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Abstract

Effective visual presentation of information has become an increasing challenge in information systems research and practice. In this study, we examined the effects of information presentation on a system's communicating to its users the respective degree of relevance of different system-suggested items. Based on the (visual) attributes discussed by the referenced theories, different presentation displays, imagery and serial-order, were designed and evaluated in a computer-based experiment that included more than four hundred undergraduate subjects. Our overall results suggest that the imagery presentation format appears to be more effective than the serial-order presentation format in supporting the target concept communication. Imagery displays that simultaneously combine the use of size, distance and color are evidently more effective than designs based on exclusive (i.e., single) use of any of these visual attributes. Imagery displays based on size or distance appear to be more effective than color-based designs. Several implications for information presentation research and practice can be obtained from our findings and are also discussed.

Keywords: Information Presentation Format, Display Design, Concept Communication

1. Introduction

The recent proliferation of information systems (IS) and exciting Internet applications has made information presentation an increasingly important challenge in IS research and practice. While various multimedia applications have expanded considerably, the visual modality remains the dominant channel through which users interact with a system. Specifically, the communication of intended (abstract) concepts between a system and its user has been identified as a fundamental issue in human-computer interaction research (Shackel 1997). The system-user communication under discussion also represents an essential interface design requirement and often requires adequate visual presentation of information.

Investigation of alternative information presentation formats and their effects on user task performance has received fairly extensive attention in previous IS research, including Bebasat and Dexter (1985), Benbasat et al. (1986), Javenpaa and Dickson (1988), Tan and Benbasat (1994), Dennis and Carte (1998), and Tractinsky and Meyer (1999). A review of prior research suggests a predominant focus on use of information presentation to support individual decision-making. As a consequence, the discussion of system-user communication of (abstract) concepts has been limited, if any. Furthermore, most prior studies have concentrated on presentation formats and therefore have provided few insights into effective display design. Collectively,

findings from many prior studies appear to suggest that use of graphical presentations is likely to enhance user decision-making and other task performances. However, consistent empirical support for this conclusion is lacking. In response, a contingency approach has emerged in examining the reported inconsistent or contradictory results, particularly with regard to the relationship between task and presentation format. Vessey (1991), for instance, proposed a cognitive fit theory to systematically examine and explain the observed superiority of different presentation formats. Anchored in a fit between information presentation and task, the cognitive fit theory describes the theoretical underpinning between information presentation and task and the subsequent effects on individual task performance.

Most previous information presentation studies, including those centering on a presentation-task contingency or specifically the cognitive fit theory, have been broad and thus have provided limited theoretical or evaluative discussion at the visual attribute level. Understanding when and why a particular presentation format may be more adequate or effective than others is an essential step in information presentation research and practice. However, investigations also need to proceed toward the identification and evaluation of particular visual attribute(s) that contribute to effective presentation display designs. Arguably, this issue (i.e., identifying and evaluating the visual attributes essential to effective display designs) is of equal importance as the selection of an appropriate presentation format and represents a logical extension to the existing literature. In this light, connecting pertinent theories from the concerning disciplines with the research/practice need just described may represent a reasonable starting point for a cross-disciplinary approach. Bernard (1991) has advocated such approaches, commenting that additional research efforts are needed to explore desirable linkages between basic theories and effective human-computer interaction artifacts. Similarly, Pylyshyn (1991) also has called for combining theory development and basic research in cognition to generate visual presentation displays that are maximally informative.

The current study examined different presentation formats and display designs by investigating their effectiveness in supporting individual users' ability to comprehend the intended meaning of system-generated concepts. The specific research questions were as follows. (1). Does information presentation have significant effects on a user's comprehending the intended meaning of system-generated concepts? (2). Do different presentation formats and display designs vary significantly in the degree of their support of a user's comprehending the intended meaning of system-generated concepts? (3). What visual attributes effectively support a user's comprehension of the intended meaning of system-generated concepts?

Of particular relevance to the study is cognitive psychology, from which several established theories were drawn to provide a theoretical foundation for our hypothesis formulation, presentation format/display designs and subsequent evaluations. The study investigated both the serial-order (e.g., list-based or tabular) and the imagery (e.g., graphical) presentation formats. Based on the visual attributes discussed by the theories referenced, specific presentation displays, serial-order and imagery, also were designed and evaluated. The specific concept examined in the study was relevance, a fundamental abstract common to many IS applications. Using the responses collected from more than four hundred business-major undergraduate students, we experimentally tested our research hypotheses and discussed their implications for information presentation research and practice. In the following section, we review relevant previous IS

research and highlight several areas that may be mediated by related cognitive psychology literature.

2. Review of Relevant Previous IS Research

A considerable number of studies on information presentation effectiveness have been conducted since the early 1980s when fairly easy-to-use and economically affordable computer graphics became available in the business world. Examples include Lucas (1981), Remus (1984), DeSanctis (1984), Bebasat et al. (1986), Dickson et al. (1986), Jarvenpaa and Dickson (1988), Javenpaa (1989), and DeSanctis and Jarvenpaa (1989), Tan and Bebasat (1990, 1994), Vessey (1991), Vessey and Galletta (1991), Dennis and Carte (1998), and many others.

