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Facilitating Browsing with Information Visualization: A Cognitive Fit Perspective

Stella Taylor
Temple University

David Schuff
Temple University

Ozgur Turetken
Ryerson University

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Stella Taylor
Fox School of Business and Management
Temple University
stella.taylor@temple.edu

David Schuff
Fox School of Business and Management
Temple University
david.schuff@temple.edu

Ozgur Turetken
School of Information Technology Management
Ryerson University
turetken@ryerson.ca

Abstract

Search engines make vast amounts of information available to Internet users. Some of these engines have incorporated information visualization techniques to facilitate browsing through these results by reducing information overload. Drawing on information foraging theory, we study the effects of augmenting visualizations with animation to help users more easily identify relevant information in search engine results. In addition, we use cognitive fit theory to study the effect of different information formats on users' performance in completing two different browsing tasks.

Keywords

information visualization, animation, cognitive fit

Introduction

The term "information overload" describes the state when the amount of available information exceeds an individual's ability to process it. This problem has been studied in accounting (Schick et al., 1990), marketing (Keller and Staelin, 1987), and information systems (Schultze and Vandenbosch, 1998). Although information overload is seen in many areas, the Internet has become a major contributor to this phenomenon (Swash, 1998). On the Internet, individuals have access to a vast array of information sources. According to Pew Internet & American Life Project Tracking surveys (2004), one of the most frequent activities on the Internet is the use of search engines. However, finding relevant information using search engines can still be a difficult task (Dumais et al., 2001; Roussinov and Chen, 2001; Turetken and Sharda, 2005) since current tools do not provide many appropriate cues to help users navigate through the large information space that a search creates.

Presentation of results from a search engine is a potential application of information visualization, which can reduce information overload by shifting some of the information processing load to sensory systems. Information visualization is a technique for combining cognitive senses with visual cues that allow for better understanding of the information (Turetken and Sharda, 2004). Consequently, people can understand information more easily when it is presented visually (Tufte, 2001). Use of visualization techniques or cues should allow individuals to more easily navigate through search results by reducing information overload.

According to Dumais et al. (2001), there is little research that identifies desirable cues in the visual presentation of search results. Card et al. (1999) suggest that other features such as animation have been underutilized in visualization. In an analysis of web space visualization, Turetken and Sharda (forthcoming) stated "a great majority of the systems surveyed…do not use animations in spite of the technical feasibility of these visual aids" (p. 50). Drawing from information foraging theory, we propose that animation can be a useful information visualization technique. In this study, we prototype a visual format that incorporates animation to help individuals navigate search engine results.

A second goal of this study is to identify which type of presentation format is most suitable for open-ended versus closed-ended tasks. We develop several formats to display search results, and using cognitive fit theory as a theoretical framework, we propose a research model to investigate how matching presentation format (from textual to animated) and task (closed-ended versus open-ended) reduces cognitive effort to achieve higher task performance and user satisfaction.

Therefore we investigate the following research question:

For certain task types, can an animated visualization of web search results facilitate higher information-seeking performance over a textual presentation?

Theoretical Framework

Approaches to Reducing Information Overload through Information Visualization

The Model Human Processor (MHP) (Card et al., 1983) explains how visual capabilities can reduce information overload. MHP is a psychological model that shows how sensory buffers, short-term memory, and long-term memory interact with sensory information to produce responses to information-related tasks (Card et al., 1983). Sensory buffers are stores for stimuli received by the senses (visual and auditory). Short-term memory (working memory) acts as a store for information that is required quickly. Long-term memory is the main source for memory. In order for individuals to complete tasks, information is taken from short term and long-term memory. Visualization allows individuals to increase sensory buffers (visual and auditory) so that short-term memory is increased. More on the psychometric mechanisms regarding visual perception can be found in a review by Turetken and Sharda (forthcoming).

Card et al. (1999) suggest six major ways that visualization can aid cognition: 1) increasing memory and processing resources for individuals, 2) reducing the search for information, 3) using visual presentations to enhance recognition of relationships, 4) making complex problems visually simple, 5) using cues to provide mechanisms for attention, and 6) providing information in a manner that can be manipulated. Turetken and Sharda (2004) state "the relative processing capacity and speed advantage of the perceptual (visual) system to the cognitive system results in the better and quicker understanding of information when supported by visual cues" (p. 416).

