RESEARCH DIRECTIONS

Cognitive Fit: A Theory-Based Analysis of the Graphs Versus Tables Literature*

Iris Vessey
Department of Accounting and MIS, The Pennsylvania State University, University Park, PA 16802

ABSTRACT

A considerable amount of research has been conducted over a long period of time into the effects of graphical and tabular representations on decision-making performance. To date, however, the literature appears to have arrived at few conclusions with regard to the performance of the two representations. This paper addresses these issues by presenting a theory, based on information processing theory, to explain under what circumstances one representation outperforms the other. The fundamental aspects of the theory are: (1) although graphical and tabular representations may contain the same information, they present that information in fundamentally different ways; graphical representations emphasize spatial information, while tables emphasize symbolic information; (2) tasks can be divided into two types, spatial and symbolic, based on the type of information that facilitates their solution; (3) performance on a task will be enhanced when there is a cognitive fit (match) between the information emphasized in the representation type and that required by the task type; that is, when graphs support spatial tasks and when tables support symbolic tasks; (4) the processes or strategies problem solvers use are the crucial elements of cognitive fit since they provide the link between representation and task; the processes identified here are perceptual and analytical; (5) so long as there is a complete fit of representation, processes, and task type, each representation will lead to both quicker and more accurate problem solving. The theory is validated by its success in explaining the results of published studies that examine the performance of graphical and tabular representations in decision making.

Subject Areas: Decision Support Systems, Human Information Processing, and Management Information Systems.

INTRODUCTION

Presentation of data in the form of graphs is becoming a viable alternative to tabular formats due to the availability of relevant hardware and software. Information in the form of pictures or graphs is generally regarded as superior to that in other representations. We have all heard the saying, "A picture is worth a thousand words," innumerable times. However, MIS researchers, in attempting to verify this statement in decision-making settings, have been less than successful. The results, in general, have been inconsistent; some studies found graphs performed better than tables, while others found tables were superior to graphs; still other studies showed no differences (see reviews by DeSanctis [17]; Jarvenpaa and Dickson [37]).

The current thinking in the graphs versus tables controversy is that task effects are causing the unexpected results; that is, that each problem representation facilitates different types of tasks [3] [17] [19] [37] [38]. Jarvenpaa, Dickson, and DeSanctis stated: "Future research efforts will keep producing contradictory results unless researchers develop some type of taxonomy of tasks and start interpreting the results within the taxonomy" [38, p. 144]. There are, however, a number of ways in which to categorize tasks. Certain authors view task complexity

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as the important characteristic, while others, for example, view recall tasks differently from decision-making tasks. The literature has yet to articulate in a coherent way, therefore, the relationship between the type of task and the problem representation that facilitates it.

This paper develops a theory that describes the relationship between graphical and tabular representations and the types of tasks they support. Further, the paper demonstrates the validity of the theory by showing that it can explain the results of the majority of published graphs versus tables studies. Like the studies themselves, the theory focuses on information acquisition and fairly simple information evaluation tasks.

The theoretical basis used to address the graphs versus tables controversy is an information processing approach [51]. Since humans are limited information processors, more effective problem solving will result when the complexity in the task environment is reduced. In this paper, the notion is developed that complexity in the task environment will be effectively reduced when the problem-solving aids (tools, techniques, and/or problem representations) support the task strategies (methods or processes) required to perform that task (see, for example, [6] [87]). This notion is termed cognitive fit. Problem solving with cognitive fit results in increased problem-solving efficiency and effectiveness. Specifically, in the graphs versus tables domain, the theory describes the effects on performance of matching the nature of the problem representation to the nature of the task.

The paper proceeds as follows. The next section presents the theoretical basis for the paradigm of cognitive fit by examining literature in human information processing and in behavioral decision theory and related application areas. The paradigm is then applied to the use of graphical and tabular representations in decision making. The validity of the theory is demonstrated by explaining the seemingly inconsistent results of studies that investigated the effectiveness of graphs and tables. A summary of the findings is presented and the implications for theory, research methodology, and practice are discussed.