Most previous investigations have tended to concentrate on target task and presentation format. Moreover, a contingent approach appears to have prevailed, particularly with regard to the notion of match between information presentation and task. DeSanctis (1984) and Benbesat et al. (1986) commented that a mismatch between the task and presentation method might have been an important cause of the equivocal results reported by previous studies. Vessey (1991) went along with the notion of matching and proposed a cognitive fit theory to analyze the effects of graphical vis-à-vis tabular presentation on user task performance. Broadly, the theoretical premises of the described match-based contingent approach maintain that the way in which information is presented affects a user's formulation of the mental model essential to the task at hand, problem-solving process/strategy selection, and ultimate task performance effectiveness or efficiency. Empirical support of the presentation-task contingency approach, including the cognitive fit theory, has been reasonably strong (e.g., Vessey 1991, Vessey and Galletta 1991, Umanath and Vessey 1994, and Dennis and Carte 1998).

The dominance of the discussed concentration on target task and presentation format suggests at least two areas where additional investigations are needed. First, there is need for examining the effects of different presentation formats and displays on system-user concept communication. Second, identification and evaluation of specific visual attributes that contribute to effective display designs are also essential. Toward these ends, a detailed understanding of the user's comprehension of the visually presented information and concepts is essential and can be analyzed using related work in cognitive psychology.

3. Analysis of System-to-User Concept Communication: A HIP Perspective

Increasingly, human information processing (HIP) theory (Newell and Simon 1972) has emerged as an important and prevailing approach to explaining the probable relationships between information presentation and individual task performance. Within HIP, the human processor model (Card et al. 1983) is particularly relevant and interesting. According to this model, a human is indeed an information processor and, at a system level, consists of several sub-systems that include the perceptual (e.g., visual and auditory sensory systems), the cognitive and the motor. Each sub-system has its own processors and memories and interacts with the others to the complete a task.

Within the perceptual sub-system, the visual sensory system carries visual sensations or stimuli detected in the external world (e.g., a presentation display) to the visual processor, which then transforms them into perception-based knowledge and stores the resultant knowledge in the visual sensory store (i.e., a short-term memory). When making decisions about how to respond to the detected visual sensations or stimuli, the cognitive sub-system retrieves the internally coded

perception-based knowledge (created by the visual processor) into its working memory, together with relevant information retrieved from associated short- or long-term memories. Serial-order and imagery have been identified as two dominant schemas for coding internal perception-based knowledge. The information transformation processes performed by the visual processor can be broadly classified as perceptual or analytical, which respectively correspond with the visual or verbal processing discussed by Paivio (1986). With an adequate information presentation, a viewer's detection and comprehension of particular visual stimuli or cues may be greatly facilitated; thus, leading to desired or improved task performance.

Mackinlay (2000) has suggested an intuitive method for enhancing concept communication and comprehension through presentation, including the communication between a system and its users. Basically, an intended concept is vividly displayed by simulating a "visual object" that a viewer can readily comprehend and mentally manipulate in a way similar to maneuvering a very familiar physical object. For instance, let's assume that an individual highly familiar with maps or pictures (i.e., physical objects) is able to and often does recognize or distinguish the closeness, similarity, importance or proximity of the different objects included in a map or picture, based on the physical (e.g., geographical) distance that separates them. In this situation, the cognitive processor can directly manipulate the physical object (i.e., a map or picture) and easily recognize the adjacency- or distance-based semantics highly comprehensible to the individual. To communicate the respective similarity or relevance of different objects, a system hence can use a presentation display that contains a visual object that vividly resembles an underlying physical object (e.g., a map or picture) that is highly familiar to the user.

The method described can be augmented when a presentation display encompasses prominent (e.g., easy-to-detect) visual cues that would facilitate the internal coding of perception-based knowledge and, at the same time, prime (or trigger) appropriate cognitive processes which, in response, produce semantics (for the detected stimuli) consistent with that readily retrievable from the viewer's memories. Several visual attributes have been examined in cognitive psychology and the pertinent theories are described as follows.

4. Pertinent Cognitive Psychology Theories

Serial-order and imagery presentations have been identified as two essential but fundamentally distinct schemata for internal perception-based knowledge representation (Anderson 1995). This schema classification is consistent with the dual-code theory discussed by Paivio (1971, 1986), who suggested the use of different presentation formats for visual and verbal information. Perceptual (i.e., visual) processing primarily deals with graphics and pictures and thus may be better supported by an imagery presentation, partially because of its capability to preserve valuable spatial and inter-data relationships. On the other hand, a serial-order presentation is often used to represent symbolic information and thus is adequate for supporting tasks that require analytical (i.e., verbal) processing, in part because of its emphasis on discrete value and element categorization rather than direct conveyance of inter-data relationships.

Display sequence is an important visual attribute for serial-order presentations that include linear lists and tabular presentations. Viewers possess and often exhibit an interesting general capacity to reason about a serial order, independent of its content (Anderson 1995). Specifically, viewers usually commit or at least attempt to commit elements contained in a serial list in a fixed order, as manifested by front-anchoring and, to a lesser extent, end-anchoring (Sternberg 1969,

Angiolillo-Bent and Rips 1982). That is, a viewer tends to pay more attention to materials located at the beginning or the end of a document (or list) than those in the middle (Hogarth 1980). In this light, the display sequence in a serial-order presentation is important (Somberg 1986) and can be used to signify intended concepts; e.g., the relevance of different system-suggested items contained in a serial order presentation.

