr>
<tr>
<td>Select All</td>
<td>1600</td>
<td>8228</td>
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<tr>
<td>Theme</td>
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<td>11540</td>
</tr>
<tr>
<td>Toolbars</td>
<td>3385</td>
<td>12493</td>
</tr>
</tbody>
</table>
Assuming that both cognition times and target selection time are independently distributed in the normal distribution, using paired t-test, there was no significant difference between male and female in menu selection time ($t=2.65 < t_{0.01}(28)$) and in cognition time ($t=1.34 < t_{0.01}(28)$).
ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Patrick E. Patterson for his advice, support, and encouragement during my graduate study. I also express my gratitude to my committee members, Dr. Adrian Sannier and Dr. Judy M. Vance for their suggestions in my research.

Especially, my deep gratitude goes to my wife, Insuk Lee for her endless love and support, and my son, Bryan Choi, who always encourages me with his smile throughout the years. I would like to express my sincere appreciation to my family.