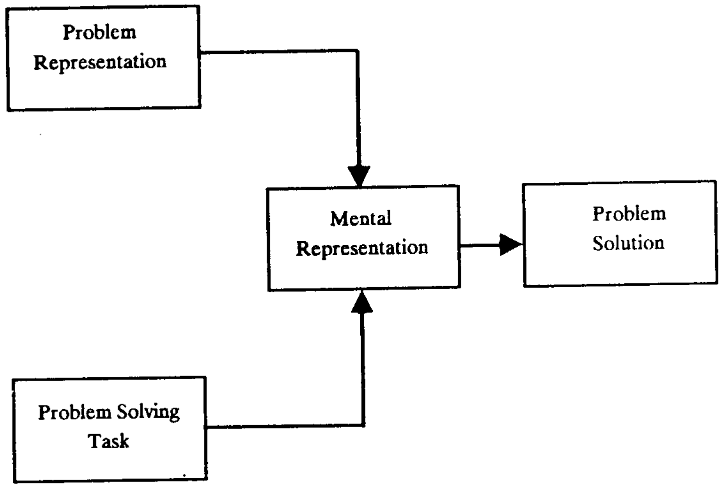
THEORETICAL APPROACH

As we have seen, researchers believe the nature of the task should be introduced as a mediating or contingent variable into graphs versus tables research studies in order to explain the inconsistent results. If task characteristics are to be considered in a comprehensive way, a theory of tasks is needed. The literature does not currently provide such a theory, nor does it promise one in the forseeable future (see, for example, [10] [25] [34] [93]). Hence, researchers must find other ways to introduce task as a variable into their theories. The nature of the task is introduced in this research via the paradigm of cognitive fit, one element of a general theory of problem solving. Within this general paradigm, the characteristics of tasks can be examined to explain performance in specific problem-solving situations. As an example, the paradigm of cognitive fit is elaborated in this section of the paper and later applied to decision making on specific tasks.

The Paradigm of Cognitive Fit

Figure 1 presents the general model of problem solving on which the cognitive fit argument is based. The model views problem solving as an outcome of the relationship between problem representation and problem-solving task. Processes in the model are represented by the flows and arrows linking pairs of elements in the

Figure 1: General problem-solving model.



model. The mental representation is the way the problem is represented in human working memory. In this context, it is a subset of the total problem space [51]. The mental representation is formulated using the characteristics of both the problem representation and the task. Specifically, it is derived from the interaction of the appropriate processes on the information in the problem representation and that required to solve the problem.

When the types of information emphasized in the problem-solving elements (problem representation and task) match, the problem solver uses processes (and therefore formulates a mental representation) that also emphasize the same type of information. Consequently, the processes the problem solver uses to both act on the representation and to complete the task will match, and the problem-solving process will be facilitated. In other words, matching representation to task leads to the use of similar, and therefore consistent, problem-solving processes, and hence to the formulation of a consistent mental representation. There will be no need to transform the mental representation to accommodate the use of different processes to extract information from the problem representation and to solve the problem. Hence, problem solving with cognitive fit leads to effective and efficient problem-solving performance.

When a mismatch occurs between problem representation and task, similar processes cannot be used to both act on the problem representation and solve the problem, and problem solvers will therefore no longer be guided in their choice of problem-solving processes. They will either formulate a mental representation based on the problem representation, in which case they will need to transform it to derive a solution to the problem; or they will formulate a mental representation based on the task, in which case they will need to transform the data derived from the problem representation into the mental representation suitable for task solution. In either case, performance will be worse than if the problem solver had been supplied a representation emphasizing the type of information that best supported task solution.

Theoretical Support for the Relationships in the Cognitive Fit Model

This section provides support for the relationships in the general problem solving model. It addresses the relationships of processes to problem representation, processes to task, and problem representation to task, highlighting the performance implications of each.

The literature provides substantial support for the fact that decision makers use processes that match the problem representation. At least three bodies of literature address this issue. First, there is considerable evidence from the human information processing literature on problem isomorphs to support the notion that the processes problem solvers use when solving a problem are specific to the problem representation. For example, Newell and Simon [51] argued strongly that the structure and organization of the problem representation greatly influence the structure of the problem space and the problem-solving processes that will be used. Hayes and Simon [31] [32] and Simon and Hayes [70] showed that subjects constructed different mental representations for structurally similar problems (isomorphs); that is, they derived the mental representation that was most readily available from the problem representation. They then selected problem-solving processes that were compatible with their mental representations. Significant performance differences result from using different problem representations and therefore different processes in solving problem isomorphs [42]. Hence, the research on problem isomorphs suggests that decision makers perform better when their problem-solving processes are adapted to the problem representation.