On the other hand, several imagery (visual) attributes have been identified as essential to a viewer's visual arousal and the resultant perception-based knowledge coding and semantics. Of particular interest are size, distance and color. The relationship between the size of an object and the resultant visual arousal and semantics has been examined. As summarized by Anderson (1995), findings from prior research suggest that a viewer's perception of the intensity or significance of the visual arousal produced by an object may increase with the object's physical size. In our context, relevance equates with significance and hence can be differentiated and communicated using nodes of different sizes (measured by their actual areas). That is, a system can use a large node to represent and communicate to the user an item that the system considers highly relevant to his or her search task.

The relationship between distance and visual arousal has also been evaluated. Respectively, Klein (1980) and Humphreys and Bruce (1989) examined the effects of distance on visual arousal and concluded that the intensity and perceived significance of visual arousal produced by an object may diminish with the distance between the object and the viewer's attention locus (e.g., anchor). The described distance-based significance is in congruence with the illusory mental model of information location discussed by Miller (1968). Furthermore, use of node-to-anchor distance to signify the relevance of different objects is also consistent with the proximity principle discussed by Marcus (1980), who suggested objects located near each other would appear to belong together. In our context, items placed close to a viewer's anchor term (i.e., attention locus) hence may be perceived by the viewer to be highly relevant to his or her search task. In effect, use of distance to signal significance, criticality or similarity is common in social psychology and organization behavior research, as manifested by the prevalent use of social distance and power distance in these areas. The central premise is that distance, physical or abstract, delineates clusters or classes; thus, objects existing in the physical world or representing abstract concepts may be perceived to bear more significance, similarity or relevance when they are placed in close adjacency to the attention locus (i.e., anchor).

Color is another motivating imagery (visual) attribute. Obviously, color codes may vary in hue, intensity (i.e., saturation) and brightness (Woodson 1981). In particular, colors of different hues may invite differing psychological or cognitive responses from viewers, who, as a result, may perceive the presented information or concepts differently (Townsend 1969). Murch (1995) has examined the effects of different color hues on visual arousal to and perception of viewers, concluding that red and blue may have contrasting connotations and thus should be used for different purposes. Broadly, red signals quick action and therefore may be effective for attracting attention, whereas blue invites receding attention. In our context, a system can use red or blue nodes to represent items highly or not highly relevant to the user's information needs.

5. Research Scope

Our research scope can be largely defined by presentation format and display, target concept, evaluation context, and user task. First, we distinguished between presentation format and

presentation display in our evaluation. In this study, "presentation format" refers to an arrangement category that follows a particular form or a consistent manifestation scheme. Both imagery[†] and serial-order presentation formats were examined. On the other hand, a "presentation display" refers to a particular presentation design distinctive in some underlying visual attribute(s) or cue(s). Different displays can be derived for the same presentation format. For instance, serial-order presentations may vary in display sequence; e.g., alphabetical order versus a rank-based sequence. Similarly, imagery presentations may use different visual attributes (e.g., size or color) to signify intended concepts. The explicit distinction was desirable and responded to the call by Benbasat et al. (1986) for examining information presentation with a finer granularity. To varying agrees, most (if not all) prior studies to date have treated graphics as a global item and have not differentiated various graphical displays. Investigating information presentation at the (visual) attribute level represents an important extension of prior IS research and may generate findings directly relevant and applicable to user interface design. When the overall superiority of one presentation format has been established or observed, it is desirable to opportunistically continue the evaluation from a general format to specific (visual) attributes.

The specific concept examined in the study was relevance, a common abstraction for denoting the extent to which one object is related to another within a defined context (Harter 1992). Our concept choice was based on its prevalence and significance and, at the same time, responded to calls for extending information presentation research beyond individual decision-making support. Informal observations of various business functions or activities suggest that abstract concepts often constitute common but critical information content in system-user interaction. When adequately represented, an intended system-generated concept may become increasingly comprehensible and meaningful to the user and thereby enhance his or her ability to act.

Specifically, the study concentrated on the concept communication that proceeds from a system to its users. Understandably, communication of intended concepts may and often does take place in both directions (Kammersgaard 1988). In an information search context, subject, key word, and selection criteria are common methods for representing user-provided concepts (to be communicated to a system). Complex representations have also been explored, including the use of case, example, feature, and structured and unstructured text. Relatively, the representation of system-generated concepts (to be conveyed to a user) has not yet received adequate attention. Informal observation of most systems designed for Internet resource discovery and online information retrieval suggest a prevalent, if not dominant, use of primitive serial-order presentations (e.g., lists) which may not be effective for the intended concept communication.

With regard to context, we focused on information search that is common and relevant across different systems and user populations. The particular task under evaluation was unknown-item search that involved multiple system-suggested items. Based on his or her knowledge about the search target(s), a user's information search task can be broadly characterized as known-item or unknown-item search (Yee 1991). In a known-item search, the user knows precisely or has a fairly good understanding of the particular object(s) he or she is seeking. On the other hand, a user embarking on an information search may not, and often does not, know exactly what the target objects are. Unknown-item searches are common and may become increasingly

[†] By imagery, we mean image-based presentation which is broader than and inclusive of the graphical presentations (i.e., bar chart and line graph) commonly examined by prior IS research.

challenging in situations where the user has to traverse multiple search spaces (e.g., topic domains) or has limited knowledge about them.

6. Research Hypotheses

Visual presentation of information can affect a viewer's internal perception-based knowledge coding and subsequent cognitive (i.e., problem-solving) process selection and execution, both of which ultimately determine his or her task performance (Anderson 1995). Hence, we posited that visual presentation of information has significant effects on a user's effectiveness in comprehending intended system-generated concepts and accordingly tested the following hypothesis.