A number of researchers report that insight and problem-solving performance can be improved with appropriate visualizations (Crapo et al., 2000; Pinker, 1997; Hong and O'Neil, 1992). According to Shneiderman (1996), "humans have remarkable perceptual abilities that are greatly under-utlized in current designs. Users can scan, recognize, and recall images rapidly, and can detect changes in size, color, shape, movement, or texture" (p. 337). Card et al. (1999) suggest that some visual cues that can be automatically processed by humans are numbers, length, size, color, intensity, direction of motion, flicker, and curvature. Visualization formats should be designed to utilize features that can be automatically processed as well as provide support for search (Card et al., 1999).

Information Foraging Theory

Information foraging (IF) theory was developed to explain human information-seeking and sense-making behavior (Chi et al., 2000; 2001). IF theory deals with understanding how an individual uses strategies and technologies to seek, gather and use information when there is a vast amount of information in the environment (Pirolli, 2003; Card et al., 2001).

Two dominant concepts in IF theory are information patches and information scent. Information patches are similar to an individual's information needs that reside in piles of documents, results, file drawers or various on-line resources (Card et al., 2001). Often users have to navigate through more than one patch (i.e. from one web site to another or from one search engine to another) to find useful information. Information scent identifies the individual's use of environmental cues in judging which information sources are important and navigating through an information space (Pirolli, 2003). Information scent is the "imperfect perception of the value, cost, or access path of information sources obtained from proximal cues, such as www links" (Card et al., 2001, p. 499). For example, on a web page, information scent is delivered by a descriptor of the page, images, and headings. These scents enable individuals to decide whether this web page is worth navigating through.

IF theory states that information scent must be strong to ensure individuals are making appropriate decisions while not missing any opportunities. Animation is defined as the autonomous motions of representations (Nakakoji et al., 2001) or a series of rapidly changing computer screen displays that represent the illusion of movement (Phillips and Lee 2005; ChanLin, 2000). This can be an effective cue or scent for finding relevant information in a limited time.

According to Hong et al.'s (2004) review of human computer interaction literature, animation is adopted to increase comprehension in information visualization (Mackinlay et al., 1994) and to attract users' attention to specific information on the screen (Nielson, 2000). Animation can be an important feature in interface design; however empirical research on animation is limited in the information systems domain (Hong et al., 2004).

Previous research in using animation on the web has investigated flashing words (Heo et al., 2001; Li and Burkovac, 1999), animation speed (Sundar and Kalyanaraman, 2004), interactive animated characters (Phillips and Lee, 2005), and effects of animation on task performance (Zhang, 2000). Craig et al. (2002) found that animation improved performance by directing attention to specific elements of the visual display. Motion is the key component of animation (Rieber, 1991) for attracting attention (Hong et al., 2004; Lang et al., 2002). As our attention is drawn to certain stimuli, animation influences how well we perceive, recall, and act on information. Objects or information that does not receive attention fall outside our understanding and therefore have little influence on performance (Proctor and van Zandt, 1994; Hong et al., 2004).

IF theory helps us understand how enhancing visualizations of search engine results using animation might help individuals find relevant information. In addition, the ease in which individuals find information may depend on matching particular visualization formats to certain types of information search tasks.

Cognitive Fit Theory

Cognitive Fit theory (CFT) was developed to explain how the fit between presentation format and decision making tasks can affect problem-solving performance (Vessey, 1991). CFT suggests that when there is a mismatch between the information format and the task, the individual will invest more cognitive effort in decision-making processes because they need to adjust their mental representation to accommodate the mismatch (see Figure 1). Cognitive effort refers to the "psychological cost of performing the task of obtaining and processing the relevant information in order to arrive at one's decision" (Hong et al., 2004, p. 159). Based on CFT, a better fit between format and task should result in improved performance, a common measure of task success (Hong et al., 2004; Agarwal et al., 1991; Vessey and Galletta, 1991).