Second, research into judgment under uncertainty has demonstrated that decision makers use three heuristics: representativeness, availability, and anchoring and adjustment [40] [77] [78] [79]. Availability is the phenomenon by which decision makers make judgments based on perceptions of the frequency of an event's past occurrence or to the probability of its present occurrence. The availability heuristic is now considered relevant to many types of judgments other than judgments under uncertainty (see, for example, the social judgment literature; [52] [74]).

Nisbett and Ross [52], in reviewing the many explanations of the availability heuristic, believed the vividness hypothesis to be the most important. They stated that "information may be described as vivid, that is, as likely to attract our attention and to excite the imagination to the extent that it is (1) emotionally interesting; (2) concrete and imagery provoking; (3) proximate in a sensory, temporal, or spatial way" [52, p. 45]. (See, also, [66] [74]). A vivid information display will therefore make the information in a problem representation more available. Further, it will be available in the way in which the information is presented. Slovic [71] illustrated the relationships between the format of the data, vividness and availability, and the processes decision makers use, in terms of concreteness:

> Concreteness represents the general notion that a judge or decision maker tends to use only the information that is explicitly displayed and will use it only in the form in which it is displayed. Information that has to be stored in memory, inferred from the explicit display, or transformed tends to be discounted or ignored. [71, p. 14]

Hence, the research on vividness and the mechanism through which it is perceived to operate (availability) again suggests that decision makers use processes that match the characteristics of the problem representation.

The third disciplinary area that suggests a close relationship between problem representation and problem-solving processes is the behavioral decision-making literature and its close associate, the consumer behavior literature. Numerous studies have been conducted, many of which examined three problem representations: (1) a brand-organized representation, in which each alternative is presented on a separate page; (2) an attribute-organized representation, in which each attribute is presented on a separate page; and (3) a matrix representation, which presents attribute information by brand and which therefore makes information available by either attribute or brand (alternative). Bettman and Kakkar [5] found, for example, that, although participants could process information in whatever way they chose, they tended to do so in ways consistent with the representation of the information. Hence, they processed by brand when they received brand-organized representations. Further, the authors argued that processability is as important as availability, thus drawing attention to the cognitive costs of decision making. (See also, [2] [7] [33] [62] [64]). Hence, behavioral decision-making research further demonstrates that decision makers adapt their processing strategies to the problem representation.

There is also evidence that decision makers use different processes in different types of tasks. Many researchers, including Einhorn and Hogarth [21], Slovic and Lichtenstein [72], and Tversky, Sattath, and Slovic [80], addressed the differences in processing strategies employed in judgment and choice tasks. In simple terms, judgment requires making decisions about a number of alternatives in a set, while choice requires selection of the preferred alternative. The most conspicuous result of these types of investigations is that judgment generally occurs via a holistic or alternative processing approach, while choice occurs most frequently via a dimensional or attribute processing approach [60]. Rosen and Rosenkoetter [60], Johnson, Payne, and Bettman [39], and Schkade and Johnson [65] compared the processes employed in judgment and choice tasks for the purpose of characterizing different processing strategies. For example, processing differences that emerge from such investigations show that, compared with judgment subjects, subjects in choice tasks take less time, use different information search patterns, use approaches that directly compare alternatives rather than considering them sequentially and devote their attention to different aspects of decision making [65].

Further, Vessey and Weber [87] showed that different psychological processes are involved in the design and coding tasks of systems development and that significant performance effects result when problem representations and problem-solving tools are used that encourage the use of processes that match those required for task solution. Hence, studies of judgment and choice and of systems development demonstrate that problem solvers adapt their processing strategies to the task to be performed.

There is also evidence that matching the problem representation directly to the task has significant effects on decision-making performance. The majority of studies conducted comes from the consumer behavior literature. Wright and Barbour [95] first stated hypotheses of this nature, although they did not test them. Bettman and Zins [6] tested the effect of alternative, attribute, and mixed alternative and attribute representations on choice tasks facilitated by either alternative or attribute processing approaches. The methodology adopted was suggested by Wright [94] who devised tasks that incorporated the solution approach participants were to use. Bettman and Zins found a difference in the time but not in the accuracy of performance, suggesting that decision makers adapt the time to complete a task while keeping accuracy constant. Further, Simkin and Hastie [67] proposed a similar interaction between certain graphical representations and types of judgment tasks. Hence, research into consumer behavior shows that decision makers perform better when the problem representation matches the task to be performed.