H1: *Visual presentation of information has significant effects on the effectiveness of a user's comprehending intended system-generated concepts.*

In a nutshell, our target task, a viewer's use of visual observation to determine his or her perceived relevance between a displayed item and the search term, essentially involved abstract spatial inter-data relationships rather than discrete data values. The underlying processing is likely to be perceptual/visual rather than analytical/verbal. Thus, the imagery presentation format is considered to be more adequate than the serial-order format, especially when the imagery presentation contains prominent visual cues essential to stimulus detection and comprehension. As a result, a sought-after match to the underlying cognitive processes is likely to be established and, in turn, lead to increased concept comprehension on the part of the user. Accordingly, we tested the following hypothesis.

H2: *The imagery presentation format is more effective than the serial-order presentation format in supporting a user's comprehension of intended system-generated concepts.*

When presented with the same concepts using different imagery displays, users conceivably may respond differently. Based on the pertinent theories referenced, we used the discussed attributes to design different displays. We hypothesized these imagery displays would yield variable effectiveness in supporting the target concept communication. In addition, Wickens (1992) has proposed a proximity compatibility principle, suggesting integration of the multiple information sources required by a problem-solving task rather than displaying them in separate presentations. We accordingly postulated that imagery displays that simultaneously combine size, distance and color are more effective than imagery designs based on exclusive (sole) use of these attributes. Consequently, the following two hypotheses were also tested.

H3: *Imagery displays based on exclusive (i.e., single) use of size, distance or color are significantly different in their effectiveness in supporting a user's comprehending intended system-generated concepts.*

H4: *Imagery displays that simultaneously combine the use of size, distance and color are more effective than those based on exclusive (i.e., single) use of these visual attributes in supporting a user's comprehending intended system-generated targets.*

7. Presentation Display Designs

A total of six different presentation displays were examined: two in serial-order format and the others employing the imagery. In our baseline design for serial-order displays, the anchor term (i.e., search word) was placed at the top of a box and all the system-suggested items were placed inside the box, following a rank order and the ascending alphabetical sequence. In either design, the exact presentation sequence used in the display was not made available to subjects. The

front-anchoring approach was adopted in all the rank-order presentation displays; i.e., more relevant items were placed near the top of the box.

A total of four different imagery displays were evaluated: three based on the exclusive (or single) use of an investigated visual attribute (i.e., size, distance or color) and the fourth one combining these attributes simultaneously. In a size-based display, the physical size (i.e., area) of a node was used to denote and communicate the degree of relevance of the system-suggested item represented by the node. The exact node size was positively proportional to the relevance of the system-suggested item represented. In a distance-based display, the node-to-anchor distance was used to signify the relevance of the system-suggested item represented by the node. The exact node-to-anchor distance was inversely related to the relevance of the system-suggested item represented by the node. Color hue was the principal visual cue in color-based displays. We specifically focused on evaluating red and blue, using a color continuum with pure red at one end and pure blue at the other to signify extremely high relevance (i.e., 100% relevance) and no relevance (i.e., 0% relevance), respectively. In addition, we used white, a neutral color, to provide the necessary transition from one end of the continuum to the other. Thus, the color of a node would gradually and smoothly change and wane from red, to white and then gradually increase to blue as the system-determined relevance value continuously decreased.

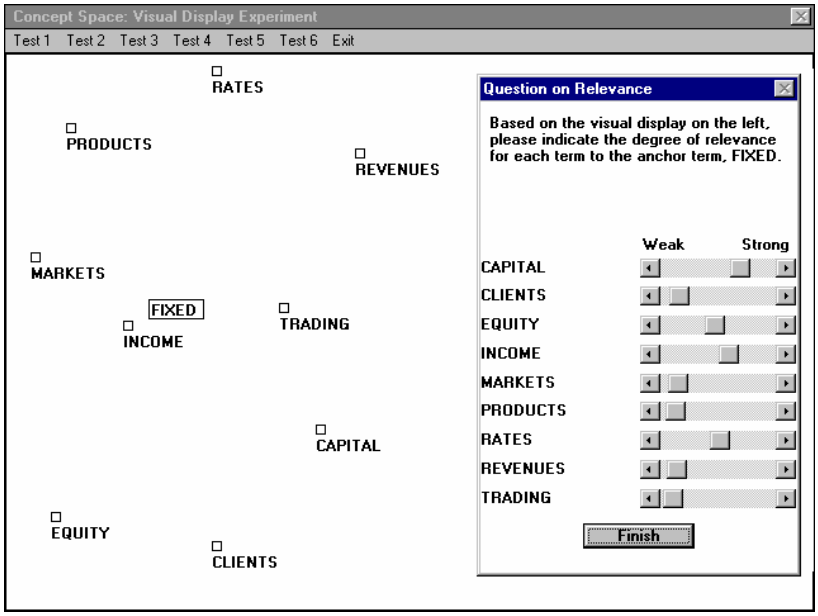

Figure 1: Sample Imagery Presentation Display – Distance-Based

Our baseline design for imagery presentation displays consisted of white nodes of equal size that were placed at an equal distance from the anchor term approximately located in the center of the computer screen. To evaluate a visual attribute, we exclusively manipulated that attribute in the display while keeping the others constant. For instance, both node size and node-to-anchor distance remained the same in a color-based display. Similarly, we manipulated the node size without changing node-to-anchor distance or node color in a size-based display. As shown in Figure 1, a distance-based display used white nodes of equal size that were placed at varying distances from the anchor term to signify the relevance of the respective system-suggested items

represented by these nodes. In addition, we also examined imagery presentation displays that combined the use of the investigated attributes (i.e., size, distance and color) simultaneously.

