Interactive Data Visualization: New Directions for Accounting Information Systems Research

ABSTRACT: Many companies today utilize interactive data visualization to present accounting information to external users on their investor relations web sites and to internal users in applications such as enterprise resource planning, Balanced Scoreboard, network security, and fraud detection systems. We develop a taxonomy for examining the current state of interactive data visualization research related to accounting decision making. We organize our review around three themes: the relationship between task characteristics and interactive data visualization techniques, the relationship between decision maker characteristics and interactive data visualization techniques, and the impact of interactive data visualization techniques on decision processes and outcomes. The review categorizes relevant research, describes the research questions addressed, and suggest avenues for further research.

Keywords: interactive data visualization; web-based financial reporting; information selection/navigation
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Research

I. INTRODUCTION

Accounting information systems (AIS) produce vast amounts of data for use by decision makers both outside and within organizations. While companies now typically report external financial information on a quarterly basis, the possibility of real-time financial reporting via the World Wide Web currently exists. Companies using enterprise resource planning (ERP) and Balanced Scorecard (BSC) systems produce extensive data for use in internal decision making. Similarly, internal control mechanisms such as network security systems and fraud detection tools produce voluminous, complex data. These developments raise the question of how decision makers can organize and make sense of the volumes of data flowing between and within organizations. Interactive data visualization is an important tool for achieving this objective.

Interactive visualization of data in financial reporting and auditing contexts is increasingly common. Several companies currently incorporate interactive data visualization features on their investor relations web sites, such as hyperlinked tables of contents, dynamic graphic images, and search engines (Kelton and Yang 2008). Recently, the Securities and Exchange Commission (SEC) mandated that all publicly held companies furnish financial statement information in extensible business reporting language (XBRL) (SEC 2008). Data submitted as XBRL will facilitate the development of interactive data viewers which allow investors to find, download, view and compare financial information across companies (Twarowski 2008; SEC 2009a, 2009b) (See Figure 1). Further, audit firms are considering using interactive data visualization to streamline analytical procedures (Bay et al. 2006; Gunn 2007).

Insert Figure 1 about here.
Companies are also using interactive data visualization tools to make sense of the vast amounts of data produced by and stored within their information systems. Dashboards, which allow users to choose among and simultaneously display multiple data representations (i.e., tables, graphs, gauges, and other visual indicators) are a popular device for organizing and displaying data produced by enterprise resource planning (ERP) and Balanced Scorecard (BSC) systems (Edwards 2005; Active Strategy 2009; SAP 2009) (See Figure 2). Similarly, companies use interactive data visualization systems to help analyze the complex, voluminous data produced by network security systems (Conti 2007; Marty 2009) (See Figure 3.) and fraud detection tools (Eick and Fyock 1996; Senator et al. 2002).

Information (or data) visualization, refers to the “use of computer-supported, interactive, visual representations of data to amplify cognition, or the acquisition and use of knowledge” (Card et al. 1999, 6). Spence (2007) suggests that information visualization consists of three elements: interaction (i.e., acquisition of different “views” of data), selection (i.e., choosing which data to display), and representation (i.e., the manner in which data are depicted or portrayed). Interaction involves the dialog between the decision maker and system as he or she explores the data set to uncover new insights. Selection refers to navigating through large or complex data sets, then choosing a subset of data for display. Information representation involves the mapping from data to representation and how that representation is rendered on a computer display. Representations can be in text or in a variety of graphical formats. In contrast to static information visualization where preparers select information items and their display

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1 Our description uses the same terms for the first and third elements as Spence’s (2007) text. We use the term “selection” to describe the second element instead of his term “presentation.”
format for decision makers, with *interactive* information visualization, users are allowed a choice of which data to display, how to represent the data, or both.

Extensive research on information visualization appears in the information systems (IS) literature. Earlier research (DeSanctis 1984; Jarvenpaa and Dickson 1988) finds conflicting results with respect to the efficacy of alternate information representation formats. Subsequent work provides evidence that cognitive fit between task and representation (Vessey 1991; Vessey and Galletta 1991) and between decision maker characteristics and representation (Shaft and Vessey 2006) supports more efficient information acquisition and more accurate decision maker performance. Thus, if the information representation format does not match task characteristics or is not appropriate for the cognitive style or expertise level of the decision maker, performance will be lower than with a format that achieves a fit. In an interactive context where there is an information representation choice, little is known about to what extent and under what conditions decision makers are able to choose the representation that provides the best fit to the task and their own individual characteristics. The cognitive fit perspective suggests that the superiority of interactive visualizations (i.e., those that allow decision makers to choose which data are viewed and how they are represented) over static visualizations (i.e., those where the data views and representations are selected by the designer) depends not only on task and decision maker characteristics, but also on the decision maker’s insight into which representation is best for a given task.

An alternate perspective based primarily on marketing research suggests that interactive visualization will improve task performance, regardless of task and decision maker characteristics. Interactive visualization tools give decision makers increased control over the flow of information (Ariely 2000), allow them to restructure the information environment (Eick
and Wills 1995), and lower the cognitive cost of restructuring information (Coupey 1994). Lurie and Mason (2007) use these findings to argue that managers using interactive visualization tools will be more likely to consider multiple factors than those using static representations, and thus use more compensatory processing strategies and make more accurate decisions.

Recent research provides important insights into the potential effects of interactive presentation of financial data on investor decision making beyond changes in information acquisition behavior. This research provides evidence that investors perceive information presented in interactive or media-rich environments to be more reliable or trustworthy (Hodge 2001; Elliott et al. 2009). Such perceptions based solely on the information environment could be problematic, as these same studies indicate that investor perceptions of information reliability and trustworthiness are positively correlated with their evaluations of earnings potential. Misplaced trust in financial information could lead to investors making inappropriate judgments.

In this paper, we present a framework that examines linkages between task and decision maker characteristics and interactive data visualization. The framework also examines the link between interactive data visualization and decision processes and outcomes. We review literature related to these linkages. In doing so, we compare the theoretical framework commonly used in the IS literature, which suggests that the efficacy of interactive visualization tools is contingent on task and decision maker characteristics to that commonly used in the marketing and judgment / decision making literatures, which suggests that interactive data visualization will be superior to static visualization in most cases. We also examine specific applications to decision making in financial accounting, managerial accounting, auditing, and accounting information systems and discuss opportunities for future interactive information visualization research related to these areas.
II. A TAXONOMY OF INTERACTIVE DATA VISUALIZATION RESEARCH

In contrast to static data visualization, interactive data visualization enables decision makers to navigate to and select the information they view as most relevant for decision making (i.e., interactive selection), specify the format used to display this information (i.e., interactive visual representation), or both. Thus, interactive data visualization is an “on demand” visualization process that allows decision makers to navigate to selected data and display it at various levels of detail and in various formats. As shown in Table 1, interactive data navigation and selection tools allow decision makers to perform functions such as marking data items of interest for further examination, exploring a large set of data through hyperlinks or visual panning techniques, changing the level of abstraction of a data representation (i.e., altering the data view from an overview down to details of individual cases), and filtering data through query tools. Interactive representation tools allow the decision maker to change the encoding of data (i.e., from tables to graphs or vice versa), reconfigure displays of graphical data, and connect data items in large or complex displays.

Insert Table 1 about here.

We organize our review of interactive data visualization research around the framework depicted in Figure 4. This figure depicts interactive data visualization characteristics (i.e., decision makers’ information selection behavior and choice of visual representation) as a direct function of decision maker and task characteristics. Interactive data visualization characteristics affect the decision maker’s decision making frame, which in turn affects decision processes and outcomes. The framework shown in Figure 4 implies three linkages that are used to develop the taxonomy of research questions listed in Table 2.
We identified studies that addressed at least one of the relationships implied by the research questions in Table 2. These studies are generally published in accounting, AIS, or IS journals. We began by selecting 14 of the 15 journals reviewed by O’Donnell and David (2000) and added one accounting journal, one AIS journal, and three IS journals in which papers relevant to our research questions appeared. Thus, we selected the following 19 journals for review: *Accounting Horizons, Accounting Management and Information Technologies* (subsequently *Information and Organization*), *Accounting, Organizations and Society*, the *Accounting Review*, *Advances in Accounting Behavioral Research*, *Advances in Accounting Information Systems* (subsequently *International Journal of Accounting Information Systems*), *Auditing: A Journal of Practice and Theory*, *Behavioral Research in Accounting*, *Communications of the ACM*, *Decision Sciences*, *Decision Support Systems*, *Information and Management*, the *Journal of Accounting Literature*, the *Journal of the Association for Information Systems*, the *Journal of Information Systems*, *Information Systems Research*, and *MIS Quarterly*. We reviewed papers appearing in these journals from 1989 to 2009. In addition, we reviewed citation lists from the papers selected out of the accounting, AIS, and IS journals (both articles cited by the identified papers and articles which subsequently cited the papers) to identify papers for inclusion from the decision making and marketing literatures. The additional papers selected were relevant to the research questions listed in Table 2 and involved accounting, information systems, or other business-related tasks.