The majority of studies cited in this section report performance measures; thus providing empirical support for the performance implications of cognitive fit. Most studies addressed accuracy of performance. In one study, however, time was the only variable to exhibit significant differences for cognitive fit [6]. Hence, care must be taken to examine all the variables in which the effect might be manifested.

Based on the above analysis, the following propositions are stated.

Proposition 1: Problem solving with cognitive fit results in increased speed and accuracy of performance.

Proposition 2: Problem solving without cognitive fit does not result in performance effects.

COGNITIVE FIT IN GRAPH VERSUS TABLE DECISION MAKING

This section applies the paradigm of cognitive fit to a specific decision-making context—decision making using graphical and tabular representations.

In developing the notion of cognitive fit in the graphs versus tables area, problem representation and problem-solving task are viewed as independent. There are two reasons for doing so. First, data and task may be presented independently, unlike certain other types of problems, such as problem isomorphs [31] [32] [42] [70]. Second, decision makers can reach solutions for the types of problems examined when the data is presented in either graphical or tabular format. The point, here, is that there are performance advantages of matching the problem representation to the task, not that this the only way in which a solution can be reached.

The separation of problem representation and task permits application of the notion of cognitive fit to graph/table decision making by identifying the distinguishing features of graphical and tabular problem representations and the types of tasks for which they have been used. The distinguishing features of importance are the types of information that each emphasizes. Cognitive fit results when the problem representation and the task both emphasize the same type of information. The use of processes appropriate to the problem representation and the task is inferred. This approach is used due to the need to develop a method for analyzing graphs versus tables studies reported in the literature, none of which addresses processes directly. The general problem solving model, Figure 1, applies to decision making using graphs and tables.

Characteristics of Decision-Making Elements

Assume that the graphs and tables under consideration are derived from equivalent data, so that all the information in one is also inferable from the other [69]. The same data are then represented in different ways in graphs and tables, so that a different type of information predominates in each. Intuitively, graphs and tables are quite distinct problem representations. Distinguishing between the two rigorously, however, is another matter. Perhaps the best existing distinctions are found in the psychology literature, which categorizes data organizations in one of two ways: images or words. One of the most concerted efforts has been associated with the dual encoding hypothesis popularized by Paivio [53] [54], which suggests that data are encoded in memory as both images and words. Numerous studies testing this hypothesis are reported in the literature (see, for example, [26] [49] [50]). Glass, Holyoak, and Santa [29] characterized the two types of problem representation as follows:

> There are few distinctions so deeply rooted in our intellectual tradition as the contrast between two types of knowledge. . . . The distinction has been characterized in many ways: as a contrast between intuition and reason, between knowledge of the whole and of its parts, between *yin* and *yang*. . . . We are going to draw a similar distinction between analog and analytic representation. [29, p. 17]

Umanath and Scamell [82], Umanath, Scamell, and Das [83], and Pracht and Courtney [58] in the information systems literature concluded that graphs are "imagistic," while tables are "verbal" in nature. We distinguish, therefore, between representations that are "imagistic" or "analogic" (graphs convey continuous information), and those that are "verbal" or "analytic" (tables convey discrete information) in their mode of data presentation. The terms used in the literature do not fully embody the characteristics of graphs and tables of interest here. For example, the term analog could be used to describe line graphs but not to describe bar charts; analytical information may be either verbal (alphabetic) or numeric in nature; tables are usually numeric rather than verbal. In the interests of generalizability, the terms spatial and symbolic are used to characterize the differences between graphical and tabular representations.

According to this classification, graphs are spatial problem representations since they present spatially related information. According to Larkin and Simon [44], a diagram (and therefore a graph) "preserves explicitly information about the topological and geometric relations among the components of the problem. . ." [44, p. 66]; that is, they emphasize information about relationships in the data. Tables are symbolic data representations since they present information that is symbolic in nature. Tables represent discrete data values. Discrete data values are the only type of information directly represented in tables.

