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Abstract

Web search engines have become a useful tool helping Web users seek required information. Such Web sites typically present searched results as a textual list that may include thousands of Web pages. Because of the unstructured content and format of information that searchers receive, they often feel the pressure of information overload, which will inevitably compromise the quality of decision-making. Although researchers as well as practitioners have developed various information visualization approaches to enhance information presentation on Web search engines, the benefits of using such technology are unknown. This study will investigate whether and under what circumstances visualization of search results enhances users' search performance. Cognitive fit theory will be used as the theoretical foundation of this paper. The objectives of the paper are 1) to extent cognitive fit theory in the emergent domain of Web searching, 2) to understand the effects of the user interface on search performance, and 3) to guide search engine designers on how to best present results to support different search tasks.

Keywords: Web search engines, information formats, cognitive fit theory, fact-finding search, exploratory search, visualization, clustering-based format, information overload

Introduction

As the World Wide Web has become increasingly popular, search engines are an important tool for Web users. According to a report on search engine usage from the Pew Internet & American Life Project (2005), 84% of adult Internet users, about 108 million Americans, have used search engines to help them find information on the Web. On an average day, over half of the Internet users in the U.S. use search engines, making online search the second most popular activity on the Internet, after emailing. A unique characteristic of online searching is that search engines may return hundreds, if not thousands, of results, and the searchers have to decide which results are useful based on the information presented on the engine's Web site. As a consequence, Web interface design plays a significant role in affecting Web users' online searching performance and their satisfaction with the Web site. Specifically, information format, which refers to how information is presented and organized (Hong et al. 2004), has been identified by information systems (IS) researchers as a critical determinant of users' online searching behavior (Chung et al. 2005; Hearst 2002; Hong et al. 2004; Roussinov and Chen 2001; Turetken and Sharda 2004; Turetken and Sharda 2005).

Web search engines typically present results in a textual list sorted by a relevance score for each document. Given a generally defined query, the resulting list may contain thousands of documents and span over one hundred pages. Previous studies have reported that search engine users are not likely to go beyond the top 20 to 30 links on the list before they get bored or frustrated, and finally leave the site due to information overload (Kuo et al. 2004; Turetken and Sharda 2005). Users are simply exposed to more information than they have the cognitive ability to process. The

overload problem poses challenges for effective knowledge discovery on the Web. On the one hand, information quality on the Web is significantly reduced; on the other hand, users have to spend enormous time and effort on filtering irrelevant information in order to get only what they need, increasing the likelihood of omitting important information. As a result, there is a need for research to enhance the presentation of search results so that the information overload problem can be alleviated.

To ameliorate information overload, researchers have proposed the use of information visualization to present search results as an alternative to the usual textual presentation (Chung et al. 2005; Fox et al. 2006; Turetken and Sharda 2004; White et al. 2006). Information visualization is referred to as the use of interactive visual representations of abstract data to amplify cognition (Shneiderman and Plaisant 2004). It can take several formats of display, such as hierarchical displays, network displays, scatter displays, and map displays (Lin 1997). Researchers have suggested that, because visualization of search results is able to show a "big picture" of the resulted items, it can support effective information exploration (White et al. 2006).

However, despite the enthusiasm of both researchers and practitioners for the use of visualization in assisting online search, the effects of implementing this technology remain unknown. Shneiderman and Plaisant (2004) found that many users resisted visual approaches and were satisfied with potent textual approaches, since textual designs "use compact presentations that are rich with meaningful information and comfortingly familiar." Scaife and Rogers (1996) called for a more systematic approach to evaluating the merits of different kinds of graphical representations. They suggested the desired approach should account for the cognitive processing people engage in when interacting with them. More importantly, it remains to be determined whether the effects of visualization on online searching behavior differ among searchers engaged in different search tasks. Task types have been identified as an important factor affecting the quality of information representation (Tan and Benbasat 1990). Nonetheless, research examining the effects of visualizing search results seldom include the type of search tasks used (Chung et al. 2005; Turetken and Sharda 2005). As a result, it is imperative for empirical studies that can help to determine which kinds of search tasks would benefit the most from a visualization presentation of results.