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2 We identified no papers relevant to our review in *Accounting Horizons, Auditing: A Journal of Practice and Theory, Behavioral Research in Accounting*, or the *Journal of Accounting Literature*. 
Our review of the papers related to the Table 2 research questions is organized as follows. First, we examine the link between task and interactive data visualization characteristics. Second, we examine the link between decision maker and interactive data visualization characteristics. Third, we examine the links between interactive information visualization characteristics and decision processes and outcomes. Within each section, we first review literature related to the questions listed in Table 2, then discuss opportunities for future research.

**Task Characteristics and Interactive Data Visualization Characteristics**

As shown in Table 2, we organize our discussion of the literature addressing the relationship between task and interactive data visualization characteristics around two questions:

1.1 How do task characteristics influence information navigation and selection behavior?
1.2 How do task characteristics influence information representation choices?

Table 3 lists studies related to these questions.

Insert Table 3 about here.

**Task Characteristics and Information Navigation / Selection**

Our initial search of the literature did not identify any articles that directly addressed how task characteristics influenced information navigation and selection behavior. Instead, we discuss the results of several studies which indicate that the benefits of interactive information navigation techniques may or may not depend on task characteristics. Ramarapu et al. (1997)

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3 Note that we do not directly examine a link between information visualization and the user’s decision making frame, or internal problem representation. While this linkage is an important component of the theories utilized in information visualization research (e.g., Vessey 1991; Shaft and Vessey 2006; Lurie and Mason 2007), this research typically does not directly examine this linkage, as decision making frames are difficult to directly assess. Instead, it examines the impact of alternative information visualizations on decision process variables and outcomes, which are more easily observed.
find that decision makers performing perceptual (spatial) tasks using nonlinear (i.e., hyperlinked) text displays make more accurate and faster decisions and have higher user satisfaction than those using linear (i.e., hierarchical) displays. Those performing analytical (symbolic) tasks make faster decisions and have higher user satisfaction when using linear displays, but are not more accurate.

Gonzalez and Kasper (1997) find that decision makers using a parallel information navigation interface (i.e., one that allows search of cues in any order) make better decisions for both familiar and unfamiliar multi-attribute choice tasks than ones using a sequential interface (i.e., one that requires search in a predefined order). Ariely (2000) finds that in general, consumers making choices in an interactive online environment liked the interface and had greater confidence in their decisions when the interface controlled information flow, i.e., the order in which information items were presented. However, participants given the high information control interface made lower quality decisions on difficult tasks. Thus, unstructured information navigation interfaces may result in better decisions on complex multi-attribute tasks, regardless of user perceptions.

Kumar and Benbasat (2004) find that interactive dynamic labeling of 3D graphs improves data comprehension performance on both simple and complex tasks. Dull and Tegarden (1999) also find that individuals using a rotatable 3D representation of momentum accounting data make more accurate predictions. Both studies therefore suggest that interactive navigation tools will improve performance on tasks involving three-dimensional data.

Goswami et al. (2008) show that an interactive chaining visualization tool decreases error detection time and increases user confidence for correcting spreadsheet link errors, but not for correcting non-link errors, thus demonstrating the importance of cognitive fit between task and
interactive visualization tool. Shmueli et al. (2006) describe a set of tools for the collection, representation, and interactive exploration of online auction data. They present an analysis suggesting that individuals who follow a semi-structured exploration process supported by interactive data representation will be able understand more effectively the characteristics and dynamics of online auction markets.

**Task Characteristics and Information Representation Choices**

Wilson and Zigurs (1999) is the only study identified in our search which directly examines the relationship between task characteristics and information representation choices. Participants in one experimental condition were assigned to perform either symbolic or spatial tasks, and allowed to choose the display representation they preferred. Seventy-seven percent of participants chose display representations consistent with cognitive fit theory for symbolic tasks, while only 46 percent chose consistently for spatial tasks.

Other studies provide indirect evidence as to when it may be appropriate to allow decision makers to choose their own display representations. Speier and Morris (2003) find that decision makers searching a real estate database are more accurate with a visual query interface for high-complexity tasks and more accurate with a text-based interface for low-complexity tasks. This suggests that for database search tasks, it may be appropriate to provide guidance in representation choice to the decision maker, depending on task complexity. Huang et al. (2006) find that decision makers extracting information from a database of expertise data are more efficient using graphs as opposed to tables to associate, compare, distinguish, and cluster data items. They also prefer using graphs versus tables for these tasks. On the other hand, there were no differences between graphs and tables for either efficiency or format preference for ranking tasks. In addition, presentation format did not affect judgment accuracy for any of the tasks. The
results therefore suggest that allowing decision makers to select their preferred representation format may improve decision efficiency, but not accuracy.

Speier (2006) examines the relationship between cognitive fit and decision making performance for low- and high-complexity data acquisition tasks in a production planning setting. Results are consistent with cognitive fit theory for low-complexity tasks and for high-complexity spatial tasks. However, decision makers performed similarly with graphs and tables in high-complexity symbolic tasks, indicating that at some point in the information evaluation stage, task complexity induces a cross-over point where the decision-maker begins to rely more on their perceptual processes for information acquisition. An implication of this finding is that as task complexity increases, allowing decision makers to choose information representations for symbolic tasks may result in more accurate and efficient decisions.

Peng et al. (2007) find that in a multi-dimensional hierarchical display of sales and advertising expense data where "drill-down" search is required to minimize decision error, cognitive fit between cues and representation minimizes judgment error attributed to non-predictive consolidated signals. Where consolidated signals are predictive, cognitive fit does not affect decision error. These results suggest that for decisions supported by multi-dimensional hierarchical data displays, allowing the decision maker to choose the information representation may only be effective for less complex tasks.

Research with respect to the efficacy of graphs for decision making involving multi-dimensional data is mixed. Umanath and Vessey (1994) find that participants using graphs to make bankruptcy predictions based on multi-attribute data are more accurate than those using tables, although the difference in accuracy between graphs and tables decreases as cognitive load increases. On the other hand, Jarvenpaa (1990) finds that in a multi-attribute, multi-choice task,
participants acquired only the visual salience of cues in graphical displays and not the particular weighting and importance of the attributes. Dilla and Steinbart (2005) find that performance evaluations made using supplemental graphical displays of Balanced Scorecard information exhibited lower consensus and consistency compared to those made using supplemental tabular displays. Finally, Hutchinson et al. (2009) find that graphical displays of sales and advertising expense data failed to mitigate biases in multi-attribute budget allocation decisions.

Future Research

As discussed above, we were unable to identify any published articles in the accounting, AIS, or IS literatures that directly examine information navigation and selection behavior. There are technological barriers to conducting such research—while research software can provide data on viewing behavior for static displays, tracing which data and representations a decision maker is viewing in an interactive environment can be a difficult problem. However, mouse tracking software is now widely used by practitioners to run website usability tests (Arroyo et al. 2006) and has been shown to produce data consistent with that obtained from eye tracking devices (Rodden and Fu 2007). Thus, experimental software that produces a reliable record of participant data viewing and manipulation behavior is indeed feasible.

Further, while the papers reviewed above suggest that interactive information navigation and selection may improve decision quality in complex tasks or tasks involving multi-dimensional data, there is not a strong theoretical framework for specifying the types of information navigation and selection strategies that are the best fit for various tasks. There is a significant body of research on information navigation and selection in the human factors area, but it focuses almost exclusively on describing strategies to enhance data analysis (Tory and Möller 2004; Yi et al. 2007). Future designs might not only enhance data analysis, but also
visually display decision makers’ mental models and help improve their mental models by finding supporting and contradictory evidence for their judgment hypotheses. Tory and Möller (2004) indicate a need for developing visualization designs based on perceptual and cognitive theories, building prototypes of these designs, and then empirically testing their effectiveness.

