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Visualization Support for Managing Information Overload in the Web Environment

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Abstract

This research focuses on the information overload problem on the Internet, and proposes a potential remedy to the overload encountered while searching the Web. We developed a system that makes use of clustering and visualization for browsing the results of a typical web search. We built two different (full and fisheye) zooming capabilities into our system, and empirically compared their success with each other as well as with the traditional non-visual presentation method through an experiment. We hypothesize that the visual systems will lead to higher success than the text-based system, and that the fisheye zooming system will lead to higher success than the full zoom system. The results of our exploratory test provide partial support for our hypotheses. This empirical support and the comments made by the participants in the experiments suggest that our design ideas are promising, and it is worthwhile to further investigate the use of clustering and visualization mechanisms for reducing information overload.

Keywords: Information visualization, human-computer interaction, Web search, experimental study.

INTRODUCTION

Today's computing and communication architecture has tremendously increased the accessibility of information across physical boundaries. One might expect that this accessibility would make the task of managing information easier since the effort in sharing big chunks of information by means of intranets, extranets, and the Internet is much less today compared to a decade ago. However, information age has actually intensified the challenge of presenting the "right information" to the "right person" at the "right time" and in the "right form." A critical problem regarding this is information overload, which occurs when an information user is exposed to more information than (s)he needs, and more importantly, is able to process. This problem has transformed the nature of knowledge management. As Denning (1982) stated, "it is now time to shift the attention from the generation of information to receiving it, i.e., controlling and filtering the information that reaches the person who must use it."

The World Wide Web (WWW) is a very important domain in which the information overload problem deserves special attention. The Web is already the largest information repository, and is continuously growing in size and prominence. In this study, we address a specific Web-related information overload problem. Web search engines are the most common tools used to search the web. Typically, a search engine presents its results as a ranked list. For broadly formulated search queries, such a list may contain thousands of documents. Research has suggested that users of search engines are not likely to go beyond the top 20 to 30 documents on these lists before getting bored or frustrated, and subsequently quitting the search (Roussinov 1999). This paper reports on our research efforts for a potential remedy to this problem and the results of an empirical study to test the success of our approach. The paper is organized as follows: in the next section, we discuss our research questions. Our research methodology is explained in the third section while the fourth discusses the results of the statistical analyses. The last section of the paper concludes with a discussion of the results.

RESEARCH DIRECTIONS

Our approach to the overload problem focuses on improving the methods used to examine search results. Arguably, once web search results are collected, the exploration of this collection is a browsing task. Following this argument, we propose that search success can be improved through superior browsing of search results. There is very little structure in the list display of web search results, which makes them difficult to browse. According to the cluster hypothesis (van Rijsbergen 1979), mutually similar documents will tend to be relevant to similar information needs. Hence, clustering can be used to reduce the overload in the browsing of search results. Cutting et al. (1992) were early adopters of this idea and developed a clustering-based browsing method. Pirolli et al. (1996) and Hearst and Pederson (1996) tested this interface, and came to the conclusion that successful use of clustering can increase effectiveness and efficiency of information retrieval (IR).

The recent advances in processing speed and graphical capabilities of today's powerful computers have made it possible to support cognitive tasks such as scanning, sorting, and selection by means of visual aids. Visualization has been popular in supporting the mentioned cognitive tasks in the exploration of information spaces such as a computer file directory (Johnson and Shneiderman 1991), a web site (Bederson et al. 1997), and a collection of web pages (Chen et al. 1997). In a recent application, Roussinov (1999) empirically showed that using partitioning (based on a variant of Self-Organizing Maps) with map-based visualization increased search speed, and was preferred by most experimental subjects. This is one of the few studies that provide empirical evidence as to the usefulness of the combined use of clustering and visualization. The attractiveness of the idea of using clustering and visualization to reduce overload and the scarcity of empirical evidence on the usability of this approach strongly suggest the need for different implementations of the idea and more empirical studies with different samples of users. This observation has led to the formulation of our first research question:

> ***Can a (clustering-based) visual presentation system improve search success over one without such a support?***

To address this question, we developed a prototype system that presents an overview of content-based clusters of search results. This overview summarizes the information space and lets its viewers recognize certain patterns. Based on this understanding, the searcher can focus on the document groups of more interest. Our proposition is that this approach will provide better information access with less overload than the ranked-list does. In that respect, the aim of our system is achieving high search success in terms of effectiveness and efficiency. In this context, our use of the term "search" assumes a user, rather than a system,perspective. Although the system we are describing does not aim to improve the available search algorithms per se, it aims to enhance the outcomes of the users'search efforts.