This study is conducted to further our understanding of whether and under what circumstances the visualization of search results enhances users' search performance. Using cognitive fit theory as its theoretical foundation, we propose a research model to explain how the fit between information formats and search tasks may influence users' online searching performance. Specifically, we investigate how the fit between two information formats (textual ranked-list versus visualization) and two search tasks (fact-finding versus exploratory) can influence users' information search time, quality of searching, and satisfaction with search engines.

This paper contributes to the knowledge of researchers as well as practitioners in the following ways. First, it extends cognitive fit theory to the Web search domain in order to help us understand the effect of information format on users' online searching behavior. Second, it would enrich our understanding of how information visualization influences searching performance by taking into account the nature of the task. Third, the findings would have implications for designers of search engine Web sites and how to best present search results to facilitate different search tasks.

The paper is organized as follows. The next section lays the theoretical foundation for the research, including a description of cognitive fit theory, information presentation formats, and type of search tasks; the cognitive search strategies are identified to support the fit between information formats and type of tasks. Then the paper proposes the research model and research hypotheses, followed by a description of the research method.

Theoretical Foundation

Cognitive Fit Theory

Cognitive fit theory (CFT) was developed to explain how graphical displays affect the decision processes and outcomes of decision making (Vessey 1991). According to CFT, different information formats, such as tables and graphics, emphasize different types of information and problem-solving processes. Similarly, different problem-solving tasks, such as trend detection and data value retrieval, also emphasize different types of information and problem-solving processes. CFT argues that when both the information format and the task emphasize the same types of information and processes, cognitive fit occurs, which produces a consistent mental representation for problem solving, and subsequently leads to faster and more accurate performance in decision-making. However,

when there is a mismatch between the information format and the task, cognitive fit does not take place. Problem solvers will need to transform some of the mental representation, expending additional effort and resulting in relatively lower performance than when there is a cognitive fit (Hong et al. 2004; Vessey 1991). Therefore, for the most effective and efficient problem solving to occur, the problem format should support the cognitive processes required to perform that task (Vessey 1991). Figure 1 illustrates the relations among the CFT elements.

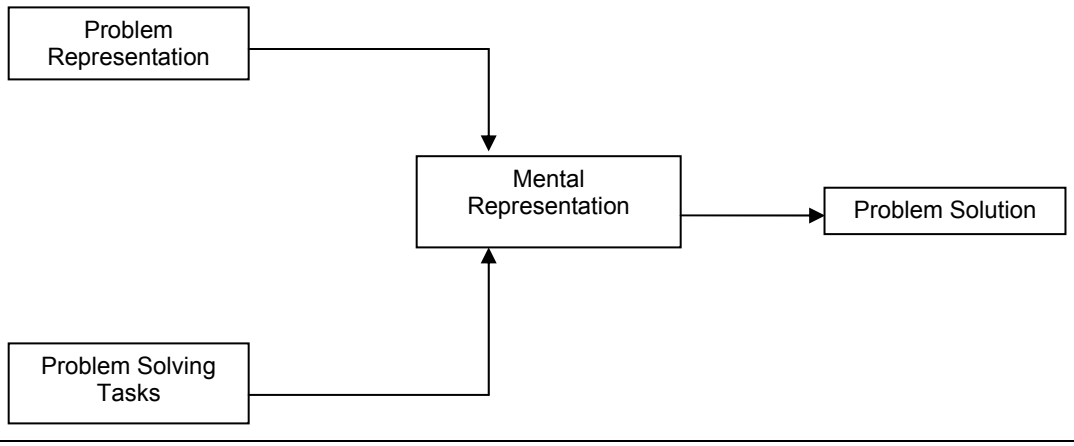

Figure 1. Model of Cognitive Fit Theory

CFT has been empirically validated in a variety of problem domains, such as online shopping (Hong et al. 2004), virtual reality (Suh and Lee 2005), and geographical information systems (Dennis and Carte 1998). These studies suggest that the cognitive fit perspective may provide a useful theoretical framework for understanding the relationship between information formats on Web search engines and users' search performance.