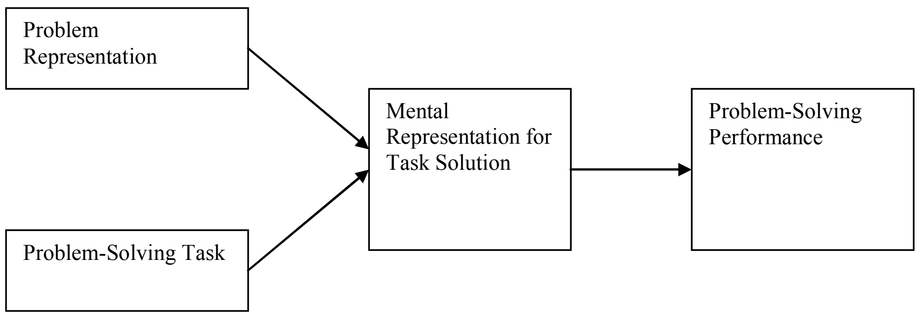

Figure 1: Conceptual Model of Cognitive Fit Theory

Fitting Visualization Techniques to Tasks

Information-seeking Tasks

According to information retrieval literature, searching and browsing are two general tasks performed to seek information on the Internet (McDonald and Chen, 2006). Both searching and browsing require the process of finding relevant information to complete an information retrieval task. In this study, we will be investigating browsing through open-ended and closed ended tasks using different user interfaces. In closed-ended tasks, individuals have narrow objectives that require finding specific results. In open-ended tasks, individuals only have general objectives that require finding as much relevant information as possible about a topic.

Information Format and Visualization Techniques

Different information formats, such as tables and graphics, emphasize different types of information and problem-solving processes (Hong et al., 2004). This study will investigate two types of presentation formats: textual and graphical. The textual representation typically presents results in an ordered list, similar to a search result page (i.e., Google). The graphical representation displays results in a two or three-dimensional picture showing the relationships among web page contents (Chung et al., 2005).

This study will use two variations of textual and graphical presentation formats: "standard" textual, textual with categories, non-animated visual, and animated visual. We will develop a prototype system for each format, and obtain the set of results to be visualized using Windows Live's search web service API. For all but the first format, the results will be clustered (based on the similarity of their content) using Carrot2 (see http://www.carrot2.org).

Relevancy of categories will also be calculated. Each search result will have a rank based on Windows Live's output. Each cluster will contain search results with varying rankings. Based on the ranking of the results within each cluster, we can determine the average relevance of that cluster using the mean reciprocal ranking (MRR). The calculation for MRR is as follows:

$$MRR = \frac{\sum_{i=1}^{n}\left(\frac{1}{Rank_i}\right)}{n}$$

where

$Rank_i$ is the rank of the ith search result in the cluster and n is the number of results within the cluster

The first prototype, called "standard textual", will be a textual presentation with results displayed in a ranked list (see Figure 2). This format provides a baseline to assess the remaining conditions. The second format used in the study is "textual with categories." In this format, the textual results will be clustered into a hierarchy, and that hierarchy will be presented as a tree on the page (see Figure 3). This prototype will also display the average relevance of each category (alongside the name of each cluster).

The "non-animated visualization" format will provide a baseline to assess the effects of the graphical display and compare it to the animation condition. The visual presentation will be a Grokker-style map (see the "mock up" diagram in Figure 4 and http://www.grokker.com) where circles will represent the different categories. Color will be used to clearly differentiate the categories, and size will be used to show the relative number of results in each category. In addition, in the finished prototype each circle will textually display the relevancy of that category.

In the fourth format ("animated visualization"), we will have the same map display as the previous prototype, but with the addition of animation (see Figure 5). For the top three categories (those with the highest MRR), the circle will blink at different rates. The most relevant category's circle will blink the fastest, followed by the second most relevant category, then the third.