As mentioned before, users of our system can zoom on a cluster that they identify in the overview. Traditionally, visual interface design has been based on undistorted views of information. Such interfaces provide separate views of context and details by displaying the zoomed-in area in full detail and pruning the out-of-zoom area. This approach (full zooming) provides the immediately needed information in sufficient detail but eliminates the less relevant information. Yet this "less relevant" information forms the global perspective in which the details are useful. Hence the presentation would be more successful if details were smoothly integrated within the context. Especially in the visualization of search result clusters where the boundaries between different areas in the visualization are rather imposed than natural, it would be desirable to examine local detail in its global context. A fisheye view (Furnas 1986) is a way to provide such a global context. Furnas introduced the concept of generalized fisheye views with a similar motivation, and suggested that such views might be useful for the computer display of large information structures like programs, databases, and online text. To our knowledge, the only system that has attempted fisheye view visualizations of web search results is VITESSE (Nigay and Vernier 1998). This system uses a visual display of search results without any content-wise or link-based organization, i.e., clustering. Hence, its benefit in reducing information overload is limited. This led to the formulation of our second research question:

> ***Can a (clustering-based) visual presentation system supporting fisheye zoom improve search success over one with full zoom only?***

For addressing this question, we have added a fisheye zooming functionality to our system. The full zoom system strictly filters out the portions of the overview that are not immediately relevant where the fisheye zoom system summarizes this information to provide context.

Other researchers have recognized the scarcity of empirical studies on the usefulness of information visualization, especially in the web domain (e.g., Roussinov 1999). Accordingly, the major feature of this study is the empirical testing of the success of our systems.

General success of an information system can have many dimensions such as system quality, information quality, use, user satisfaction, individual impact, and organizational impact. Different researchers have used differing sets of these measures depending on the purpose of their study (DeLone and McLean 1992). From a user-oriented perspective, system success can be defined in terms of the success of the end-user performing tasks that are supported by the system (individual impact), and their satisfaction with the system (user satisfaction). End-user success, in turn, has two dimensions: effectiveness and efficiency. Effectiveness is a measure of how desirable the user's outcomes are, whereas efficiency refers to how well (s)he uses the available inputs (physical resources or time) in producing those outcomes.

Previous work in human computer interaction has identified a number of factors affecting user success and satisfaction. Among these are the presentation interface itself (Santhanam and Sein 1994), the characteristics of the task, for example its level of difficulty (Suh and Jenkins 1992), amount of training (Suh and Jenkins 1992), contextual variables such as individual characteristics and experience (Santhanam and Sein 1994), and interactions between some of these factors, for example "cognitive fit," (Vessey 1991), and "task and interface match" (Tan and Benbasat 1990).

In this specific study, we take a user-oriented approach, and propose that the overall success in the performance of specific search-related tasks is determined by the following: the success of the interface in presenting the information (with little overload), the tasks themselves, the amount of user training, and contextual variables such as individual differences and experience. Subsequently, the overall success leads to end-user success (effectiveness and efficiency) and end-user satisfaction. In the next section, we discuss the operationalization of these variables.

METHODOLOGY

Prototype Development

The prototype system that we developed to implement our design ideas has a main module created by server-side scripting (Microsoft Active Server Pages). This module prompts users for a query and sends that query to the AltaVista search engine. Once the results are retrieved, the module uses the hierarchical clustering routine of IBM's IntelligentMiner to cluster the documents. The resulting hierarchy structure is visualized by a custom-built Java applet that provides the overview and zoom capabilities as described earlier. A detailed description of this system with the visualization algorithms can be found elsewhere.

Hypotheses

The only independent variable that is of interest in this study is the presentation method. It can take three levels: fisheye view visualization, full zoom visualization, and no visualization. The other independent variables are either held constant (amount of training and task) or controlled (contextual variables).

We operationalize the effectiveness dimension of "end-user success" as suggested by Tan and Benbasat (1990) among others. The number of correct answers given in a limited time to a set of objective questions answered within the search results is a surrogate for effectiveness. Meanwhile, the time to complete the task of answering these questions is our surrogate for efficiency. Todd and Benbasat (1992) challenged the assumption that if decision makers have expanded processing capabilities, they will use them to analyze problems in more depth for making better decisions. According to the authors, a possible explanation for why this proposition has not been supported empirically can be attributed to the conservation of effort as explained in behavioral decision making theories. "If this is so, then the use of a decision aid may result in effort savings, but not improved decision performance" (Todd and Benbasat 1992). In their study, experimental subjects behaved as if effort minimization was an important consideration, and did not produce higher quality decisions with better aids. Following from this viewpoint and the operationalizations as described, we convert our research questions into the following hypotheses:

H1: *The subjects will spend less time by using the visual systems than they do by using the text-based system while correctly answering as many questions using each system.*

H2: *The subjects will spend less time by using the fisheye zoom system than they do by using the full zoom system while correctly answering as many questions using each system.*