Information Format Used by Search Engines

Information format is the presentation and organization of information about the available alternatives and their attributes (Hong et al. 2004). On search engine Web sites, there are two popular formats to organize search results. The first format (such as Google, Yahoo!, and AltaVista) is to display one result in each row after the results have been ranked by their relevance to the search key words. In addition, because such a format displays each result in text form, we call this the textual ranked-list format. Figure 2 contains a screen shot of Google's search result list, which uses the textual ranked-list format. The second format (e.g. Grokker.com, Kartoo.com) displays a two-dimension picture showing the relationships among the returned Web pages based on their contents, which we refer to as the clustering-based visualization format. Figure 3 shows an example of search results using this format.

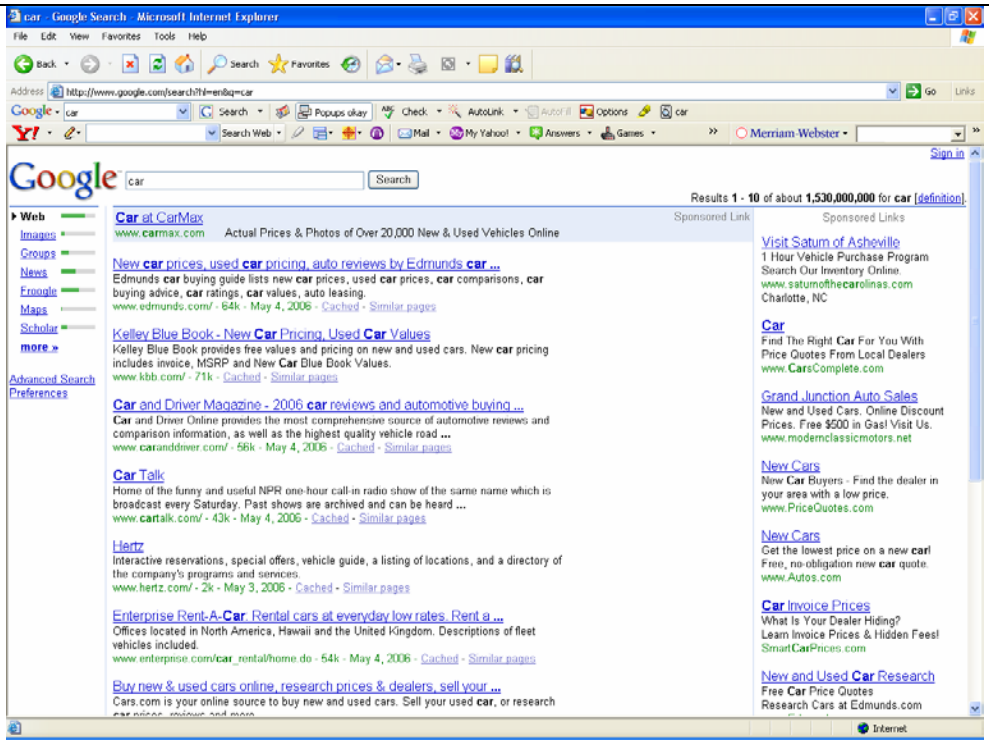

Figure 2. Example of the Textual Ranked-List Format (www.google.com Keyword: Car)