Earlier accounting research suggests possible directions for investigating how data selection and navigation tools might assist in the performance of auditing and accounting related tasks. There are studies which examine in detail the data acquisition and processing strategies of audit professionals (e.g., Biggs and Mock 1983; Biggs et al. 1988; Johnson et al. 1993), management accountants (Shields 1980, 1984), and financial statement users (Biggs 1984; Biggs et al. 1985; Biggs et al. 1993; Hunton and McEwen 1997). Data from these studies might be used to form propositions about information navigation and selection features that would best support auditors’ and accountants’ judgments. These propositions could then be empirically tested using prototype systems. Once initial studies using this methodology are conducted, they could be extended to tasks not yet examined in the accounting and AIS literature, such as navigating ERP data for internal decision making and using interactive data viewers which allow investors to download, view, and compare XBRL-tagged financial information across companies.

Direct research into the relationship between task characteristics and information representation choices is also limited. In this case, however, cognitive fit theory provides a framework for investigating when it may or may not be effective to allow decision makers to choose their own representations. Unfortunately, the research discussed in this survey does not yet give a clear or consistent picture as to tasks for which cognitive fit may or may not apply. There is a need for further studies similar to Wilson and Zigurs (1999), where participants are allowed to choose their own information representation. One limitation of many studies using the
cognitive fit model, however, is that they typically involve fairly simple data acquisition tasks. Shaft and Vessey’s (2006) extended cognitive fit model may be useful in designing studies which address the relationship between task characteristics and representation choice for more complex tasks, such as financial statement analysis, budgeting, and performance evaluation.

**Decision Maker Characteristics and Interactive Data Visualization Characteristics**

As shown in Table 2, we organize our discussion of the literature addressing the relationship between decision maker and interactive data visualization characteristics around three questions:

1. How do decision maker characteristics affect information navigation and selection?
2. How do decision maker characteristics affect the choice of information representation?
3. Do decision makers choose task-appropriate representations?

Table 4 lists studies related to these questions.

> Insert Table 4 about here.

**Decision Maker Characteristics and Information Navigation / Selection**

Our literature search identified two papers documenting how decision maker characteristics affect their information search behavior. Hunton and McEwen (1997) find that more experienced financial analysts tend to use more directive, as opposed to sequential search strategies. Further, there is a positive correlation between directiveness of search and judgment accuracy. Hodge and Pronk (2006) tracked information viewing behavior of investors visiting the Investor Relations website of a large electronics firm. Professional investors were more likely to view only PDF format, as opposed to HTML financial statements than nonprofessional
investors. Nonprofessional investors considering the company as a new investment were less likely to view only PDF format financial statements than current nonprofessional investors. The implications of these data are that nonprofessional investors, especially those evaluating a company as a new investment, prefer to utilize the navigational capabilities present in the HTML format.

Kelliher and Mahoney (2007) investigate the effects of personality style (perceiving versus judgment) and perception type (sensing versus intuition) on search behavior in a management performance evaluation task. They find that individuals with a dominant perceiving personality style search a greater proportion of information in a display of management performance data than those with a dominant judgment personality style. They find an interaction between personality style and perception type for search time and variability: dominant perceiving personality style individuals with sensing perception types take less time to search information and have less variable information search strategies than individuals with the other three combinations of personality style and perception types. Further, as the number of alternatives increases, dominant perceiving personality style and intuition perception type individuals search more by alternatives, while the search behavior of dominant judgment personality style and sensing perception type individuals does not change.

Turetken and Schuff (2007) provide indirect evidence with respect to the relationship between decision maker characteristics and information search behavior. They examine the impact of field dependence and prior experience on system analysts’ information search performance in conventional, context-free data flow diagrams (DFDs) versus context-aware DFDs with fisheye views. They find that fisheye models result in more accurate performance
compared to traditional displays for field-dependent subjects and that fisheye models are most effective at improving task completion time with inexperienced subjects.

Wheeler and Jones (2003, 2006) provide indirect evidence with respect to decision maker characteristics and preferences for a decision aid that allows interactive navigation of data. Participants in both studies performed a credit rating task, using an interface that provided one of two features: (1) static output from a regression-based model or (2) an interactively searchable database of prior applicant information and ratings. Wheeler and Jones (2003) find an association between perceived competency with each decision aid type and decision aid choice. They also found that participants were more committed to and involved with their chosen decision aid. However, they found only limited support for the prediction that participants choosing the database aid would have better judgment performance than those assigned to use it. Wheeler and Jones (2006) find partial support for the prediction that cognitively ambivalent participants are more likely to switch decision aids. Further, as switching behavior increased, accuracy with the more interactive decision aid increased.

**Decision Maker Characteristics and Information Representation Choice**

Vera-Munoz et al. (2001) find that when cash flow data are presented in an inappropriate format, experienced managers are better able to determine relevant information than are less experienced managers. Experience level has no effect when information is presented appropriately. Thus, domain-specific knowledge appears to be related to decision makers’ ability to choose an appropriate internal problem representation.

Mahoney et al. (2003) find that decision accuracy and response time for individuals interpreting probabilistic management accounting data are jointly affected by cognitive fit and cognitive abilities. In particular, lack of cognitive fit does not seem to affect field independent
users’ judgment accuracy, even though it increases response time for such individuals. Speier and Morris (2003) find that high spatial ability participants using an interactive visual query interface in a real estate search task had higher judgment accuracy than low spatial ability participants. At the same time, spatial ability did not affect accuracy for participants using a text-based interface. Findings from both of these studies suggest that in an interactive environment, choosing an “incorrect” representation is less of a problem for individuals with high cognitive abilities.

Cardinaels (2008) finds that more knowledgeable participants performing a complex judgment task using managerial accounting data are more accurate when using tables, while less knowledgeable participants are more accurate using graphs. More knowledgeable participants spend more time in information search with tables, but information display format does not affect less knowledgeable participants’ information search time. Dilla et al. (2009) find that non-professional investors spend relatively more time viewing graphs on a simulated investor relations web site with text and graphical displays than professional investors. Their results suggest that the nonprofessionals spend relatively more time viewing the graphical displays either because the graphical information is more salient to them or is perceived as easier to use.

To summarize, prior research suggests that since users with higher expertise or higher cognitive ability have better-developed internal problem representations, they are more likely to choose appropriate information representations. Even if such users choose an inappropriate representation, they may still be able to make accurate judgments, but such judgments may require more cognitive effort due to the need to reconfigure information acquired from the external representation to fit their internal problem representation. Thus, it appears that allowing representation choice may be an effective tool for improving judgments for high expertise or
high cognitive ability decision makers, but that it may not improve or even have negative impacts on judgments for others.

Task-Appropriate Information Navigation Features and Representations

Wheeler and Jones (2003) find that a majority of decision makers in a high predictability environment inappropriately choose a static, regression-based decision aid over an interactive matrix display which better supported accurate decision processes. They also found that approximately half of decision makers inappropriately choose the interactive matrix display in a low predictability environment. Wilson and Zigurs (1999) find that a majority of participants chose display representations consistent with cognitive fit theory for symbolic tasks, while slightly fewer than half chose consistently for spatial tasks. Thus, there is limited evidence that decision makers’ ability to choose an appropriate level of interactivity or an appropriate visual representation is contingent on task characteristics.

Future Research Opportunities

As with the link between task characteristics and information navigation behavior, earlier accounting research suggests possible directions for further investigating how different types of decision makers search and acquire information in the performance of auditing and accounting related tasks. There are a number of studies which provide detailed evidence with the respect to differences between expert and non-expert auditors’ (Biggs et al. 1988; Bedard and Biggs 1991) and financial analysts’ (Biggs 1984; Bouwman 1984; Bouwman et al. 1987; Anderson 1988) search processes using hard copy displays. Data from these studies might be used to form propositions about information navigation and selection features that would best support judgments made by individuals with varying levels of accounting and auditing expertise. These

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4 Wheeler and Jones (2003) provide only limited evidence about decision makers’ ability to choose an appropriate level of interactivity, as the regression-based and interactive matrix display decision aids were mutually exclusive choices, thus confounding the presence (absence) of the statistical aid and interactive display.
propositions could then be empirically tested using prototype systems. There is also a need for similar investigation of information navigation and selection features that would best fit decision makers’ individual characteristics, such as cognitive style and abilities.