8. Study Design and Procedures

8.1 Study Design

A computer-based experiment was performed to test our hypotheses. The study design was detailed as follows.

Treatments: Each investigated display design constituted a treatment. Table 1 summarizes the treatments included in the study. When comparing the imagery vis-à-vis the serial-order presentation format, we aggregated evaluation results of all the displays belonging to each format and used the resultant composite data in the evaluative analysis.

Presentation Format	**Presentation Display (i.e., Treatment)**
Serial-Order	Ascending alphabetical order
Serial-Order	Rank-order with front-anchoring
Imagery	Size-based
Imagery	Distance-based
Imagery	Color-based
Imagery	Simultaneous use of size, distance and color

Table 1: Summary of Treatments Included in the Study

Subjects: The target subject pool was the incoming undergraduate class admitted to the business college at a major university in the southeastern United States. Choice of subjects was based on accessibility and their frequent information search needs. All subjects were enrolled in a "Computers in Business" course, which offered an introduction to Management Information Systems. Arrangements were made with the instructors teaching this course to solicit subjects' voluntary participation in the study in return for minor extra credit.

Experimental Design: We adopted a once-repeated measure experimental design (Winer 1971) in which each subject was presented with all the treatments randomly. Choice of the experimental design was made on the basis of its relative strength in testing our hypotheses while taking into account within-subject variations. Through randomization, our experimental design avoided the adverse effects of a fixed treatment sequence; thus, reducing potential biases resulting from the treatment order or carry-over effects. A display design was used in each search task. The exact task-display pairing was determined by the computer's system clock, which essentially served as a pseudo-random-number generator.

Host Information Retrieval System: The host information retrieval system was the concept-space retrieval system developed at the University of Arizona (Chen and Lynch 1992). Prior to the experimental evaluation, we prepared and submitted queries (i.e., search words) to the system, which returned a set of items presumably relevant to each search task submitted. Each system-suggested item had a weight value (ranging from 0 to 1) that represented its degree of relevance with respect to the submitted search word (as determined by the system).

Topic Domains: A total of three topic domains were included in the study: General Business, Linear Programming and Sino-British Negotiations. Choice of topic domains was made based on

input document availability and anticipated variations in subjects' knowledge about the respective domains. Based on results from pre-study interviews with a subset of the target subjects, General Business appeared to be the topic domain with which the target students were most familiar. Sino-British Negotiations, on the other hand, seemed to be the least familiar to the subjects. Together, these topic domains provided reasonable diversity, allowing us to explore the potential effects of users' domain knowledge on their comprehension of intended system-generated concepts conveyed by a presentation display. Sources for the input documents used in the study included Lexus/Nexus, Dow Jones News Retrieval, and ABI/INFORM.

Experiment Tasks: Sequentially, each subject was presented with the results of six different search tasks, two from each included topic domain. In each display, we included nine system-suggested items that varied in relevance to the anchor term; thus, making a total of ten items per display. The decision to include nine system-suggested items in each evaluation was based on the information processing capacity constraints discussed by Miller (1956). In addition, this design choice also followed the common practice of including approximately ten items in each display screen.

When evaluating a presentation display, a subject used his or her visual perception to judge each system-suggested item's relevance with respect to the anchor term and specified it by using the sliding ruler provided. Specifically, the question items and associated sliding rulers were placed side by side with the evaluated presentation display on the same computer screen. As sample task screen is shown in Figure 2. Subjects had unlimited time to evaluate each display but needed to complete all six tasks before exiting the experiment. Throughout the experiment, subjects were constantly reminded to avoid or suppress reliance on the semantics of the anchor term and

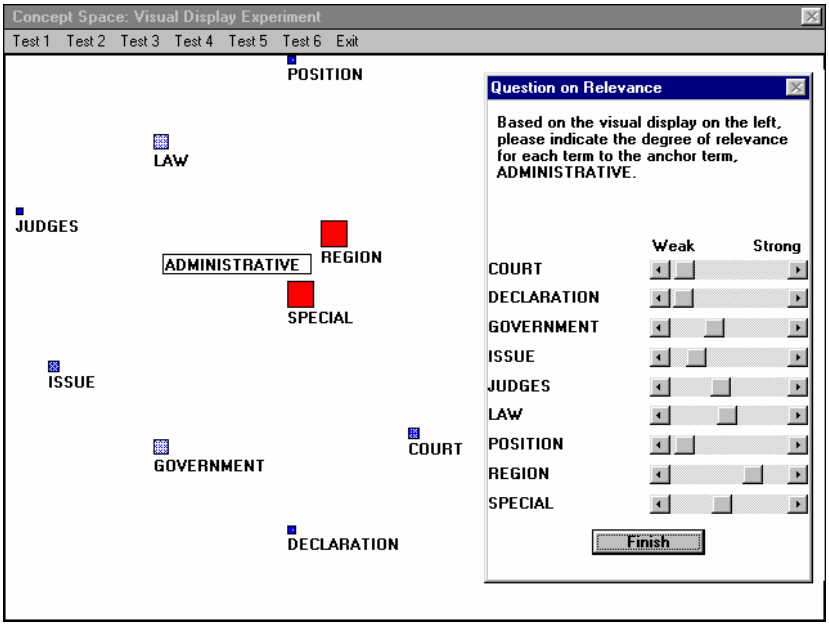

Figure 2: Sample Task Screen – Imagery Display Combining Size, Distance and Color

system-suggested items in their evaluations. The experiment flow was irreversible; that is, subjects could not retrieve or revise their evaluative responses once submitted.