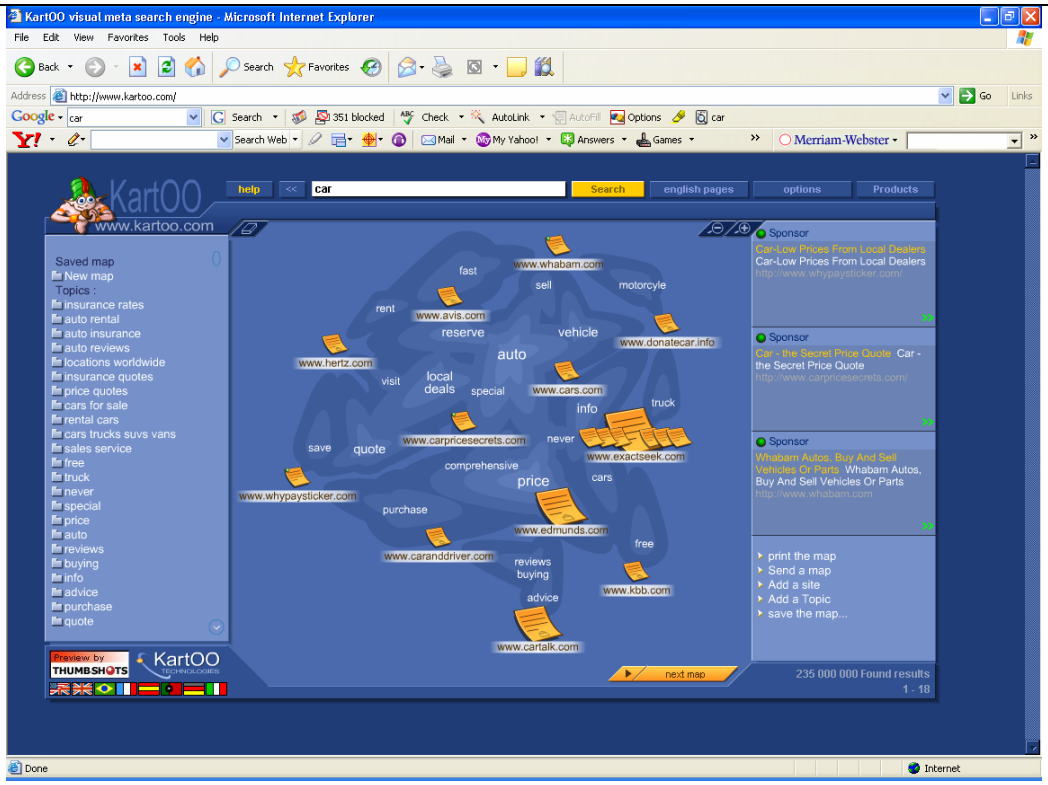

Figure 3. Example of the Clustering-Based Visualization Format (www.kartoo.com Keyword: Car)

CFT classifies information presentation formats as symbolic or spatial, a distinction that is useful for comparing the two formats used on search engine Web sites. Symbolic formats (e.g. tables) present information that is symbolic and emphasize information on discrete data values. Because the textual ranked-list formats of search engines indicate only the discrete search results without showing the relationships among them, they are considered in this paper a symbolic presentation. According to CFT the symbolic presentation format facilitates extracting and acting on discrete result values.

Spatial formats (e.g. graphics), on the other hand, explicitly preserve information about the topological and geometric relations among the components of the problem. Spatial formats emphasize relationships in data. The clustering-based visualization format organizes target Web sites (represented by icons) into clusters. Web sites included in one cluster are related to the same topic. The distance between two clusters represents the relevance of the two topics. Unlike a textual ranked-list format, a clustering-based visualization format allows online searchers to examine search results by their categories and help to understand the relationship between the categories. Because the clustering-based visualization format emphasizes the relationships among search results, it is considered a type of spatial presentation format.

Type of Search Tasks

Internet users who conduct online search are driven by information needs. Some searchers have specific questions to resolve (e.g. How tall is the average female giraffe?), whereas other searchers only have a general idea of what they are looking for (e.g. "I want to know something about Baroque."). Many researchers have attempted to classify search tasks based on searchers' information needs (Broder 2002; Hearst et al. 2002; Marchionini 2006; Rose and Levinson 2004; Sheiderman and Plaisant 2004; Vandenbosch and Higgins 1996). For example, Vandenbosch and Higgins (1996) identified two fundamental types of information acquisition tasks: focused search and scanning search. In focused search, people are looking for specific information to solve particular problems, while scanning search occurs when people browse through information in order to increase their understanding of a topic with no particular problem to solve or question to answer.