As discussed earlier, there are technological barriers to conducting research into the relationship between decision maker characteristics and information navigation and selection behavior. Fortunately, recent technological advances make the development of experimental software that produces a reliable record of participant data viewing and manipulation behavior feasible. In addition, accounting and AIS researchers should reconsider the usefulness of small sample studies for documenting experts’ information navigation and selection behavior. Such studies were once fairly common in accounting research (e.g., Biggs and Mock 1983; Biggs et al. 1988). They still are frequently used in information visualization research in engineering and related disciplines, such as Wolf et al.’s (2009) recent study documenting how and why experts are more effective at utilizing a multidimensional visualization tool in a complex design process. Such descriptive studies would be particularly effective in better understanding how auditing, accounting, and financial analysis professionals navigate and make sense of complex financial data.

Two lines of research suggest a path for future research into the relationship between user characteristics and representation choice. First, research addressing accountant expertise suggests that allowing representation choice may not affect experts’ judgment accuracy, although it may affect their efficiency. Second, research using a cognitive fit framework indicates a similar prediction for individuals with high levels of cognitive ability. In both cases, a research design similar to Wilson and Zigurs (1999), where participants are allowed to choose their own information representation, would be useful for further investigating the relationship between
user characteristics and representation choice. Further, Shaft and Vessey’s (2006) extended cognitive fit model may be useful in designing studies which address the relationship between task characteristics and representation choice for more complex tasks.

**Interactive Data Visualization, Decision Processes, and Outcomes**

As shown in Table 2, we organize our discussion of the literature addressing the relationship between data visualization characteristics and decision making processes and outcomes around three questions:

3.1 How does interactivity affect decision making processes and outcomes relative to static representations?

3.2. How does information navigation and selection affect decision making processes and outcomes?

3.3 How does representation choice affect decision making processes and outcomes?

Table 5 lists empirical studies related to these questions.

Insert Table 5 about here.

**Interactivity and Decision Processes and Outcomes**

Hodge (2001) compares investor judgments made using static hard copy displays to those made using a hyperlinked online display. Participants who viewed online hyperlinked materials misclassified more unaudited information as audited and assessed the credibility of the unaudited materials as higher than those who viewed hard copy materials. Credibility assessments were positively correlated with earnings potential judgments. Providing online participants with a decision aid in the form of an “AUDITED / NOT AUDITED” label mitigated these effects.

An important aspect of interactivity is allowing decision makers to select decision aiding information, as opposed to designers pre-determining which information to provide. Wheeler and
Jones (2003) either assigned users to or allowed them to choose between a static, regression-based decision aid or an interactive matrix display in a credit rating task. The regression-based aid was designed to facilitate more accurate evaluations in low predictability cases; the interactive matrix was designed to facilitate more accurate evaluations in high predictability cases. Users who chose the regression aid instead of having it assigned to them made more accurate decisions, regardless of predictability. Those who chose the interactive matrix display made more accurate decisions when task predictability was low, but not when it was high. Further, there was a positive correlation between decision makers’ confidence in their choice of decision aid and accuracy. Overall, the results of this study suggest that allowing users to choose their own decision aids can be beneficial, especially for knowledgeable individuals confident in their decision aid choice.

Another aspect of interactivity is media richness. The richness of a media environment can be defined by the complexity of data representations (i.e., single versus multi-dimensional graphs, static versus animated displays), communication medium (i.e., text versus audio or video), and presence of multiple media. Huang and Windsor (1998) compare judgments of professionals evaluating a business expansion plan using a text-based versus multimedia decision support system. Participants who used a multimedia system identified fewer threats and opportunities than those who used a text-based system. Using the same task and experimental design, Huang (2003) finds that users of text-based systems browsed more pages of information than multimedia system users, while multimedia system users spent more time browsing each page and more time browsing in total. Media type did not affect navigation efficiency, i.e., how efficiently a decision maker can retrieve a document without using unnecessary links. Hong et al. (2004) find that flashing a search target in an online consumer product display increases
search efficiency only when information is displayed in a list, as opposed to a matrix format. Flash does not improve product recall, regardless of list format. Jahng et al. (2006) find that a fit exists between product complexity and electronic commerce interface richness. Specifically, consumer attitudes and intent to purchase are highest when the degree of product complexity matches the degree of interface richness.

Wheeler and Arunachalam (2008) investigate judgment performance in familiar (general knowledge) and unfamiliar (accounting) judgment tasks, providing information in either a single medium (text or video only) or multimedia (both text and video) environment. Results suggest that the multimedia environment appears to decrease task understanding. Thus, participants were more willing to apply externally provided decision weights when using multimedia for both task types. Further, judgments for familiar tasks were less compliant with external weights and more inconsistent with decision makers' internal decision weights in the multimedia environment.

Elliott et al. (2009) investigate the effect of text versus video formats for online restatement announcements. When the CEO’s firm is the only firm restating (i.e., the restatement is prompted by a firm-specific issue), participants viewing the restatement announcement online via video make larger investments in the firm and are more confident in the firm’s future ability to meet analysts’ expectations than are participants who view the restatement announcement online via text. This effect is not observed when the CEO’s firm and its industry peers are restating (i.e., the restatement is prompted by an industry-wide concern). Effects are moderated by participants' perceptions of the CEO's trustworthiness.

In a small sample study, Roscoe and Horwoth (2009) examined investment chartists’ decision making techniques. They found no association between charting techniques and investment performance. This suggests that the value of interactive visualization tools designed
to support charting activity is as a heuristic tool to help investors to organize and understand market data, as opposed to facilitating an optimal or correct solution to a decision problem.

Heer et al. (2009) studied the behavior of collaborative groups assigned to conduct an unstructured analysis of U.S. historical labor data. They used a platform that provided not only an array of interactive visualization techniques, but also a social analysis interface where participants could share and track each others’ observations, comments, and questions about the data. Results show that participants used individual data visualizations and social navigation of others’ observations as complementary tools.

Research discussed in this section suggests that allowing users to select the way in which decision aiding information is presented in an accounting-related judgment task may improve judgment accuracy under most conditions. It also indicates that the effectiveness of media-rich decision support environments depends on an appropriate match between task characteristics and support environment features. Further, media-rich environments may influence investor perceptions of the credibility and trustworthiness of financial information and consequently have an impact on their investment judgments. Finally, environments which combine interactive visualization and social networking capabilities may facilitate data analysis for collaborative groups working either within an organization (e.g., audit or management teams) or outside organizational boundaries (e.g., investment groups).

*Information Navigation and Selection and Decision Processes and Outcomes*

Several of the papers listed in Table 5, Panel B have already been discussed in earlier sections, as they indicate that the relationship between information navigation and selection capabilities and decision processes and outcomes is contingent either on task characteristics (Ariely 2000; Dull and Tegarden 1999; Gonzalez and Kasper 1997; Kumar and Benbasat 2004;
Ramarapu et al. 1997) or decision maker characteristics (Hunton and McEwen 1997; Turetken and Schuff 2007). The remaining papers discussed here all focus on one specific task.

Nelson et al. (1999) find that participants using an immersive virtual reality environment (C2) were more accurate at detecting clusters and radial sparseness than those using an interactive two-dimensional visualization tool (XGobi). Selection of data through a brushing technique took longer with C2. The results suggest that virtual reality technologies may be helpful for the visualization of complex data sets.

Haubl and Trifts (2000) had participants perform a consumer choice task using data on multiple attributes for a large set of product alternatives organized by brand and model. Participants were either unaided, given one of two decision aids designed to display attribute information on a subset of products, or provided both decision aids. Results show that both decision aids resulted in more efficient search processes and higher quality decisions. Schuff et al. (2006) find that undergraduate students given an assignment to locate information in a large file of e-mail messages had higher accuracy when provided with an interactive tool for clustering messages by attributes or combinations of attributes. Both of these studies show that tools for organizing large sets of textual data can facilitate more accurate decisions.

Three studies suggest that formatting of online financial information affects investors’ information search behavior and investment decisions. Hodge et al. (2004) find that participants who choose to use an XBRL-enhanced search engine are more likely to acquire footnote information and use it in making investment decisions. Cong et al. (2008) find that individuals who use syndication technology are more effective in acquiring relevant information updated frequently and integrating information for investment decision making than individuals who do not use such technology. Arnold et al. (2009) find that investors using a tagged display format
spend less time viewing risk information and view fewer items than those using a standard text display format. However, the correlation between time spent viewing risk information and investor judgments is stronger for the tagged format. This suggests that the tagged format may improve investor information search efficiency and judgment effectiveness.