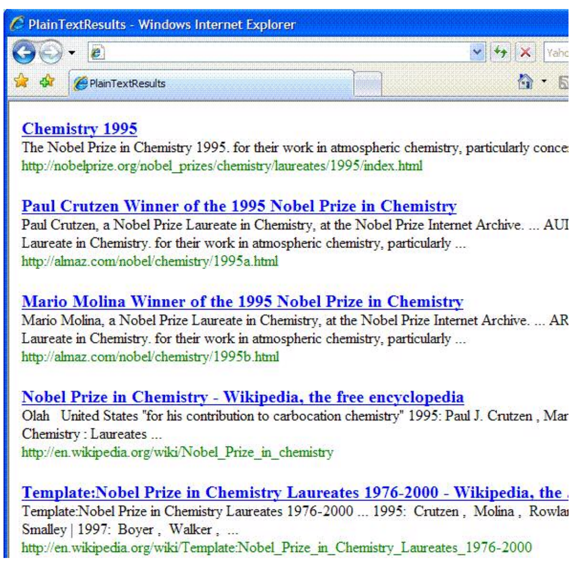

Figure 2: First Format: Standard Textual

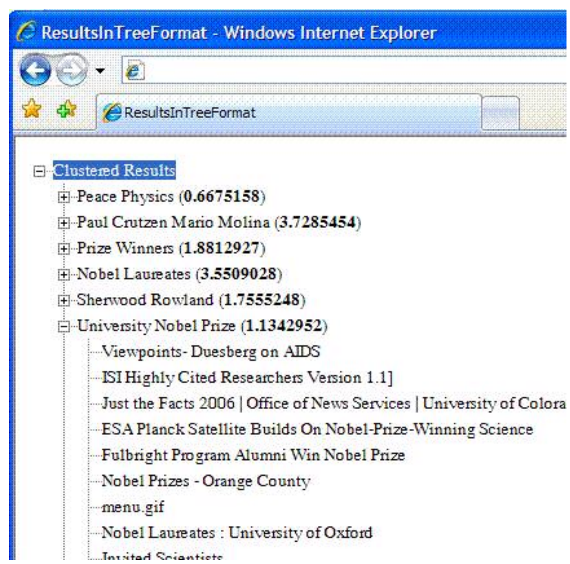

Figure 3: Textual with categories

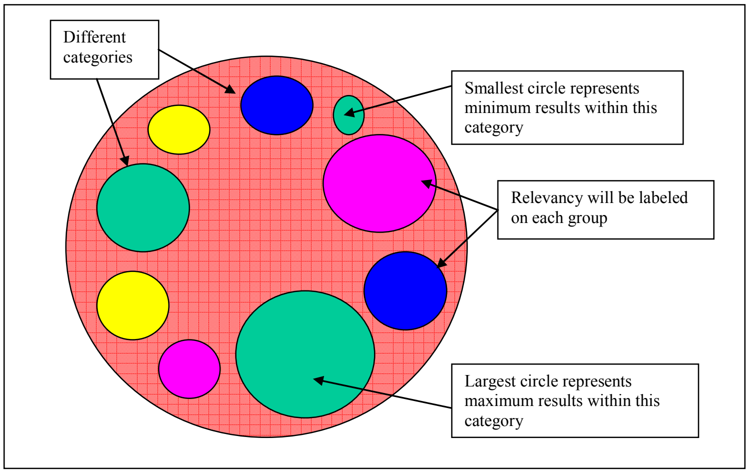

Figure 4: Third Format: Non-animated visualization

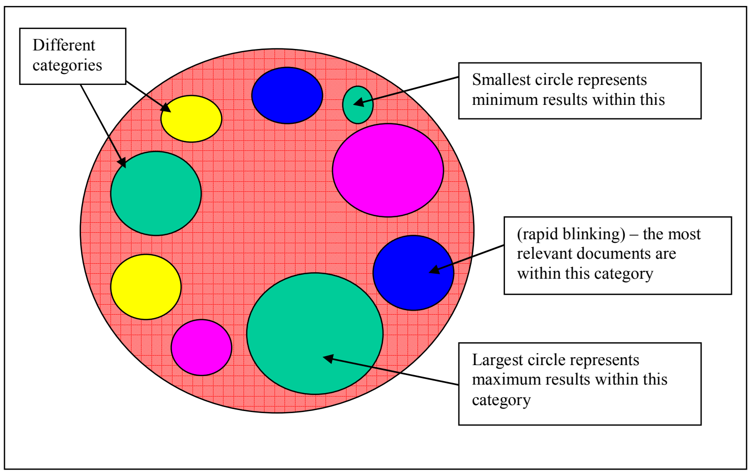

Figure 5: Fourth Format: Animated visualization

Hypotheses

Based on CFT, we propose that more positive outcomes will occur when there is a match between the visualization format and the information-seeking task. For example, when individuals are performing closed-ended tasks, the answer is narrowly defined and their search has a specific goal, reflected in a specific query. Using a textual presentation, the most relevant results (those that match the text of the query) are found easily by looking to the top of the ordered list. Because there will be a greater cognitive fit (the format of the results matches the task), subjects should require less cognitive effort when using a textual ordered list over one where the results are grouped into categories. This is because this requires understanding the structure of and navigating through the categorized set of results. Similarly, subjects using more complex, sophisticated interfaces to navigate the results should require increasing levels of cognitive effort (visual compared to textual, and animated compared to non-animated). Therefore, we hypothesize:

H1a: For closed-ended tasks, there will be less cognitive effort required when using textual format over visualization format.