Hearst et al. (2002) identified three types of search tasks as lying along a conceptual continuum: directed search, informal browsing, and text mining. In their classification, a directed search consists of well-defined questions to which a short phrase can be an acceptable response. An informal browsing task is usually driven by an open-ended question where searchers are looking for a collection of answers relating to a topic of interest. For example, "What are some good design ideas for landscaping my yard?" A text mining task is also known as a knowledge discovery task. It requires a searchers' ability to track trials of reasoning, process information cues, and evaluate the findings. Compared with directed search task, the other two types of tasks identified by Hearst et al. have higher-level information needs that are beyond simple "question answering" and tend to be more exploratory in nature. These high-level tasks require searchers to spend time scanning, comparing, and making qualitative judgments. Similarly, Marchionini (2006) described the differences between lookup search and exploratory search. He argued that lookup search is based on a need for fact retrieval and exploratory search is based on knowledge acquisition and accretion. In summary, researchers have recognized that the kinds of search tasks can be defined according to different layers of information needs. Building on previous research, we identify two major types of Web search tasks: fact-finding and exploratory.

Fact-finding search is the most basic kind of search and has been the focus of development for database management systems and much of what Web search engines support (Marchionini 2006). The objective of this search type is simply to require factual results. In fact-finding search tasks, searchers' intentions are well defined (e.g. "How tall is the average female giraffe?"). In addition, the users should be able to find the results by entering a list of keywords ("giraffe, female, height") or a natural language question ("What is the height of the average female giraffe?") (Hearst et al. 2002). Finally, the results returned to this type of tasks are usually discrete and specific results ("4.4 meters"), such as numbers, names, short statements, or specific files of text.

Exploratory search tasks, on the other hand, are often motivated by complex problems or a poor understanding of terminology and information space structure. When undertaking such tasks, searchers may lack the knowledge or contextual awareness to formulate definite query terms. Consequently, they submit a tentative query and try to make sense through exploring the retrieved information, selectively seeking and passively obtaining cues in order to decide where the next steps lie (White et al. 2006).

In short, fact-finding search tasks are characterized by well-defined intentions, articulated search queries, and directed outcomes, whereas exploratory search tasks are characterized by non-specific information needs, iterative query steps, and uncertain outcomes.

Cognitive Search Strategies and Fit between Information Formats and Search Tasks

Although cognitive fit theory suggests that the result presentation format should match searchers' Web search tasks in order to ensure better performance and a more positive searching experience, it does not explicitly show which information format will fit best with which search task. This section sheds light on the relationship between task types and information formats. Specifically, the cognitive search strategies that fact-finding searchers and exploratory searchers use can provide us with useful insights on sorting out the fit.

Researchers of human-computer interaction have found that the searchers engaged in different kind of search tasks employ different search strategies and tactics (Fox et al. 2006; Hearst 2002; Marchionini 2006; Resnick and Vaughan 2006). Navarro-Prieto et al. (1999) conducted a study analyzing the dependencies between search tasks and cognitive search strategies. They used two types of search tasks: fact-finding and exploration-oriented, and two search strategies: bottom-up and top-down. They found that fact-finding searchers tend to employ bottom-up search strategies in which they use specific keywords, look into the results, and then go back until they find the desired information. Most exploration-oriented searchers, on the other hand, use top-down strategies in which they search in a general area and then narrow down their search.

Because bottom-up search strategies focus on specific search results, the cognitive process required by this strategy is analytical and emphasizes precision (Dennis and Carte 1998; Vessey 1991). As Marchionini (2006) pointed out, lookup (fact-finding) search tasks are suited to analytical strategies that begin with carefully specified queries and yield precise results with minimal need for result set examination and item comparison. In contrast, top-down search strategies emphasize viewing search results in general areas and discovering relations among the different areas. Therefore, perceptual processes that underscore the visual assessments of elements' relative magnitudes are appropriate.