*Information Representation Choice and Decision Processes and Outcomes*

Wilson and Zigurs (1999) is the only study identified in our survey directly addressing the effects of information representation choice on decision processes and outcomes. Participants in this study were assigned a display type at random, selected an information display without guidance, or selected a display with guidance. Participants preferred making display choices without guidance to having one assigned; they also preferred making display choices with guidance as opposed to without guidance. Those who made display choices without guidance had higher judgment accuracy in symbolic, but not spatial tasks, compared to participants assigned a display type. Participants who were offered display selection guidance had higher judgment accuracy on both symbolic and spatial tasks than those who chose displays without guidance. They also had a lower response time on spatial tasks. These results suggest that allowing decision makers to choose displays with guidance produces more efficient and accurate decisions than pre-assigned displays or allowing display choice without guidance. However, as implied in the discussion of studies reviewed earlier in this paper, there may be boundary conditions to this finding dependent on task and decision maker characteristics.

*Future Research Opportunities*

There are a number of opportunities for future research into the relationship between interactivity and decision processes and outcomes in accounting. First, studies that allow decision makers to choose levels of interactivity and types of information representation would
help determine under what circumstances allowing such choices results in more efficient information search processes and more effective decisions. Such research might be conducted using tasks such as budgeting or performance evaluation, given the availability of commercial visualization tools for management accounting data. Second, research that further examines how increasing interactivity and media richness affects decision makers’ perceptions of data reliability is potentially important. This is especially true in the financial disclosure area, where research to date suggests that increased interactivity and media richness have a positive impact on perceived reliability and potentially, on a firm’s attractiveness as a potential investment (Hodge 2001; Elliott et al. 2009). Third, there is a need for more research into how XBRL tagging of financial statement data, especially textual data, affects investor information search processes and judgments. This is important as research to date in this area suggests that nonprofessional investors prefer more easily searchable financial documents (Hodge and Pronk 2006) and that such documents may have a positive impact on their information search efficiency and judgment effectiveness (Hodge et al. 2004; Arnold et al. 2009). Finally, there are substantial opportunities for research into how groups use information visualization to organize and make sense of accounting data. Such research will be challenging because of the difficulties associated with adapting existing collaborate visualization software for accounting applications and with organizing groups of participants to work on complex accounting problems. However, research in this area is potentially important, given the trend towards digitally integrated organizations (Hunton 2002) and the promise of online collaboration as an effective method for analysis of complex data within such organizations (Heer et al. 2009).
IV. SUMMARY AND CONCLUSIONS

Interactive visualization of accounting data is becoming more common, both in external disclosure and internal data analysis contexts. It is a potentially powerful tool for organizing and making sense of the volumes of data flowing between and within organizations. Therefore, it is important to understand when and how interactive data visualization can result in more effective and efficient decision making.

To obtain this understanding, we reviewed literature related to information visualization in IS, AIS, and accounting. To organize our review, we developed a research framework organized around three questions: What is the impact of task characteristics on interactive data visualization? What is the impact of decision maker characteristics on interactive data visualization? and What is the impact of interactive data visualization techniques on information processing strategies and ultimately decision making outcomes?

In analyzing the literature reviewed in this paper, we consider two alternative research perspectives on the role that interactive information visualization might play in improving decision processes and judgments in accounting. The first is based on cognitive fit theory, which suggests that cognitive fit between task and representation (Vessey 1991; Vessey and Galletta 1991) and between decision maker characteristics and representation (Shaft and Vessey 2006) supports more efficient information acquisition and more accurate decision maker performance. It suggests that the effectiveness of a given information visualization technique depends not only on task and decision maker characteristics, but also on the decision maker’s insight into which representation is best for a given task. An alternate perspective based primarily on marketing and judgment / decision making research suggests that interactive visualization will improve task performance, regardless of task and decision maker characteristics. This perspective suggests that managers using interactive visualization tools will be more likely to consider multiple
factors than those using static representations, and thus use more compensatory processing strategies and make more accurate decisions (Lurie and Mason 2007).

Most of the research discussed in this review is consistent with a cognitive fit perspective: it suggests that the effectiveness of information visualization techniques such as interactive information and navigation tools and interfaces that allow the user to select their preferred information representation depends on task characteristics such as the dimensionality and complexity of data and decision maker characteristics such as domain-specific expertise and cognitive ability. A few papers reviewed suggest that facilitating information search or otherwise providing a more interactive display interface may improve decision processes and outcomes regardless of user characteristics, consistent with the alternate perspective on information visualization from the marketing and judgment / decision making literatures. Along with these findings, however, there is some evidence that decision makers consider financial information presented in interactive or media-rich environments to be more reliable or trustworthy (Hodge 2001; Elliott et al. 2009). At the same time, labeling whether such information does or does not have independent professional assurance may mitigate this effect (Hodge 2001). This suggests that policy makers need to consider further the effects of interactive financial disclosure formats on investor perceptions and decision processes and how assurance on interactively presented data might further affect these perceptions (Plumlee and Plumlee 2008).

With interactive data visualizations, users can better organize, acquire, and process complex sets of accounting information. Yet, inappropriate information navigation support or inappropriate data representations may impede information processing and increase the probability of decision biases, instead of mitigating them (Lurie and Mason 2007). Further, interactive navigation techniques or data representations that may be useful for experienced
decision makers knowledgeable in the accounting domain may result in inefficient or inaccurate decisions for less knowledgeable users. It is therefore important that research continues to examine the boundary conditions under which interactive tools are useful for sense-making of accounting data.

Our review suggests a considerable gap between the use of interactive information navigation and selection techniques for accounting data and research examining the effects of these techniques on decision making. Results thus far suggest that interactive visualization techniques are a good fit for complex tasks, although the degree to which interactivity improves decision processes and judgments may depend on user characteristics such as domain expertise and cognitive ability. Results from earlier research which documents the information search processes of auditors, accounting professionals, and financial statement users might be used to form testable propositions about information selection and navigation features that would best support accounting-related judgments. Following the approach commonly used in the human factors literature (Tory and Möller 2004), these propositions could be tested by developing visualization designs based on perceptual and cognitive theories, building prototypes of these designs, then empirically testing their effectiveness.

Direct research into the circumstances under which information representation choices improve decision processes and judgments is also limited. In this case, however, cognitive fit theory provides a framework for investigating when it may or may not be effective to allow decision makers to choose their own representations. There is a need for further studies similar to Wilson and Zigurs (1999), where participants are allowed to choose their own information representation.
Nearly all of the research discussed in this review concerns information visualization for individual decision making. Given that accounting data is often viewed and analyzed by teams of professionals, it is important for research to examine the role of interactive data visualization in group decision making settings. Heer et al (2009) illustrate how the analysis of complex data within organizations might be studied by integrating data visualization and social networking technologies. While implementing the methodology used by these researchers to study accounting issues poses substantial technical and logistical challenges, a field study using their methodology in an accounting context could make a substantial contribution to the AIS literature.

The majority of the papers reviewed for this article come from the IS literature. A number of the AIS papers reviewed could have easily appeared in either IS or AIS journals, as they involved tasks that might be performed by managers without specialized accounting training (Wilson and Zigurs 1999; Wheeler and Jones 2003, 2006; Kelliher and Mahoney 2007; Peng et al. 2007). This suggests the question: What is the state of interactive visualization research in accounting?

Interactive information visualization research at present is best-developed in the financial accounting area. This is due in large part to the emergence and wide acceptance of online financial reporting and the SEC mandate that companies furnish financial information in XBRL format. A number of studies have recently appeared in which participants interact with realistic online display environments (Arnold et al. 2009; Dilla et al. 2009; Elliott et al. 2009). However, these all involve analysis of single companies. One area deserving of further investigation is the

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5 It should be noted that accounting-related research occasionally appears outside accounting journals. For example, Hutchinson et al. (2009) involves the use of accounting data in determining advertising budgets and Lurie and Mason (2007) have a section in which they discuss the use of information visualization to achieve efficiencies, cost reductions, and improved productivity.
judgment processes and decisions of investors using an XBRL-facilitated interactive viewer to evaluate multiple companies at the same time.

There is a substantial gap between available visualization technology and empirical research in the management accounting area. We identified two studies which examine interactive search for the relatively simple task of extracting individual data items (Kelliher and Mahoney 2007; Peng et al. 2007) and one study which manipulates static representation in a complex iterative budgeting task (Cardinaels 2008). Yet, despite the availability of interactive visualization tools for internal data (Edwards 2005; Active Strategy 2009), none of the papers reviewed addressed interactive visualization of complex management accounting data sets. Because of the availability of technology (Arroyo et al. 2006; Rodden and Fu 2007) that can track the behavior of participants using a management accounting visualization system (Active Strategy 2009; SAP 2009), substantial opportunities for investigating the effectiveness of interactive information visualization techniques in management accounting contexts exists.