As a surrogate for end-user satisfaction, we use the scores obtained from a satisfaction survey administered to the subjects regarding each presentation. According to this operationalization, the following additional hypotheses are formulated:

H3a: *The visual systems will result in higher user satisfaction (scores) than the text-based system.*

H3b: *The fisheye zoom system will result in higher user satisfaction (scores) than the full zoom system.*

Experimental Design

Tasks

Finding the right tasks to test the usability of a Web-based design is a challenge. Our main motivation in this study is to provide support in browsing the results of a search query that retrieves a large number of pages (hits). Accordingly, our first criterion for the experimental tasks is that they result in a large number of hits. Similarly, we want the tasks to have multiple aspects and produce a large number of clusters. The purpose of our experiment is to test the success of our design principles. Hence we do not want the personal traits or backgrounds to influence the results. For this reason, we want the tasks to be on general topics so that a group of subjects will not be systematically more knowledgeable about the tasks compared to others.

Shneiderman (1997) classified information search objectives into the following:

1. Specific fact-finding,
2. Extended fact-finding,
3. Open-ended browsing, and
4. Exploration of availability.

In the web domain, the availability of material is subject to continuous change. Thus, it is not easy to determine exploration of availability. Open-ended browsing is invaluable in real-life information search activities. However, in a controlled experiment, it is very difficult to measure the outcomes of a loosely defined objective such as “finding new work on voice recognition in Japan.”

Fact-finding questions are a good means of testing the success of a presentation system. The answers to such questions can be found within the collection of search results. Yet, finding those answers, especially in a fast manner, requires the ability to effectively overview the document collection, and to focus on a specific part when needed. We believe that the visual systems, especially with the fisheye zooming, will facilitate this better focusing and refocusing. Subsequently, the search tasks in this study were on (specific or extended) fact finding. We designed three tasks, Task A, Task B, and Task C, with virtually similar difficulty levels.[1] This similarity allows us to control for the “task” variable.

Table 1. Sample Experimental Questions (Task A)

1. Where can I get good filet mignon in Madison, WI?
2. What was the population of Hong Kong in 1998?
3. Find two other books by the author of Jurassic Park.
4. Name three shows that took stage in Broadway in 1989.

Control Variables

The amount of training was controlled by holding it constant for each subject. Age, sex, native language (English vs. other), cognitive style, and web search experience are the other control variables. Figure 1 displays our research model with the complete set of conceptual and operational variables.

[1]Some of these questions were modified from those that were used in a panel on Web Search at the 1998 ACM Conference on Advances in Information Retrieval.

Measurements

To measure "Wb search experience, we adopted a two-item scale (Wang et al. 2000) composed of the frequency and duration of search engine use. We used the Group Embedded Figure Test (GEFT) (Witkin et al. 1971) for determining "cognitive style." his test is known to measure a very salient, i.e.,field dependent dimension of cognitive style (Witkin et al. 1971). Subjects of the GEFT are assigned a score between 0 and 18 depending on how many simple figures "embedded" in more complex ones they can identify. Finally, we adopted a multi-item scale from Stasko et al. (2000) for measuring "satisfaction. The measurement of the other variables in the model is straightforward.