Previous research has shown that information presentation format is the primary factor influencing the decision process (Dennis and Carte 1998; Vessey and Galletta 1991). According to cognitive fit theory, symbolic presentation formats, including textual ranked-list, emphasizes analytical processes; spatial presentation formats, including clustering-based visualization formats, entail perceptual processes. Because fact-finding task and textual ranked-list format both require analytical processes, a consistent mental representation (cognitive fit) will be formed when the textual ranked-list format is used by fact-finding searchers. Similarly, because spatial presentation formats, including clustering-based visualization and exploratory tasks both emphasize perceptual process, using clustering-based visualization for search results presentation will result in a cognitive fit. Table 1 shows the cognitive fits that resulted from matching information presentation formats and task types. The presence of cognitive fit will lead to better task performance, such as the time taken to finish the task and the accuracy of task results (Vessey and Galletta 1991).

Table 1. Fit between Information Formats and Search Tasks

	Fact-Finding Search Tasks	Exploratory Search Tasks
Textual Ranked-List	Fit	No Fit
Visualization Clustering-Based	No Fit	Fit

Research Model and Hypotheses

The research model is shown in Figure 4.

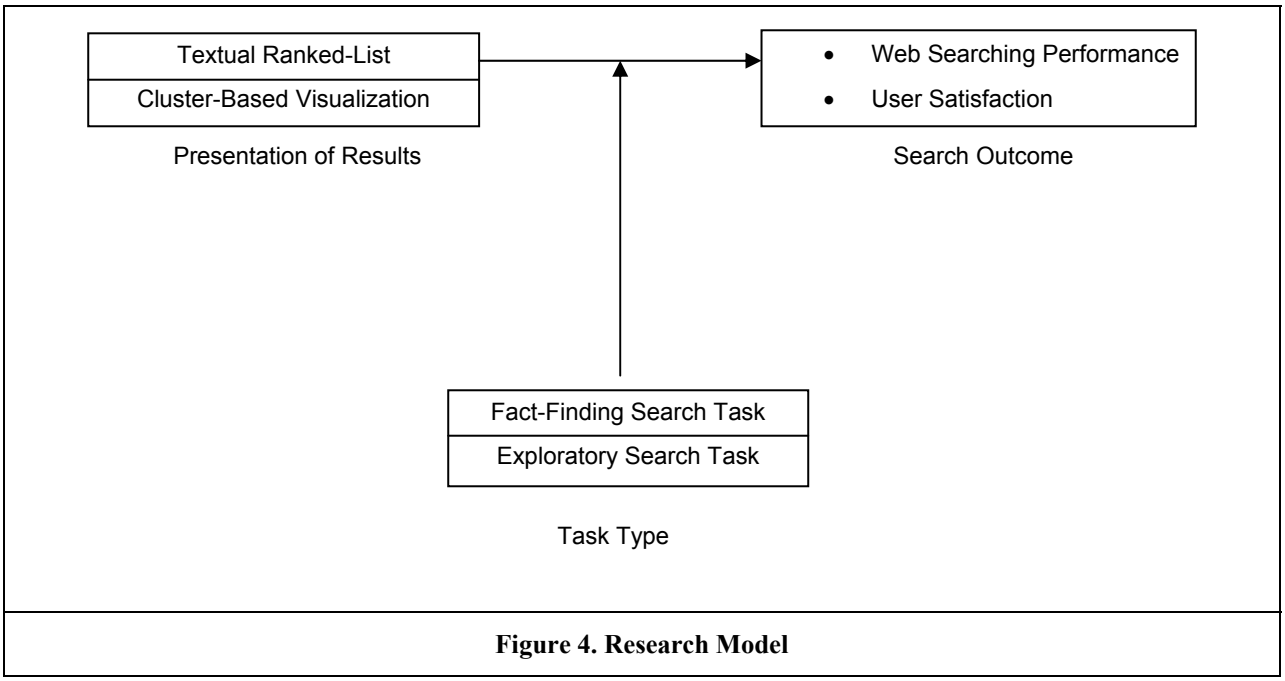

Figure 4. Research Model

Web-Searching Performance

Time is often used as an indicator of performance in decision-making tasks involving different information formats (e.g. Hong et al. 2004, Tureken and Sharda 2005). Taking less time to complete a Web search task indicates more efficient searching and better presentation of search results. In this study we select time as a performance measure of information search efficiency, and define it as the time it takes searchers to perform the fact-finding or exploratory search task on the Web.