Experiment Instrument: Developed in Borland C++, the experiment instrument selected a particular display design for each search task and presented to a subject the search results using that display. Respectively, a total of six display designs and search tasks were included, resulting in 36 possible task-display combinations from which the exact pairings for a subject were determined randomly by the computer's system clock. In each display design, the instrument included a set of sliding rulers, one for each question item. All sliding rulers were used to indicate a subject's perceived relevance, ranging from 0 to 100. To reduce the risk of incomplete responses, the instrument had built-in mechanisms that restricted a subject from proceeding to the next search task or taking an early exit from the experiment simply by clicking on the *Finish Button* located at the bottom of the computer screen. Thus, a subject could not exit from a current task without attempting to move the sliding rulers provided. The instrument also included a database developed with a Paradox Engine to collect subjects' responses submitted during the experiment.

Dependent Variable: Our dependent variable was a concept-deviation index. Effectiveness was the evaluative focus, denoting the accuracy level a user exhibited in comprehending intended system-generated concepts. We measured the effectiveness using a concept-deviation index whose value was obtained by averaging over all the system-suggested items (contained in the display) the absolute difference between the system-determined and the subject-perceived relevance for each item. For instance, the concept-deviation index value was 0.2 when, on average, the subject-perceived degree of relevance deviated by this amount from that determined by the system. When evaluating a presentation format, we obtained an overall concept-deviation index value by aggregating the index values from all the displays pertaining to that format and used the resultant (composite) value in the data analysis.

8.2 Study Procedures

Pretest: A pretest that involved 21 target subjects was conducted to fine-tune the experiment instrument and administration. The participants took part in the pretest voluntarily and were excluded from the subsequent study. Results from the pretest were satisfactory and led to several minor modifications in instrument design and experiment administration procedures. The subsequent formal study proceeded in multiple sessions, due to limited laboratory capacity. Each session included a maximum of 30 subjects. The same experimenters administered all the sessions, following a scripted process.

Experiment Administration: At the beginning of an experiment session, subjects were given several minutes to read a two-page summary that explained the purpose of the study and its overall procedures and intended data usage. The experimenters verbally reviewed the experiment purpose and process with the subjects who were then provided with a demonstration of the entire experiment process. Subjects were explicitly asked and constantly reminded to base their evaluations on visual perceptions rather than on the semantic meanings of the included items. Additional demonstrations were provided until all subjects clearly signaled their readiness for the study. All subjects were given unlimited time to complete the experiment but were repeatedly reminded to re-examine their responses before submission, because of the irreversible design of the instrument.

9. Data Analysis Results and Discussion

Of the 512 target subjects, 438 took part in the study, showing an 85.5% participation rate. The research results specific to the hypothesis testing are discussed as follows.

9.1 Effects of Information Presentation (H1)

We performed an analysis of variance (ANOVA) to examine the effects of information presentation on the target concept communication. As shown in Table 2, our analysis results suggested that effects of information presentation on the target concept communication were of statistical significance, as indicated by a p-value of less than 0.01. Thus, Hypothesis 1 was supported.

	Source	SS	DF	MS	F	P-Value
Concept-Deviation Index	Display	32,823	5	6,364.6	47.5	< 0.01
	Error	292,731	2,185	134.0		

Table 2: ANOVA - Effects of Information Presentation on Target Concept Communication

9.2 Comparative Evaluation of Serial-Order and Imagery Presentation Format (H2)

The imagery presentation format appeared to be more effective than the serial-order presentation format in supporting the target concept communication. The observed superiority of the imagery over the serial-order format was of statistical significance, as suggested by the p-value being less than 0.01. As shown in Table 3, a user was likely to comprehend intended system-generated concepts more accurately when provided with an image rather than a serial-order presentation. Thus, responses from the subjects supported Hypothesis 2.

	Serial-Order Format	Imagery Format	Difference	P-Value
Mean (S.D.)	37.6 (12.8)	34.0 (14.7)	3.6	< 0.01

Table 3: Comparative Analysis of Imagery and Serial-Order Presentation Format

9.3 Evaluations of Different Visual Attributes (H3 & H4)

Using two- and one-tailed student-t statistics, we performed a series of pair-wise comparisons to test Hypotheses 3 and 4, respectively. Our data analysis results suggested that imagery displays were consistently and significantly more effective than any serial-order design, regardless of the specific imagery visual attribute(s) used. As shown in Table 4, displays based on exclusive use of color were significantly less effective than those based on the single use of size or distance. Size-based displays were more effective than the distance-based designs. However, the improvement was not significant statistically. Thus, Hypothesis 3 was partially supported. While exhibiting significant improvements over the color-based designs, displays simultaneously combining the use of size, distance and color were not significantly more effective than those based on single use of size or distance (as shown in Table 4). Thus, Hypothesis 4 was also partially supported.