The gap between technology and empirical theory-driven research is even greater in the auditing and network security areas. We did not find any papers addressing the effects of interactive information visualization techniques on decision processes and judgments in these areas. It appears that interactive information visualization techniques would be useful for making industry comparisons in analytical procedures (Gunn 2007) and for interpreting output from fraud detection outcomes (Bay et al. 2006). At one time, there was considerable interaction between the AIS research and audit practice communities in the development of decision aids (Messier and Hansen 1987). It remains to be seen whether the same level of mutual interest and cooperation could develop with respect to the development of interactive visualization aids for use in auditing.
Use of interactive visualization to make sense of network security data is well-documented in the professional and academic literature (Conti 2007; Marty 2009), yet we did not find any studies in our review which reported theory-based empirical tests of information visualization effectiveness in this area. In this case, the lack of theory-driven research does not appear to be due to lack of cooperation between the academic and professional communities. Indeed, extensive descriptive research on interactive visualization of network security data appears in the computer science and engineering literatures (Marty 2009). It remains for IS or AIS researchers to perform empirical, theory-driven research in this area.

There is not yet a well-developed body of research directly addressing the effects of interactive information visualization on decision processes and judgments in accounting. The IS and AIS literature reviewed in this article provides a starting point for developing a theoretical framework which specifies the boundary conditions under which various interactive visualization techniques may or may not improve decision making efficiency and effectiveness. Researchers considering accounting information visualization research would do well become familiar with the human factors literature for ideas regarding research methodology, especially with respect to small sample studies in complex task environments. Accounting and AIS research over the last few years has moved away from the use of such studies, even though they were once common in the literature (e.g., Biggs and Mock 1983; Biggs et al. 1988). Both small sample studies and the currently dominant paradigm in accounting and AIS of theory-based larger sample studies of less complex tasks or of task components can contribute to our understanding of the effects of interactive information visualization on decision processes and judgments in accounting.
REFERENCES


<table>
<thead>
<tr>
<th>Technique</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data selection tools</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select</td>
<td>Mark data items of interest.</td>
<td>Spotlight features which allows users to highlight selected items in large spreadsheets or graphical displays and locate these items even after rearranging the display.</td>
</tr>
<tr>
<td>Explore</td>
<td>Show other data.</td>
<td>Panning or movement of cursor across a graphical display. Clicking on hyperlinks embedded in large, complex documents such as online annual reports.</td>
</tr>
<tr>
<td>Abstract / elaborate</td>
<td>Show more or less detail.</td>
<td>Move cursor over screen to view more or less detailed information (e.g., SmartMoney.com (2009), Tibco (2009) Spotfire, SAP (2009) Spotfire or SEC Interactive Financial Report viewer).</td>
</tr>
<tr>
<td>Filter</td>
<td>Show data based on specific condition(s).</td>
<td>Query tools embedded in database / spreadsheet products, enterprise computer programs (e.g., Oracle, SAP, PeopleSoft), and specialized audit programs (e.g., ACL, IDEA).</td>
</tr>
<tr>
<td><strong>Representation tools</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encode</td>
<td>Show different representation of data.</td>
<td>Convert tabular representations to graphs or vice versa. Change graph type (e.g., from pie chart to histogram).</td>
</tr>
<tr>
<td>Reconfigure</td>
<td>Show different arrangement of data.</td>
<td>Adjust baselines or axis scales, reverse attributes displayed on x- and y- axes.</td>
</tr>
<tr>
<td>Connect</td>
<td>Show related data items.</td>
<td>View leveled set of data flow diagrams or entity relationship diagrams. Highlight patterns in complex transaction data.</td>
</tr>
</tbody>
</table>
TABLE 2
Research Taxonomy for Interactive Information Visualization

1. Link between task characteristics and interactive data visualization.
   1.1 How do task characteristics influence information navigation and selection behavior?
   1.2 How do task characteristics influence information representation choices?

2. Link between decision maker characteristics and interactive data visualization.
   2.1. How do decision maker characteristics affect information navigation and selection?
   2.2. How do decision maker characteristics affect the choice of information representation?
   2.3 Do decision makers choose task-appropriate information navigation features and representations?

3. Link between interactive data visualization and decision-making processes and outcomes.
   3.1 How does interactivity affect decision making processes and outcomes relative to static representations?
   3.2. How does information navigation and selection affect decision making processes and outcomes?
   3.3 How does representation choice affect decision making processes and outcomes?
TABLE 3
Selected Papers Addressing Questions Related to Impact of Task Characteristics on Interactive Data Visualization Techniques

Panel A: How do task characteristics influence information navigation and selection behavior?

<table>
<thead>
<tr>
<th>Reference</th>
<th>Task</th>
<th>Participants</th>
<th>Key Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonzalez and Kasper (1997)</td>
<td>Choose best alternative in home selection and fluid dynamics tasks</td>
<td>Undergraduate</td>
<td>Parallel navigation interactivity results in better decision quality than sequential navigation interactivity for both tasks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>business students</td>
<td></td>
</tr>
<tr>
<td>Ramarapu et al (1997)</td>
<td>Judgment tasks similar to Vessey &amp; Galletta; data represented in text and arranged in &quot;linear&quot; (hierarchical) or &quot;nonlinear&quot; (hyperlinked) format</td>
<td>MBAs</td>
<td>For perceptual (spatial) tasks, nonlinear displays resulted in higher user satisfaction and more accurate, faster decisions; for analytical (symbolic) tasks, nonlinear displays resulted in higher user satisfaction and faster, but not more accurate decisions.</td>
</tr>
<tr>
<td>Dull and Tegarden (1999)</td>
<td>Make predictions using momentum accounting data</td>
<td>Undergraduate</td>
<td>Decisions are more accurate with dynamic than static 3-D representations; task requires less time with static representations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>accounting students</td>
<td></td>
</tr>
<tr>
<td>Ariely (2000)</td>
<td>Evaluate products</td>
<td>Undergraduate</td>
<td>Decision aid allowing user to control sequence of information cues improves judgment quality in a low cognitive load environment. With high cognitive load, no initial difference in performance between environments where user did or did not have control over cue presentation, but judgment quality with information control improved with practice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>students</td>
<td></td>
</tr>
<tr>
<td>Kumar and Benbasat (2004)</td>
<td>Answer graph comprehension questions</td>
<td>Undergraduate</td>
<td>Providing decision makers with dynamically labeled 3D graphs leads to improved decision support across a variety of task complexity conditions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>and graduate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>students</td>
<td></td>
</tr>
<tr>
<td>Shmueli et al. (2006)</td>
<td>Analysis of online auction data</td>
<td>n/a</td>
<td>Individuals who follow a semi-structured exploration process supported by interactive data representation will be able to understand auction pricing data more effectively.</td>
</tr>
<tr>
<td>Goswami et al. (2008)</td>
<td>Spreadsheet error correction</td>
<td>Undergraduate students</td>
<td>An interactive chaining visualization tool decreased participants' error detection time and increased their confidence for correcting link errors, but not for correcting non-link errors.</td>
</tr>
</tbody>
</table>
### TABLE 3

**Selected Papers Addressing Questions Related to Impact of Task Characteristics on Interactive Data Visualization Techniques**

(continued)