Accuracy is another dependent variable that is frequently used in IS research to indicate the effectiveness of information technologies (Chung et al. 2005; Kuo et al. 2004; Tureken and Sharda 2005). We use accuracy as a measure of search quality, and it can be defined as the number of relevant documents resulting from a search.

Our earlier analysis identifies an interaction effect between the information format and the search task on performance measures. When there is a match between the two, searchers will perform better in terms of their decision-making outcomes. This is because effort spent on fine-tuning any mismatch in mental representation can be minimized. Specifically, we expect that textual format (which emphasizes detailed values) matches the fact-finding task, and the visualization format (which emphasizes relationship among concepts) matches exploratory search task. When the matches occur, the searchers' information search time will be reduced and the accuracy of search results will be increased. Therefore, we propose the following hypotheses:

H1a: For fact-finding tasks, the use of textual format will result in shorter search time than the use of visualization format.

H1b: For exploratory tasks, the use of visualization format will result in shorter search time than the use of textual format.

H2a: For fact-finding tasks, the use of textual format will result in higher levels of accuracy than the use of visualization format.

H2b: For exploratory tasks, the use of visualization format will result in higher levels of accuracy than the use of textual format.

User Satisfaction

The searchers' satisfaction with their searching experience is another variable of interest.

It is possible that searchers' high-quality performance for a certain task may be caused by the large amount of effort they spend. Hence, although the searchers are able to perform well, they may not like the search engine Web site and decide not to use it anymore due to the extra effort they have to make. Because a fit between information format and search tasks can eliminate a transformation of searchers' mental representation, searchers' efforts are minimized. As a result, this paper proposes that searchers' satisfaction with a search engine Web site will be higher when the site's information form matches the search task than when there is a mismatch between the two.

The following hypotheses are proposed:

H3a: For fact-finding search tasks, the use of textual format will result in higher levels of user satisfaction than the use of cluster-based visualization.

H3b: For exploratory search tasks, the use of cluster-based visualization will result in higher levels of user satisfaction than the use of textual format.

Research Method

Subjects

We will recruit a total of 150 undergraduate students of business from a university in the southeast region of the U.S. Participation in the study will be voluntary, but will add 10 extra points toward participants' final exam scores for an introductory business computing class. All participants will be trained on how to use the experimental Web sites.

Experimental Web site and Search Tasks

Previous IS researchers have built prototype systems in order to empirically investigate the effects of information visualization on user performance (Chung et al. 2005; Hong et al. 2004; Turetken and Sharda 2005; Roussinov and Chen 2001). In this study, we will design a search Web site with an architecture based on that used by Turetken and Sharda (2004). We will develop two interfaces for the system: one with the textual ranked list format and one with the cluster-based visualization format.

In fact-finding tasks, subjects will be asked to use the experimental Web sites to obtain an answer to a specific question. For example, "What was the population of U.S. in 1992?" The exploratory search tasks will be questions for which participants need to provide relevant answers. Since we do not and cannot expect the participants to find all the relevant information to answer the question, we will design the questions so that their answer space is well structured. For example, "Please give us three reasons why gasoline prices recently went up in the U.S."