	Color-Based	Distance-Based	Size-Based	Combined
Mean (S.D.)	39.5 (13.0)	33.0 (15.7)	31.6 (13.6)	31.7 (14.8)
Difference		6.5	1.4	-0.01
P-Value		< 0.01	> 0.05	> 0.05

Table 4: Comparative Analysis of Different Imagery Presentation Displays

10. Conclusion and Future Research

Overall, our findings can be summarized as follows. First, information presentation appears to have significant effects on a user's effectiveness in comprehending intended system-generated concepts. Second, the imagery presentation format is more effective than the serial-order format for communicating intended system-generated concepts to users. Third, imagery displays that simultaneously combine the use size, distance and color are probably more effective than designs based on exclusive use of one of these visual attributes. Fourth, displays based on exclusive use of color are significantly less effective than those based on single use of size or distance.

The study has contributed to information presentation research in several ways. Responding to the call for a well-grounded approach to examining information presentation, we used the HIP-based model human processor to analyze the process of a viewer's comprehending intended concepts conveyed by a system. We extended prior IS research by applying pertinent cognitive psychology theories to examine different information presentations at the (visual) attribute level. Thus, our study findings shed light on the particular visual attributes potentially contributory to effective display designs. Our evaluation also supplemented the decision-making focus of most prior research. Specifically, we examined system-to-user concept communication, a fundamental aspect of human-computer interaction that has not yet received adequate attention. Last but not least, we included different topic areas in our evaluation to explore the potential effects of user domain knowledge on the magnitude and significance of presentation-enhanced concept communication between a system and its users.

Results from the study have also benefited information presentation practices, particularly in user interface design for effective human-computer interaction support. Compared with the serial-order presentation format common to modern information systems, imagery presentations may offer a more interesting, natural and effective alternatives for supporting a system's conveying an intended concept to its users. Developers of Internet-based search systems and online information retrieval systems may need to seriously consider use of imagery displays that contain appropriate, possibly multiple, visual attributes to represent and communicate essential information/concepts, especially in situations where users exhibit limited knowledge about the search domain(s). As suggested by Lancaster and Warner (1993), text may not be the most effective presentation format for information retrieval systems and thus alternative presentations need to be explored and evaluated. Inclusion of multiple visual attributes in an interface design may be worth consideration. As suggested by our findings, imagery displays that simultaneously combined the use of size, distance and color were more effective than those based on exclusive (single) use of one of these attributes. Size and distance may be significantly more effective than color in supporting system-to-user concept communication. Equipped with these findings, system developers arguably may become increasingly capable of selecting and bundling potentially complementary visual attributes in their presentation and interface designs.

As a point of departure for continued investigation of information presentation for system-to-user concept communication support, this study has several limitations. First, the visual attributes examined in the study were fairly primitive. For example, our distance-based display evaluation used the linear node-to-anchor distance rather than a multi-dimensional representation. Conceivably, the relevance of different nodes of equal distance from the anchor term may be perceived differently, depending on the precise node location on a 2- or 3-dimensional display. Similarly, our color evaluation focused on color hue and basically was confined to a red-versus-blue comparison, due to the theory referenced. Understandably, users may perceive color codes of same hue but different saturation or brightness as having different connotations. In addition, users' perceived effectiveness of different presentation formats and displays may be culture-specific. Drawn from a particular geographic region, our subjects possibly might have exhibited considerable differences in visual arousal detection and comprehension, as compared with users in other parts of the world. These limitations and others represent some areas that need further research attention.

References

Anderson, J.R., *Cognitive Psychology and Its Implications*, 4th edition, W.H. Freeman and Company, New York, NY, 1995.

Angiolillo-Bent, J.S. and L.J. Rips, "Order Information in Multiple Element Comparison," *Journal of Experimental Psychology: Human Perception and Performance*, 8 (1982), 392-406.

Bernard, P., Bridging Basic Theories and the Artifacts of Human-Computer Interaction in *Design Interaction: Psychology in the Human-Computer Interface*, J.M. Carroll (Eds.), Harvard University Press, Cambridge, MA, 1991.

Benbasat, I. and A.S. Dexter, "An Experimental Evaluation of Graphical and Color-enhanced Information Presentation," *Management Science*, 31 (1985), 1348-1364.

Benbasat, I., A.S. Dexter and P. Todd, "An Experimental Program Investigating Color-enhanced and Graphical Information Presentation: An Integration of the Findings," *Communications of the ACM*, 29 (1986), 1094-1105.

Card, S.K., Noran, T.P., and Newell, A., *The Psychology of Information-Computer Interaction*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1983.

Chen, H. and K.J. Lynch, "Automatic Construction of Networks of Concepts Characterizing Document Databases," *IEEE Transactions on Systems, Man and Cybernetics*, 22 (1992), 885-902.

Dennis, A.R. and T.A. Carte, "Using Graphical Information Systems for Decision Making: Extending Cognitive Fit Theory to Map-based Presentations," *Information Systems Research*, 9 (1998), 194-203.

DeSanctis, G. "Computer Graphics As Decision Aids: Directions for Research," *Decision Sciences*, 15 (1984), 463-487.

Dickson, G.W., G. DeSanctis and D.J. McBride," Understanding the Effectiveness of Computer Graphics for Decision Support: A Cumulative Experimental Approach," *Communications of the ACM*, 29 (1986), 40-47.