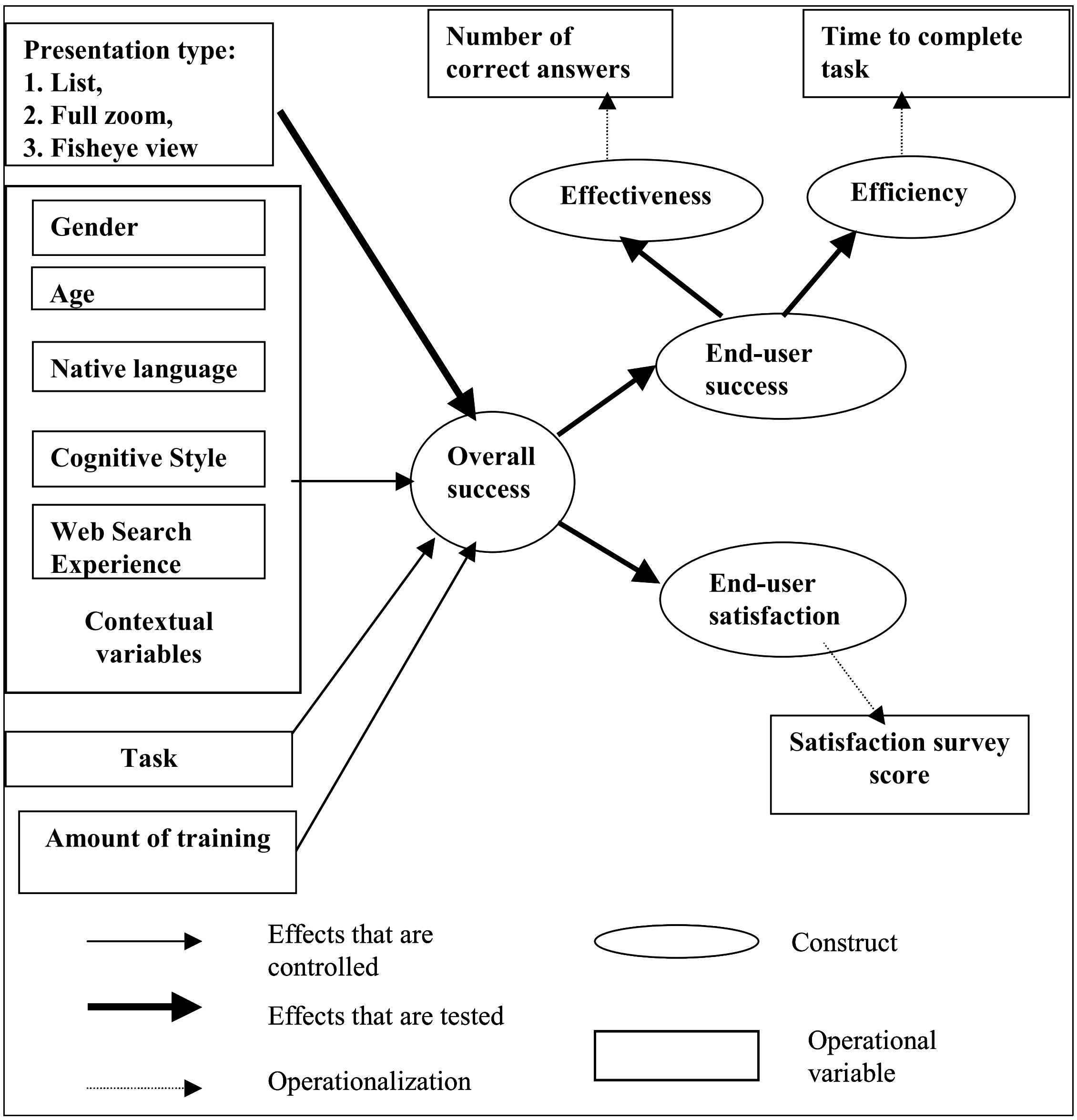

Figure 1. The Research Model

(This model does not explicitly show interaction between the independent or dependent variables, yet the existence of interactions must be tested for an empirical study.)

Procedure

We conducted controlled experiments with business (mostly MIS) students. Each experimental session started with the subjects filling out a questionnaire on their demographics and web experience, and going through the cognitive style test.

The subjects were randomly assigned to one of three groups. They underwent a training session that resembled the experimental phases, which familiarized them with the experimental procedure and the forms used for data collection. The subjects were trained with a task similar to the actual experimental tasks. After the training, there were three phases of experimentation. In each phase, subjects were given tasks A, B, and C in the same order. The difference was in the presentation method of the search results as shown in Table 2.

Table 2. The Experimental Design

Phase	**Task/Support**		
	Group 1	**Group 2**	**Group 3**
Phase 1	**1** Task A No visualization	**2** Task A Full zoom	**3** Task A Fisheye zoom
Phase 2	**4** Task B Fisheye zoom	**5** Task B No visualization	**6** Task B Full zoom
Phase 3	**7** Task C Full zoom	**8** Task C Fisheye zoom	**9** Task C No visualization

This experimental design facilitates all three modes of presentation methods to be used for all three tasks. Assuming that the order in which the subjects are exposed to the presentation methods has no significant effect (i.e., no phase-task combination and learning effect), the success (number of correct questions and time to finish the task) and satisfaction of the subjects with a specific presentation can be found by aggregating the success (i.e., performance) and satisfaction measures from the three different groups. We test the validity of this assumption in the next section. The reason that we chose such a design over a regular repeated-measures design is to control for the effect of the sequence in which the subjects are exposed to the differing presentation methods. If significant differences between presentation methods were found with a regular repeated measures design, we would have no way of knowing whether this was a learning effect.

Figures 2, 3, and 4 show alternative ways of presenting the results to the query for the second question of Task A. Figure 2 is the visual overview, which is common to both methods of visualization. Figures 3 and 4 display the alternative ways of zooming the "populous world" section of the overview in Figure 2.

During an experimental session, subjects were given 12 minutes (an average of three minutes per question) for the completion of each experimental phase and were reminded of the time left for the specific phase every three minutes. At the end of each phase, subjects evaluated the mode of presentation that they had experienced in that particular phase. A total of six sessions of the experiment (each with a different sample) were held. The first session was used for testing the experimental procedure, and the second one did not yield usable data due to a technical problem. This resulted in a total sample size of 78 subjects.