*Panel B: How do task characteristics influence information representation choices?*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Task</th>
<th>Participants</th>
<th>Key Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jarvenpaa (1990)</td>
<td>Multi-attribute, multi-alternative choice task</td>
<td>Undergraduate students</td>
<td>With alpha-numeric displays, information is acquired in correspondence with the importance weights of the attributes, with graphical displays, information is acquired in correspondence with the visual salience of the attributes.</td>
</tr>
<tr>
<td>Umanath and Vessey (1994)</td>
<td>Make bankruptcy prediction judgments</td>
<td>Business graduate students</td>
<td>Decision makers provided with graphs are more accurate than those with tables; performance difference between graphs and tables decreases as cognitive load increases.</td>
</tr>
<tr>
<td>Wilson and Zigurs (1999)</td>
<td>Spatial and symbolic judgment tasks, some participants allowed to choose representation</td>
<td>Undergraduate students</td>
<td>Higher proportion of users make representation choices consistent with cognitive fit theory for symbolic tasks than for spatial tasks.</td>
</tr>
<tr>
<td>Speier and Morris (2003)</td>
<td>Use query interface (text-based or visual) to complete a home-finding task</td>
<td>Undergraduate students</td>
<td>Interactive visual query improved accuracy for a high complexity task, accuracy was higher with text-based query for a low complexity task. Decision times were higher with visual query and a high complexity task, and with text-based query and a low complexity task.</td>
</tr>
<tr>
<td>Dilla and Steinbart (2005)</td>
<td>Performance evaluation based on Balanced Scorecard data</td>
<td>Undergraduate accounting students</td>
<td>Judgment consistency and consensus is higher with supplemental textual displays of Balanced Scorecard data than with graphical displays.</td>
</tr>
<tr>
<td>Speier (2006)</td>
<td>Acquire production planning task data using graphs or tables</td>
<td>Undergraduate students</td>
<td>Results were consistent with cognitive fit theory for low-complexity tasks and high-complexity spatial tasks; decision makers performed similarly with graphs and tables in high-complexity symbolic tasks.</td>
</tr>
<tr>
<td>Huang et al.</td>
<td>(2006)</td>
<td>Extract information from a database of expertise data</td>
<td>Business graduate students</td>
</tr>
<tr>
<td>Peng et al.</td>
<td>(2007)</td>
<td>Acquire sales and advertising expense data in an environment where data presented in a hierarchical, drill-down display</td>
<td>Undergraduate students</td>
</tr>
<tr>
<td>Hutchinson et al.</td>
<td>(2009)</td>
<td>Allocate an advertising budget based on past revenue and multi-attribute advertising expense data</td>
<td>Undergraduate students and marketing professionals</td>
</tr>
<tr>
<td>Reference</td>
<td>Task</td>
<td>Participants</td>
<td>Key Results</td>
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</tr>
<tr>
<td>Wheeler and Jones (2003)</td>
<td>Credit rating task</td>
<td>MBAs</td>
<td>Users' choice of a given decision aid correlates with their perceived competency in using that aid.</td>
</tr>
<tr>
<td>Hodge and Pronk (2006)</td>
<td>Investors accessing online financial information</td>
<td>Professional and nonprofessional investors</td>
<td>Professional investors are more likely to use only PDF format (i.e., non-navigable) financial statements than nonprofessional investors. Nonprofessional investors considering the company as a new investment are less likely to use only PDF format financial statements than current nonprofessional investors.</td>
</tr>
<tr>
<td>Wheeler and Jones (2006)</td>
<td>Credit rating task</td>
<td>MBAs</td>
<td>Ambivalent participants are more likely to switch decision aids. Switching behavior is positively correlated with accuracy when using an interactive decision aid, but switching behavior does not affect accuracy when using a non-interactive aid.</td>
</tr>
<tr>
<td>Kelliher and Mahoney (2007)</td>
<td>Attribute by alternative search task involving management performance data.</td>
<td>Undergraduate students</td>
<td>Information search behavior is contingent on personality style, decision maker's preferred type of perceiving, and interaction between personality style and information load.</td>
</tr>
<tr>
<td>Turetken and Schuff (2007)</td>
<td>Systems analysis and design exercise</td>
<td>Undergraduate and graduate MIS students</td>
<td>Fisheye models result in better performance compared to traditional displays for field-dependent subjects. Fisheye models are most effective at improving task completion time with inexperienced subjects.</td>
</tr>
</tbody>
</table>
### TABLE 4
Selected Papers Addressing Questions Related to Impact of Decision Maker Characteristics on Interactive Data Visualization Techniques (continued)

**Panel B: How do decision maker characteristics influence information representation choices?**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Task</th>
<th>Participants</th>
<th>Key Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vera-Munoz et al.</td>
<td>Relevance assurance task</td>
<td>Accountants with at least two years of accounting experience</td>
<td>Participants are more likely to choose an appropriate problem representation when they receive an appropriate task format or when they have more management or public accounting experience.</td>
</tr>
<tr>
<td>Mahoney et al.</td>
<td>Spatial and symbolic accounting judgments involving uncertainty</td>
<td>IMA members</td>
<td>Field independent participants are more accurate, but slower than field dependent participants when task type and representation do not match. Field dependence does not affect performance when task type and representation match.</td>
</tr>
<tr>
<td>Speier and Morris</td>
<td>Used query interface (text-based or visual) to complete a home-finding task</td>
<td>Undergraduate students</td>
<td>Participants with lower spatial ability had lower decision accuracy than those with high spatial ability when using an interactive visual interface. Spatial ability did not affect accuracy for participants using a textual interface.</td>
</tr>
<tr>
<td>Cardinaels</td>
<td>Complex decision making task using managerial accounting information</td>
<td>Undergraduate business students</td>
<td>More knowledgeable participants are more accurate when using tables; less knowledgeable ones are more accurate using graphs. More knowledgeable participants spend more time in information search with tables; information display format does not affect less knowledgeable participants’ information search time.</td>
</tr>
<tr>
<td>Dilla et al.</td>
<td>View simulated investor relations web site and make investment judgments</td>
<td>Professional and non-professional investors</td>
<td>Nonprofessional investor participants spend a greater proportion of time viewing graphical displays than professionals.</td>
</tr>
</tbody>
</table>
TABLE 4
Selected Papers Addressing Questions Related to Impact of Decision Maker Characteristics on Interactive Data Visualization Techniques (continued)

Panel C: *Do decision makers choose task-appropriate information navigation features and representations?*