Each subject will be asked to answer one fact-finding question and one exploratory question, using the textual format, and then answer another two questions of each type, using the visualization format. That means a subject will perform under all four task/format treatment conditions (Textual/Fact-finding, Textual/Exploratory, Visualization/Fact-finding, Visualization/Exploratory). A repeated-measures design with two within-subjects factors (task type and information format) is used because it can measure the subject effect (e.g. varying reading speeds or preferences for information formats) and increase statistical power. Counterbalancing will be used to control for the order effects such as subject fatigue, boredom, or learning. However, a fully counterbalanced study using two treatments with two levels for each would yield 24 possible treatment orders, a number that would prove unwieldy. Consequently, we will use partial counterbalancing, randomly selecting four orders from among the 24 possible orders. Accordingly, subjects will be randomly assigned to one of the four groups in which a specific order of the treatment combinations is given.

Procedures

Previous literature suggested that individual cognitive skills and previous experience could influence searchers' performance and their satisfaction toward using the Web site (Hong et al. 2004). In order to control for these cognitive biases, a pretest will be conducted to identify two tasks differing in type but both with similar levels of

familiarity to the subjects. We will ask 30 students (who will not participate in the main experiment) to rate a list of candidate tasks on familiarity levels.

At the start of the experiment session, the subjects will be given a description of the search task. Search time will be measured in minutes. A log file will be generated by the computer to record each participant's start time and end time on the task. Accuracy will be measured by the number of relevant pages. When they finish, subjects will be asked to save the Web pages that they consider relevant to the search task. An expert in information searching will be asked to record the number of pages that should be considered relevant to the task. A questionnaire adapted from Hong et al. (2004) will be distributed to participants before they leave the experiment site to investigate their experiences and satisfaction with the search interface (see the Appendix).

Analysis

A repeated-measures analysis of variance will be used to test the hypotheses in this paper.

Conclusion

As the Internet has become a mass medium, people have come to rely on it as an important information source. It is vital that search engines should adapt to and provide support for users' diverse requirements, as users' search needs vary from simple fact seeking to extensive exploring. Recently researchers have recognized that human's remarkable perceptual abilities are greatly underutilized in most current Web interface designs (Shneiderman and Plaisant 2004). Research efforts originating from various scientific backgrounds have been devoted to improving the usability of online search engines (Fox et al. 2006; White et al. 2006). Information visualization is an important part of such efforts. Nevertheless, although the implementation of information visualization on search engine Web sites is promising, the functions of traditional textual ranked-lists are still desirable since such information displays may ensure better search results for less ambiguous search activities.

This paper examined the interaction effect between information format and search tasks in influencing searching behavior. Utilizing cognitive fit theory as the theoretical framework, this research would make a theoretical contribution by extending the theory to Web search domain, which is emergent in IS research. It would also help to improve researchers' understanding of users' online searching behavior. As this understanding grows, new modalities will emerge to aid searchers. In addition, this study would have implications for search engine practitioners that the understanding of searchers' information needs should guide designers in shaping Web sites.

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Appendix

Questionnaire for Subjects

Please indicate the degree to which you would agree with the following statements by choosing a number from 1 to 10, where 1 indicates "strongly disagree" and 10 indicates "strongly agree".

* Reverse coded scales

Strongly Disagree									Strongly Agree
1	2	3	4	5	6	7	8	9	10

1. To complete the search task, using this Web site was very frustrating.
2. To complete the search task, using this Web site took too much time.
3. To complete the search task, using this Web site required too much effort.
4. To complete the search task, using this Web site was too complex.
5. I easily found the information I was looking for.*
6. To complete the search task, using this Web site was easy. *
7. Using a Web site built in this format to perform similar search activities would be pleasant.*
8. Overall, I like using a Web site using this format to perform similar search activities. *

Finally, please tell us more about yourself:

1. What is your age
   - (A) Under 20
   - (B) 20 – 25
   - (C) 26-30
   - (D) 30-35
   - (E) Above 35
2. What is your gender
   - (A) Male
   - (B) Female
3. What is your major:
   - (A) Finance
   - (B) Accounting
   - (C) Management
   - (D) International Business Management
   - (E) MIS
   - (F) Operations Management
   - (G) Others: _____