RESULTS

Preliminary Analyses

As explained earlier, our data can be analyzed as if they were collected through a repeated measures design, assuming the order that the subjects were exposed to different presentation methods, (the main effect to be tested) has no significant effect on their performance and satisfaction. Accordingly, we tested the validity of this assumption by revisiting our experimental design (see Table 2 with the cell numbers from 1 to 9). Three factors differentiate these cells from each other: the presentation method, task, and phase. To isolate the effect of the task and phase combination from the effect of the presentation method, we performed a test to compare the levels of the three dependent variables between cells 1, 5, and 9, between cells 2, 6, and 7, and between cells 3, 4, and 8 separately. In this way, we only compare the effect of the task and phase combination since the "method" in each of these comparisons is constant.

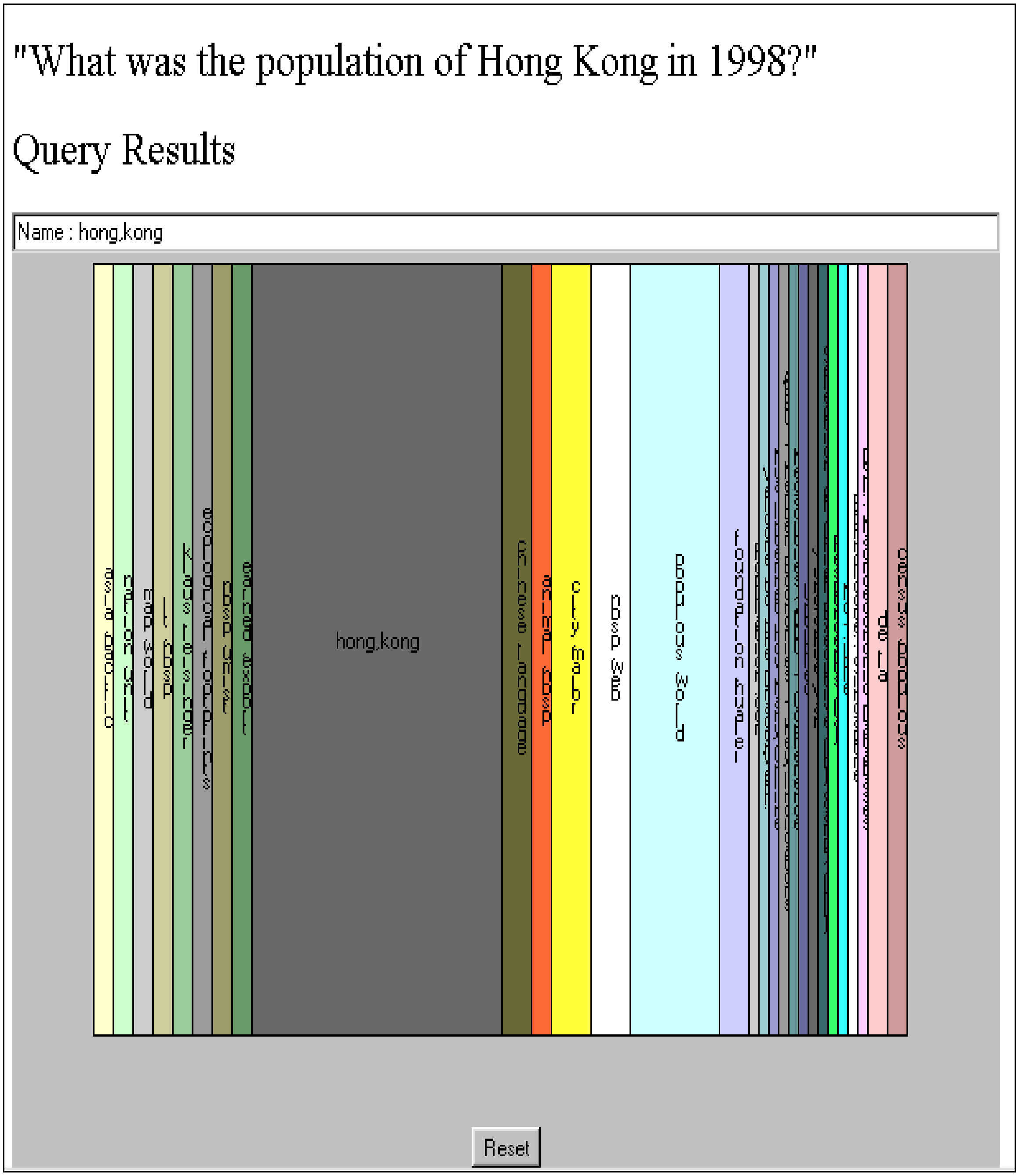

Figure 2. Visual Overview of the Search Results to Query 2

We performed a separate Multivariate Analysis of Variance (MANOVA) to test the effect of the phase-task combination on the dependent variables for each presentation method. The test results showed that there was no significant difference between the three groups in terms of performance and satisfaction (*no visualization*, p = 0.191, *full zoom*, p = 0.185, *fisheye zoom*, p= 0.899). Thus the phase-task combination has no significant effect on the success and satisfaction of the experimental subjects meaning that the dependent variable measures can be treated as the repeated measures of the same variables with a within-subjects factor of presentation method. Accordingly, the test of hypotheses can be performed simultaneously by means of repeated measures MANOVA and multiple (paired) comparisons.