H1b: For closed-ended tasks, there will be less cognitive effort required when using standard textual format over textual with categories.

H1c: For closed-ended tasks, there will be less cognitive effort required when using non-animated visualization format over animated visualization format.

When individuals are performing open-ended tasks, the answer is not as well-defined. Therefore, they need to synthesize multiple results in order to arrive at an answer. Because of this, individuals using a textual presentation may have to browse through many sites throughout the set of query results (and not necessarily those at the top of the list). This may result in a longer time to complete the task, and possibly frustration and even quitting the task altogether. Therefore, the relationship described above between the information presentation and cognitive effort required for closed-ended tasks should be reversed. Grouping related results into categories can provide cues that lead them to relevant information, thus helping them complete the task successfully. A visual map should further help users navigate the results, and the use of animation as a cue to highlight relevance should help further still. Therefore, we hypothesize:

H1d: For open-ended tasks, there will be less cognitive effort required when using visualization format over textual format.

H1e: For open-ended tasks, there will be less cognitive effort required when using animated visualization format over non-animated visualization format.

H1f: For open-ended tasks, there will be less cognitive effort required when using textual with categories over standard textual format.

Table 1: Summary of Cognitive Fit

	Standard textual	**Textual with categories**	**Non-animated visualization**	**Animated visualization**
Closed-ended task	Cognitive fit	Low cognitive fit	Lower cognitive fit	Lowest cognitive fit
Open-ended task	Lowest cognitive fit	Lower cognitive fit	Low cognitive fit	Cognitive fit

We will measure cognitive effort using Hong et al.'s (2004) instrument that combines cognitive decision effort and cognitive convenience. Because this survey was originally developed for the e-commerce domain, we will rephrase the questions to suit the current context.

We will now discuss each of the dependent variables and the related hypotheses.

Performance

Following from the previous arguments, individuals will perform better by making better decisions regarding which information is relevant to their information needs when there is a match between presentation format and task. We will measure performance through effectiveness and efficiency (Chung et al., 2005; Vessey and Galletta, 1991).

Effectiveness

Effectiveness of the visual format is measured by two factors: exactness and the F-value (Chung et al., 2005). Exactness refers to how well the visual format helps individuals find correct answers to closed-ended tasks (since those questions require specific answers). Precision measures how well an individual finds pertinent results (and avoid extraneous results). Recall measures how well an individual finds all relevant results. According to Chung et al. (2005), precision and recall are most appropriate for open-ended tasks since there are no specific answers. To create an answer key for the task, three experts (unfamiliar with the study), will perform the tasks in advance.

The formulas for exactness, precision, recall and F-value are (adapted from Chung et al., 2005):

$$\text{Exactness} = \frac{\text{Number of correctly answered questions}}{\text{Total number of questions}}$$

$$\text{Precision} = \frac{\text{Number of relevant results identified by the participant}}{\text{Number of all results identified by the participant}}$$

$$\text{Recall} = \frac{\text{Number of relevant results identified by the participant}}{\text{Number of relevant results identified by experts}}$$

$$\text{F-Value} = \frac{2 * \text{Recall} * \text{Precision}}{\text{Recall} + \text{Precision}}$$

When individuals are able to find the answers to their query without having to filter through unnecessary information, less cognitive effort will be required to complete the task, resulting in higher performance. For open-ended tasks, the F-value will determine effectiveness. For closed-ended tasks, exactness will determine effectiveness.

H2: Effectiveness will be higher when there is less cognitive effort required (i.e., when there is a match between the visualization format and the information-seeking task).

Efficiency

According to Chung et al. (2005), efficiency refers to the amount of time it takes individuals to complete the search task. We will measure efficiency for all open-ended tasks separately from the closed-ended tasks. For both tasks, subjects should be able to complete the task more quickly when less cognitive effort is required.

H3a: Subjects will take less time to complete the closed-ended task when there is less cognitive effort required.

H3b: Subjects will take less time to complete the open-ended task when there is less cognitive effort required.

Satisfaction

Individuals satisfied with the visualization of their query results should express a greater willingness to use that particular search engine again. DeLone and McLean (1992) state that one measure of IS success is user satisfaction. Turetken and Sharda (2005) use satisfaction as a measure to identify whether users were satisfied with a particular information format. Chung et al. (2005) measured "usability," which was defined as how satisfied users were with the browsing method. In this study, we use satisfaction as a surrogate for usability to measure users' assessment of the given information format. For measuring satisfaction, we will use a multi-item scale from Stasko et al. (2000). We believe when there is a match between information format and task, less cognitive effort will need to be invested, leading individuals to be more satisfied with the format.