<table>
<thead>
<tr>
<th>Reference</th>
<th>Task</th>
<th>Participants</th>
<th>Key Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilson and Zigurs</td>
<td>Judgment tasks similar to Vessey &amp; Galletta; participants: (1) assigned displays at random, (2) selected displays without guidance, (3) selected displays with guidance</td>
<td>Undergraduate students</td>
<td>A higher proportion of users make representation choices consistent with cognitive fit theory for symbolic tasks than for spatial tasks. Participants preferred their own choice to pre-selected displays. They also preferred receiving display selection advice to making their own choice.</td>
</tr>
<tr>
<td>Wheeler and Jones</td>
<td>Credit rating task; participants were assigned to decision aids or allowed to choose</td>
<td>MBAs</td>
<td>In a high predictability condition, a majority of users chose a less accurate regression decision aid over an interactive matrix display. In a low predictability condition, approximately one-half of users chose the more accurate matrix display over the regression decision aid.</td>
</tr>
<tr>
<td>Reference</td>
<td>Task</td>
<td>Participants</td>
<td>Key Results</td>
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<td>----------------------</td>
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</tr>
<tr>
<td>Huang and Windsor</td>
<td>(1998) Identify threats and opportunities in a business expansion plan</td>
<td>Experienced managers and professionals</td>
<td>Managers and professional employees who used a multimedia DSS identified fewer threats and opportunities than those who used a text-based system.</td>
</tr>
<tr>
<td>Hodge</td>
<td>(2001) Judged whether financial information was audited / not audited; assessed information credibility and firm earnings potential</td>
<td>MBAs</td>
<td>Participants using web-based presentation vs. paper misclassified more unaudited information as audited and assessed information to be more credible. Clearly labeling web-based information as audited / not audited mitigated overrating of credibility and lowered earnings potential judgments, but did not reduce classification error rate.</td>
</tr>
<tr>
<td>Wheeler and Jones</td>
<td>(2003) Credit rating task</td>
<td>MBAs</td>
<td>Participants were more accurate when choosing a regression model decision aid than when it was assigned. They were more accurate using an interactive database aid when it was chosen rather than assigned in a low predictability environment. Participants had higher accuracy when they were committed to their choice of decision aid</td>
</tr>
<tr>
<td>Huang</td>
<td>(2003) Identify threats and opportunities in a business expansion plan</td>
<td>Experienced managers and professionals</td>
<td>Users of text-based systems browsed more pages of information than multimedia system users. Multimedia system users spent more time browsing each page and more time browsing in total. Media type did not affect navigation efficiency.</td>
</tr>
<tr>
<td>Hong et al.</td>
<td>(2004) Acquire product information from an online display</td>
<td>Undergraduate students</td>
<td>Flashing a search target increases search efficiency only when information is displayed in a list format. Flash does not improve product recall, regardless of</td>
</tr>
<tr>
<td>Authors</td>
<td>Year</td>
<td>Study Description</td>
<td>Participants</td>
</tr>
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</tr>
<tr>
<td>Jahng et al.</td>
<td>2006</td>
<td>Purchase a product from an electronic commerce site</td>
<td>Undergraduate students</td>
</tr>
<tr>
<td>Wheeler and Arunachalam</td>
<td>2008</td>
<td>Familiar (general) and unfamiliar (accounting-related) judgment tasks, performed in single medium (text or video cues) or multimedia (both text and video) environments</td>
<td>Undergraduate accounting students</td>
</tr>
<tr>
<td>Elliott et al.</td>
<td>2009</td>
<td>Investment and earnings potential judgments</td>
<td>MBA students with professional experience</td>
</tr>
<tr>
<td>Heer et al.</td>
<td>2009</td>
<td>Collaborative analysis of U.S. historical labor data</td>
<td>IBM corporate intranet users and students</td>
</tr>
<tr>
<td>Roscoe and Horwoth</td>
<td>2009</td>
<td>Use of charting in investment analysis</td>
<td>Non-professional investors</td>
</tr>
<tr>
<td>Reference</td>
<td>Task</td>
<td>Participants</td>
<td>Key Results</td>
</tr>
<tr>
<td>----------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>-----------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Gonzalez and Kasper (1997)</td>
<td>Choose best alternative in home selection and fluid dynamics tasks</td>
<td>Undergraduate business students</td>
<td>Parallel navigation interactivity results in better decision quality than sequential navigation interactivity for both tasks.</td>
</tr>
<tr>
<td>Ramarapu et al (1997)</td>
<td>Judgment tasks similar to Vessey &amp; Galletta; data represented in text and arranged in &quot;linear&quot; (hierarchical) or &quot;nonlinear&quot; (hyperlinked) format</td>
<td>MBAs</td>
<td>For perceptual (spatial) tasks, nonlinear displays resulted in higher user satisfaction and more accurate, faster decisions; for analytical (symbolic) tasks, nonlinear displays resulted higher user satisfaction and faster, but not more accurate decisions.</td>
</tr>
<tr>
<td>Dull and Tegarden (1999)</td>
<td>Make predictions using momentum accounting data</td>
<td>Undergraduate accounting students</td>
<td>Decisions more are accurate with dynamic than static 3-D representations; task requires less time with static representations.</td>
</tr>
<tr>
<td>Nelson et al. (1999)</td>
<td>Detecting clusters, intrinsic dimensionality, and radial sparseness in complex data</td>
<td>Statistics graduate students, staff, and faculty</td>
<td>Participants using an immersive virtual reality environment (C2) were more accurate at detecting clusters and radial sparseness than those using an interactive two-dimensional visualization tool (XGobi). Selection of data through a brushing technique took longer with C2</td>
</tr>
<tr>
<td>Ariely (2000)</td>
<td>Evaluate products</td>
<td>Not disclosed</td>
<td>Decision aid allowing user to control sequence of information cues improves judgment quality in a low cognitive load environment. With high cognitive load, there is no initial difference in performance between</td>
</tr>
<tr>
<td>Authors</td>
<td>Year</td>
<td>Task Description</td>
<td>Participants</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------</td>
<td>----------------------------------------------------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Haubl and Trifts</td>
<td>2000</td>
<td>Choose a product from an electronic commerce site; participants unaided or assigned one or both of two decision aids designed to facilitate information search</td>
<td>Undergraduate students</td>
</tr>
<tr>
<td>Hodge et al.</td>
<td>2004</td>
<td>Make an investment decision using financial statement information</td>
<td>MBAs</td>
</tr>
<tr>
<td>Kumar and Benbasat</td>
<td>2004</td>
<td>Answer graph comprehension questions</td>
<td>Undergraduate and graduate students</td>
</tr>
<tr>
<td>Schuff et al</td>
<td>2006</td>
<td>Locate information contained in e-mail messages</td>
<td>Undergraduate students</td>
</tr>
<tr>
<td>Turetken and Schuff</td>
<td>2007</td>
<td>Systems analysis and design exercise</td>
<td>Undergraduate and graduate MIS students</td>
</tr>
<tr>
<td>Cong et al.</td>
<td>2008</td>
<td>Acquiring online investment news items</td>
<td>Undergraduate students</td>
</tr>
<tr>
<td>Arnold et al.</td>
<td>2009</td>
<td>Judge risk and predict stock price for a potential investment</td>
<td>Nonprofessional investors</td>
</tr>
</tbody>
</table>
### TABLE 5
Selected Papers Addressing Questions Related to Impact of Interactive Data Visualization Techniques on Decision Making Processes and Outcomes (continued)

**Panel C: How does representation choice affect decision making processes and outcomes?**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Task</th>
<th>Participants</th>
<th>Key Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilson and Zigurs (1999)</td>
<td>Judgment tasks similar to Vessey &amp; Galletta; participants: (1) assigned displays at random, (2) selected displays without guidance, (3) selected displays with guidance</td>
<td>Undergraduate students</td>
<td>Compared to random assignment, users selecting displays had higher accuracy in symbolic, but not spatial tasks, also had higher response time for both types of tasks. Compared to unaided selection, users receiving display choice guidance had higher accuracy in symbolic and spatial tasks, and lower response time for spatial tasks, but not for symbolic tasks.</td>
</tr>
</tbody>
</table>
FIGURE 1
Sample Page from SEC Interactive Data Viewer

### 3M Co
Annual Report (2007-12-31)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales Revenue, Net</td>
<td>24,402</td>
<td>22,923</td>
<td>21,167</td>
</tr>
<tr>
<td>Cost of Sales</td>
<td>12,738</td>
<td>11,713</td>
<td>10,466</td>
</tr>
<tr>
<td>Selling, General and Administrative Expense</td>
<td>5,915</td>
<td>5,006</td>
<td>4,831</td>
</tr>
<tr>
<td>Research, Development and Related Expenses</td>
<td>1,368</td>
<td>1,522</td>
<td>1,274</td>
</tr>
<tr>
<td>Disposal Group, Not Deconsolidated, (Gain) Loss on Disposal</td>
<td>(849)</td>
<td>(1,074)</td>
<td></td>
</tr>
<tr>
<td>Costs and Expenses, Total</td>
<td>18,269</td>
<td>17,227</td>
<td>16,313</td>
</tr>
<tr>
<td>Operating Income (Loss), Total</td>
<td>6,133</td>
<td>5,696</td>
<td>4,844</td>
</tr>
<tr>
<td>Interest and Debt Expense</td>
<td>219</td>
<td>122</td>
<td>82</td>
</tr>
<tr>
<td>Other Nonoperating Income</td>
<td>(132)</td>
<td>(51)</td>
<td>(55)</td>
</tr>
<tr>
<td>Nonoperating (Income) Expense, Total</td>
<td>78</td>
<td>71</td>
<td>20</td>
</tr>
<tr>
<td>Income (Loss) from Continuing Operations before Income Taxes, Minority Interest, and Income (Loss) From Equity Method Investments, Total</td>
<td>6,115</td>
<td>5,626</td>
<td>4,828</td>
</tr>
<tr>
<td>Income Tax Expense (Benefit)</td>
<td>1,964</td>
<td>1,723</td>
<td>1,627</td>
</tr>
<tr>
<td>Minority Interest in Net Income (Loss) of Consolidated Entities</td>
<td>55</td>
<td>51</td>
<td>55</td>
</tr>
<tr>
<td>Income (Loss) before Cumulative Effect of Change in Accounting Principle, Total</td>
<td>4,996</td>
<td>4,081</td>
<td>3,146</td>
</tr>
<tr>
<td>Cumulative Effect of Change in Accounting Principle</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The XBRL financial data on which this web site operates were submitted to the SEC on an "unaudited" or "unreviewed" basis primarily for the purpose of testing the XBRL format and technology, and do not constitute official SEC filings. Users of this web site should not rely on the XBRL data or documents rendered by the web site in making investment decisions.
FIGURE 2
Sample Dashboard Display from ActiveStrategy Enterprise Software

[Image of a dashboard display from ActiveStrategy Enterprise Software]
FIGURE 3
Screenshot of IP Routes from an Internet Security Tool
FIGURE 4
Characteristics of Interactive Data Visualization and Implications for Decision Making

Task Characteristics
- directed vs. exploratory
- task type
- complexity
- context

Decision Maker Characteristics
- expertise
- experience
- cognitive style
- memory

Interactive Data Visualization Characteristics
- interactivity
- information selection / navigation
- visual representation

Decision-Making Frame

Decision Making Processes and Outcomes
- information acquisition
- search strategy
- time spent on decision
- accuracy