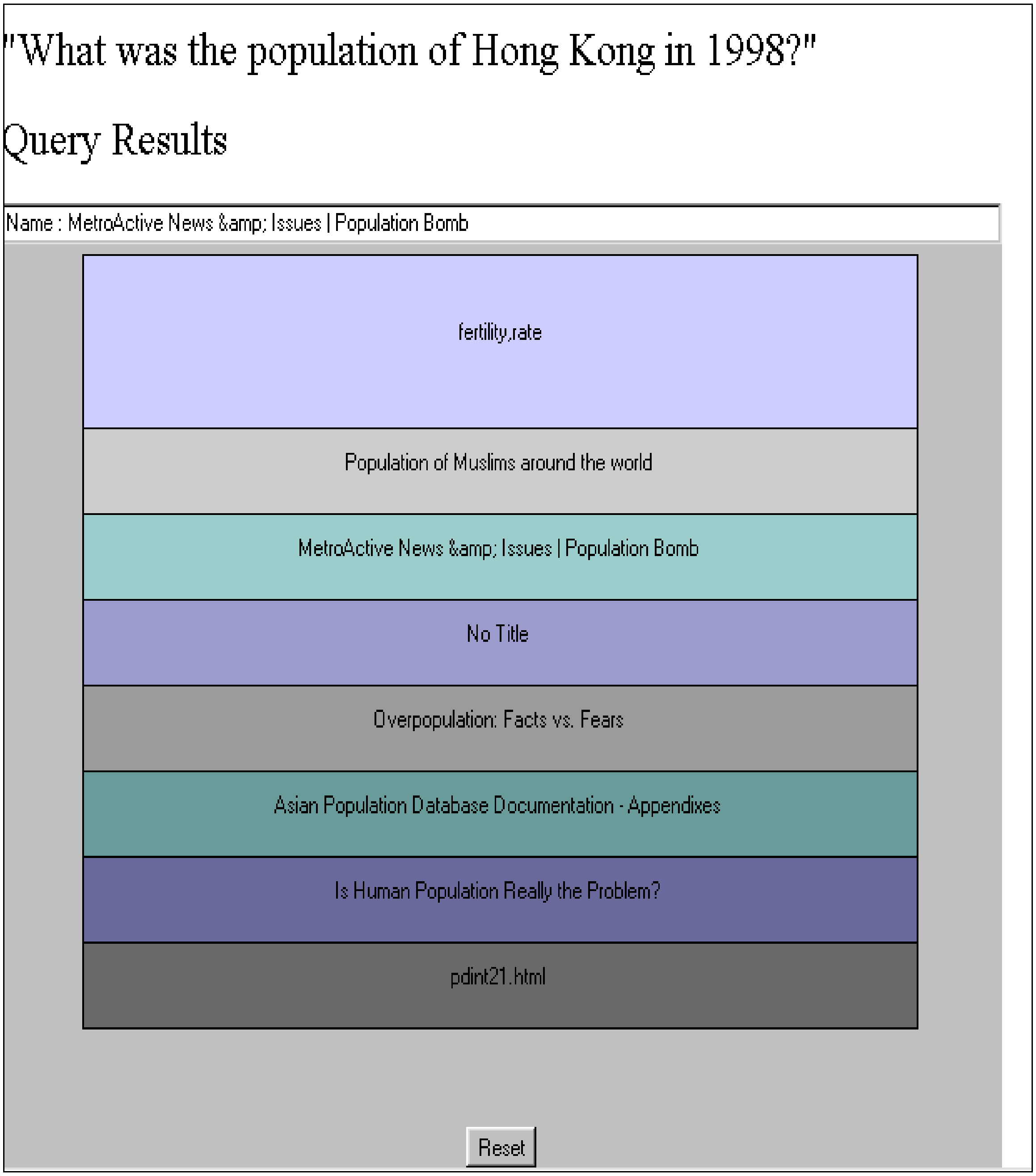

Figure 3. "Full" Zooming of the "Populous World" Section of Figure 2

The original data set contained missing variable values for a total of 12 cases. Because there were only a few missing values for each of these cases, we chose to replace these values by the average of the variable from the other cases. Also, to improve the quality of the analyses, we eliminated those subjects who scored only one correct answer or none in each phase.