H4: Satisfaction will be higher when there is less cognitive effort required.

Motivation

Motivation is defined as the amount of desire and willingness to complete the activity. We believe that an individual's motivation will affect their performance on completing the task regardless of a match between the format and task. Self-determination theory (SDT) (Deci and Ryan, 2000) states that individuals are motivated both intrinsically (completing a task or behavior voluntarily) and extrinsically (completing a task based on external rewards or forces rather than satisfaction from completing the task itself). When individuals are motivated to participate and complete the tasks, they will have higher levels of effectiveness and efficiency.

H5: Greater levels of motivation will have a positive effect on effectiveness.

H6: Greater levels of motivation will have a positive effect on efficiency.

To evaluate an individual's motivation, we will use the Situational Motivation Scale (SIMS) (Guay et al. 2000).

The research model is represented in Figure 6.

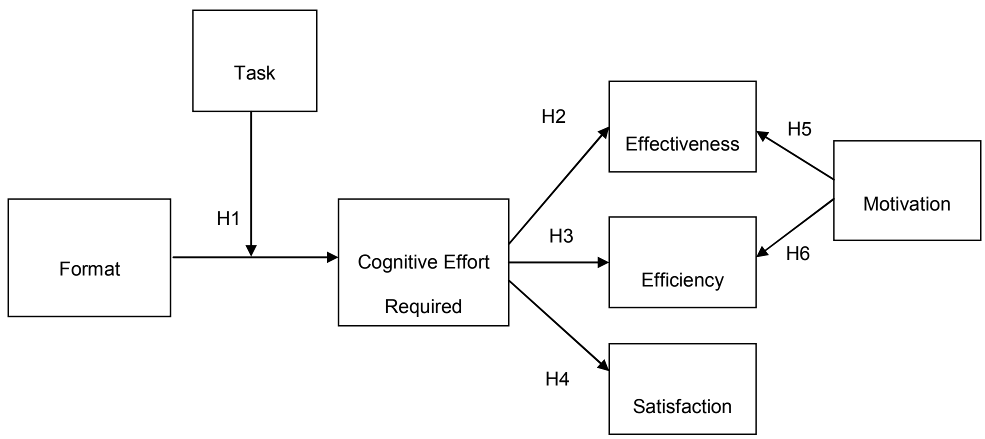

Figure 6: Research Model

Experimental Design

This study will be conducted using student subjects at a large university in the northeastern United States. We will collect demographic data such as age, gender, experience on the Internet, and primary language for each participant for control purposes.

This study will employ a between-subjects research design. Participants will be randomized to one of the four treatments (the method of presenting search results) and perform two tasks (Tasks "A" and "B"). In each treatment, half of the participants will perform Task A first, while the other half will perform Task B first. This will allow us to control for a learning effect that may develop while performing different tasks on the same prototype.

Task A will consist of open-ended questions and Task B will consist of closed-ended questions, based on characteristics of questions asked in similar studies (Turetken and Sharda, 2005; Chung et al., 2005). An example of a closed-ended question is "Find all the movies that have been set in Philadelphia" and an example of an open-ended question is "Create a tour for two people visiting Philadelphia, Pennsylvania for the first time."

We will use Structural Equation Modeling (SEM) to analyze the data. Because there is a mediating variable (cognitive effort), SEM will allow us to test the entire model at once instead of breaking it up into two parts. SEM also incorporates path analysis and factor analysis. A factor-loading will be conducted on the final instrument to analyze the discriminant and convergent validity of the constructs.

Contribution

This study makes several contributions. First, we will develop a visualization interface for search engine results using multiple cues: color, size and animation. Since color and size were previously used in visualization of search engine results, we are primarily interested in studying animation as a visual cue. Second, we will identify which tasks (closed-ended or open-ended) are a better cognitive fit with different presentation formats.

Third, the results of this study will help web designers understand the effects of animation on visualization, specifically regarding search engine results. Chen (2005) found that one of the unsolved problems of information visualization is aesthetics or identification of features that are insightful and visually appealing rather than utilizing features that are just appealing to the user. The results of this study will help designers of web search engines understand the impact of using animation as characteristics or features of information visualization for faster and better searching performance.

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