Harter, S.P., Psychological Relevance and Information Science, *Journal of the American Society for Information Science*, 43 (1992), 602-615.

Hogarth, R.M., *Judgment and Choice: The Psychology of Decision*, Wiley, New York, N.Y., 1980.

Humphreys, G.W. and V. Bruce, *Visual Cognition: Computational, Experimental, and Neuropsychological Perspectives*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1989.

Jarvenpaa, S.L. and G.W. Dickson, "Graphics and Managerial Decision Making: Research-based Guidelines," *Communications of the ACM*, 31 (1988), 764-774.

Javenpaa, S.L., "The Effects of Task Demands and Graphical Format on Information Processing Strategies," *Management Science*, 35 (1989), 285-303.

Kammersgaard, J., "Four Different Perspectives on Human-computer Interaction," *International Journal of Man-machine Studies*, 28 (1988), 343-362.

Klein, R., Does Oculomotor Readiness Mediate Cognitive Control of Visual Attention in *Attention and Performance*, R.S. Nickerson (Eds.), Lawrenece Erlbaum Associates, Hillsdale, NJ, 1980.

Lacaster, F.W. and A.J. Warner, *Information Retrieval Today*, Information Resources Press, Arlington, VA, 1993.

Lucas, H.C., "An Experimental Investigation of the Use of Computer-based Graphics in Decision Making," *Management Science*, 27 (1981), 757-768.

Mackinlay, J.D., "Opportunities for Information Visualization," *IEEE Computer Graphics and Applications*, 20 (2000), 22-23.

Marcus, A., "Computer-assisted Chart Making From the Graphic Designer's Perspective," *Proceedings of SIGGRAPH '80*, Seattle, Washington, July 14-18, 1980, 1-6.

Miller, G.A., "The Magic Number Sever, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *Psychological Review*, 63 (1956), 81-97.

Miller, G.A., "Psychology and Information," *American Documentation*, 19 (1968), 286-289.

Murch, G., Color Graphics: Blessing and Ballyhoo in *Readings in Human-Computer Interaction: Toward the Year 2000*, 2nd edition, R.M. Baecker et al. (Eds.), Morgan Kaufmann Publishers, San Francisco, CA, 1995.

Newell, A., and H.A. Simon, *Human Problem Solving*, Englewood Cliffs, NJ, Prentice-Hall, 1972.

Paivio, A., *Imagery and Verbal Processes*, Holt, Rinehart & Winston, New York, NY, 1971.

Paivio, A., *Mental Representations: A Dual Coding Approach*, Oxford University Press, New York, NY. 1986.

Pylyshyn, Z.W., Some Remarks on the Theory-Practice Gap in *Designing Interaction, Psychology at the Human Computer Interface*, edited by J.M. Carroll, Cambridge University Press, Cambridge, UK, 1991.

Remus, W.E., "An Empirical Investigation of the Impact of Graphical and Tabular Data Presentations on Decision Making," *Management Science*, 30 (1984), 533-542.

Shackel, B., "Human-computer Interaction – Whence and Whither," *Journal of the American Society for Information Science*, 48 (1997), 970-986.

Somberg, B.L., "A Comparison of Rule-based and Personally Constant Arrangements of Computer Menu Items," *Human Factors in Computing Systems and Graphics*, Proceedings of CHI+GI Conferences, Boston, MA, The Association for Computing Machinery, Inc. 1986.

Sternberg, S., "Memory Scanning: Mental Processes Revealed by Reaction Time Experiments," *American Scientist*, 57 (1969), 421-457.

Tan, J.K. and I. Benbasat, "The Effectiveness of Graphical Presentation for Inormation Extraction: A Cumulative Experimental Approach," *Decision Sciences*, 24 (1994), 167-191.

Tan, J.K. and I. Benbasat, "Processing Graphical Information: A Decomposition Taxonomy to Match Data Extract Tasks and Graphical Representation," *Information Systems Research*, 1 (1990), pp.416-439.

Townsend, B., "The Physiology and Psychology of Color," *British Journal of Photography*, 125 (1969).

Tractinsky, N. and J. Meyer, "Chartjunk or Goldgraph? Effects of Presentation Objectives and Content Desirability on Information Presentation," *Management Information Systems Quarterly*, 23 (1999), 397-420.

Umanath, N.S. and I. Vessey, "Multi-attribute Data Presentation and Human Judgment: A Cognitive Fit Perspective," *Decision Sciences*, 25 (1994), 795-824.

Vessey, I., "Cognitive Fit: Theory-based Analyses of the Graphs Versus Tables Literature," *Decision Sciences*, 22 (1991), 219-241.

Vessey, I. and D. Galletta, "Cognitive Fit: An Empirical Study of Information Acquisition," *Information Systems Research*, 2 (1991), 63-84.

Wickens, C.D., *The Proximity Compatibility Principle: Its Psychological Foundation and Its Relevance to Display Design*, Technical Report, ARL-92/NASA92-3, Aviation Research Laboratory, Institute of Aviation, University of Illinois at Urbana-Champaign, 1992.

Winer, *Statistical Principles in Experimental Design*, McGraw Hill, New York, NY, 1971.

Woodson, W.E., *Human Design Handbook*, McGraw-Hill, New York, NY, 1981.

Yee, M.M., "System Design and Cataloging Meet the Users: User Interface Design to Online Public Access Catalogs," *Journal of American Society for Information Science*, 42 (1991), 78-98.