Hypotheses Testing with the Revised Data

The normal P-P plots showed that the dependent variables are normally distributed; therefore, either ANOVA or MANOVA are appropriate to analyze the data. We preferred a repeated-measures MANOVA to three separate repeated-measures ANOVAs, because we found significant correlations between the dependent variables. We conducted a MANOVA with a within-subjects

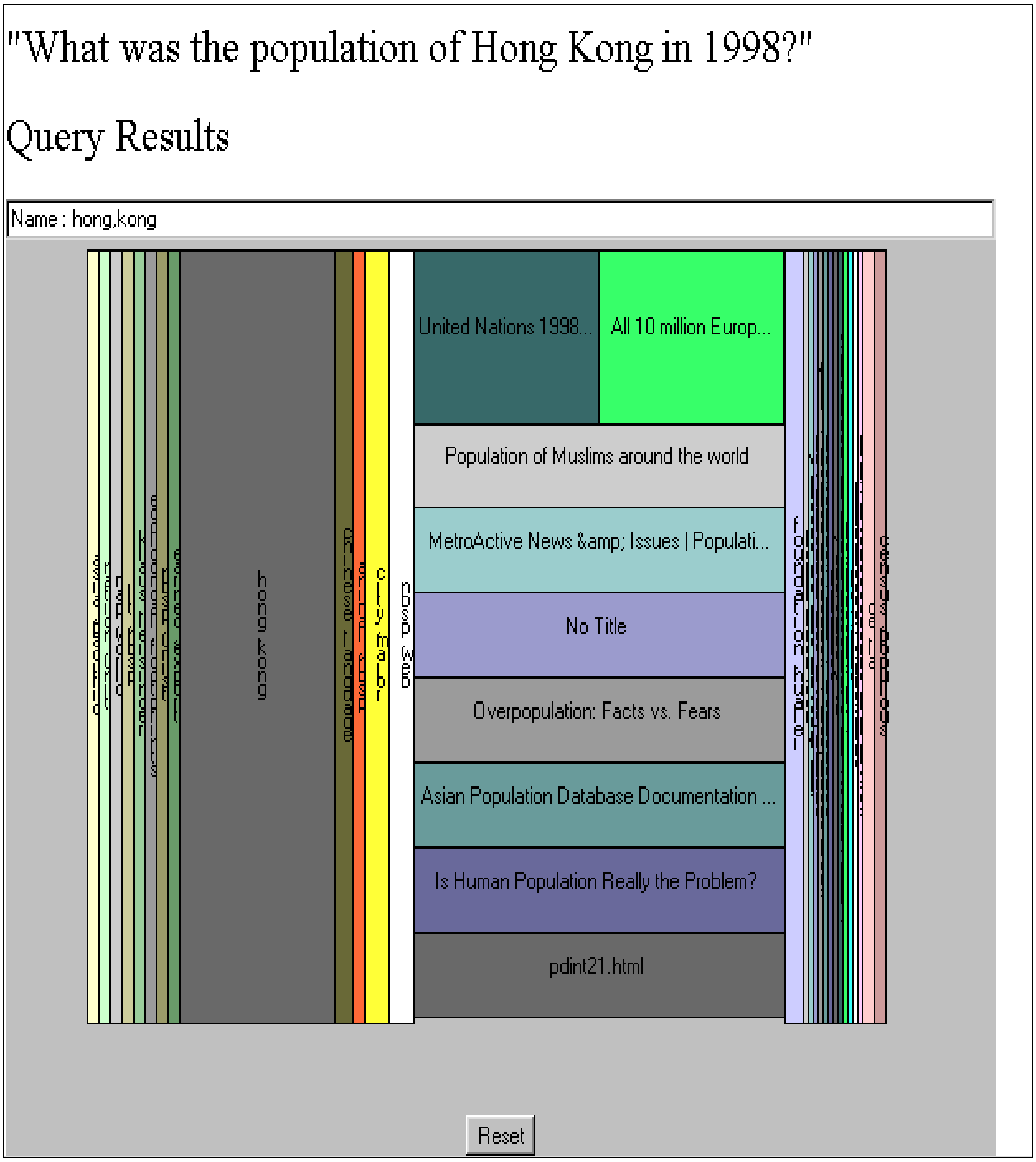

Figure 4. "Fisheye" Zooming of the "Populous World" Section of Figure 2

factor of presentation method, and between-subjects factors of sex, native language, age, web experience, and cognitive style (field independence). We included multiple (paired) contrasts to compare the visual systems to the non-visual, and the fisheye zoom system to the full zoom system without separate tests.

Table 3 displays the descriptive statistics based on method. As seen in Table 3, on the average, the subjects had the highest scores, i.e. found the largest number correct answers, without visualization, next the score obtained with the full zoom visualization method, and then that with the fisheye view method, i.e., $score_{no\ visualization} > score_{full\ zoom} > score_{fisheye}$. On the other hand, $time_{fisheye} < time_{full\ zoom} < time_{no\ visualization}$, and $satisfaction_{fisheye} > satisfaction_{full\ zoom}$, and $satisfaction_{no\ visualization} > satisfaction_{fisheye}$. To verify the statistical significance of these findings, we performed significance testing in a stepwise manner starting at the multivariate level. The results of the multivariate level analysis showed that the effect of presentation method is significant ($p = 0.025$), and those of all interaction terms are not. This implies an overall difference between the success of the different presentation methods, and this difference is independent of the level of the control variables. The ability to test our hypotheses depends on whether the effect of presentation method is significant at the individual dependent variables level, for which we looked at the univariate tests, and found that the effect of the presentation method is significant for the time variable only (p = 0.000). This means that there is insufficient evidence to support hypothesis H3 (no significant difference in satisfaction), and that the testing of hypotheses H1 and H2 boil down to the testing of significant speed differences between the visual and textual presentation methods, as well as those between the full zoom and fisheye systems since no significant difference in number of correct answers was found. Following the stepwise approach, these two hypotheses are tested by means of paired comparisons, the results of which are displayed in Table 4.

Table 3. Descriptive Statistics for the Modified Sample (N = 57)

Dependent Variable		Mean	Std. Deviation
Score	**Full Zoom**	1.4825	1.0175
	fisheye Zoom	1.4386	.9067
	No Visualization	1.6737	.9477
Time	Full Zoom	507.2105	125.5025
	Fisheye Zoom	479.4035	141.4043
	No Visualization	580.1053	149.4160
Satisfaction	**Full Zoom**	3.3193	1.5431
	Fisheye Zoom	3.3421	1.4490
	No Visualization	3.8772	1.4652

Table 4. Paired Comparisons

Source	Measure	METHOD	Type III Sum of Squares	df	Mean Square	F	Sig.
METHOD	**SCORE**	**Level 2 vs. Level 1**	4.459	1	4.459	2.455	.124
		Level 3 vs. Previous	.832	1	.832	.505	.481
	TIME	**Level 2 vs. Level 1**	71515.541	1	71515.541	4.470	***.040***
		Level 3 vs. Previous	173770.086	1	173770.086	12.776	***.001***
	SATISF	**Level 2 vs. Level 1**	.155	1	.155	.123	.727
		Level 3 vs. Previous	.592	1	.592	.250	.620

Table 5. Summary of Hypotheses Testing

Hypothesis	Support
H1	Support in hypothesized direction
H2	Support in hypothesized direction
H3	No support

According to the comparison in Table 4, the effect of the method on the time it took the subjects to complete the tasks using the visual systems as opposed to the text-based system and that using the fisheye zoom system as opposed to the full zoom system are significant. Since the effect of the method on score is not significant, we conclude that the hypotheses H1 and H2 are supported. The summary of the hypotheses testing results is displayed in Table 5.

CONCLUSIONS AND DISCUSSION

It is our conviction that the system developed in this study is a promising step in the application of fisheye views to information search display issues. However, the main contribution of this paper is that it discusses how the previous theory on user-interface design could apply to a recent and relevant problem, and that it portrayed a comprehensive empirical study based on this theoretical understanding. In that sense, the (partial) support that we have found for the hypotheses is significant. Yet, there were still some inevitable effects that hurt the validity of our study. These are discussed below.

One complaint that we heard from more experienced Web searchers was about the lack of freedom in formulation of search queries. The lack of such freedom was due to the nature of the tasks that we chose. In the future, it would be interesting to test the systems with complex tasks such as finding information for writing a report on a well-known philosopher and evaluating the quality of the resulting information. Such a quality rating may be used as a surrogate of effectiveness instead of the quantity-based score that we used.

Another observation was that subjects who did not "buy into" the experiment had a harder time learning and using the visual systems. This observation points to the existence of an interaction between the method and an omitted contextual variable "subject involvement." Likewise, we did not consider the fact that our visual presentation systems were unfamiliar to the subjects and this may have caused some variation in the dependent variables, especially in the satisfaction scores, that our model cannot explain. Our inability to envision such weaknesses in advance points to the need for more theory-building research on interface design taking into consideration the characteristics of today's systems and their users. Nevertheless, the support for our hypotheses suggests that our design ideas are promising, and it is worthwhile to focus on improving the implementation of the system. Preprocessing of search results into clusters and then applying fisheye-based visualization is likely to give the user significant power in using the web search results.

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