Spatial representations facilitate viewing the information contained therein at a glance without addressing the elements separately or analytically. Hence, perceptual processes provide an appropriate access to the data in a graph. On the other hand, symbolic representations facilitate extracting specific data values. Hence, analytical processes provide an appropriate access to the data in a table. It is clear, therefore, that graphs and tables are problem representations that emphasize different characteristics of a given data set.

Now, identification of the types of decision-making tasks that graphs and tables might support is needed. Tasks can be classified into elementary tasks and those that involve higher level decision-making activities [51]. Elementary tasks require just one operation on the data. They are principally information acquisition tasks and tasks involving comparison of two data values. Further, they include tasks for which the type of information that best supports their solution can be readily identified. Decision-making tasks, such as those involving judgment or inference, are more complex tasks that may be decomposed into several subtasks; that is, they involve both information acquisition and information evaluation [21]. The paradigm of cognitive fit can be applied to those tasks in which the nature of the task and/or subtasks can be determined. These are elementary tasks and some of the simpler decision-making tasks. In this paper, these tasks are referred to as information acquisition and (simple) information evaluation tasks.

Although there is no comprehensive theory of tasks, specific tasks used in graph/table decision making can be examined to determine the abstract characteristics of those tasks that are facilitated by each problem representation. Washburne [89], as long ago as 1927, reported empirical evidence to support the notion that tables facilitated the recall of specific amounts; pictographs of simple comparisons;

bar charts of complex comparisons; and line graphs of trends; clearly identifying the need for a contingency approach to choosing presentation formats. The majority of more recent studies used essentially two types of tasks. Two task types can be inferred from the work of Jarvenpaa and Dickson [37] where they stated: "Vendors and graphics proponents have generally advocated the use of graphics over tables for the following elementary tasks: (1) summarizing data, (2) showing trends and relationships over time, (3) comparing data points and relationships of variables, (4) detecting deviations or differences in data" [37, p. 767]. They further stated, "We are unaware of any claims having been made, however, to suggest that graphics are more effective for (5) point reading" [37, p. 767].

Umanath and Scamell [82] and Umanath, Scamell, and Das [83] empirically validated these two basic task types from the perspective of recall. They refer to them as intraset pattern and point value recall tasks (although the terms they use vary a little both within and between the two papers). In [82], the results for "specific fact recall" tasks suggested no difference in the effectiveness of graphs and tables, when an effect for tables was expected. In [83], however, specific fact recall tasks were shown to consist of both point value recall and simple comparisons. Reanalysis of the data showed that point value was facilitated by tables, while simple comparison was facilitated by graphs [83].

Umanath et al.'s task types are used as the basis for determining the nature of tasks that are best supported by tables and those that are best supported by graphs. The first type of tasks (those said to be facilitated by graphs) assess the problem area as a whole rather than as discrete data values. These tasks require making associations or perceiving relationships in the data. For the purposes of this analysis such tasks are referred to as "spatial." Spatial tasks also include interpolating values. Examples of spatial tasks are:

> "Who earned the most in the year 1100, the wool, silk, or Calimala merchants?" [89, p. 375]. (This is a comparison of two data values. It is, therefore, spatial in nature.)
>
> "Between the years 1100 and 1438 whose earnings increased most rapidly, those of the wool, silk, or Calimala merchants?" [89, p. 375] (This is a comparison of trends and is spatial in nature.)
>
> "Did sales exceed the cost of goods sold?" [19, p. 41] (This question requires assessing relationships in the data. It is, therefore, spatial in nature.)

The second type of tasks (those said to be facilitated by tables) involve extracting discrete data values noted in [37], [82], [83], and [89]. These tasks, then, lead to precise data values, and are referred to as "symbolic" tasks. The following are examples of symbolic tasks:

> "How much did the wool merchants earn in the year 1100?" [89, p. 375] (This question requires a specific amount as the response. It is, therefore, symbolic in nature.)
>
> "What was the company's net income for the past year?" [19, p. 41] (This question also requires a specific amount as the response and is therefore symbolic in nature.)

Note that spatial problems may be restated as symbolic problems. For example, the spatial problem from [19] above could have been worded: By what amount did sales exceed the cost of goods sold? Since this question requires a specific amount as the response, it is now a symbolic problem.

Spatial tasks require making associations or perceiving relationships in the data. Hence, these tasks are best accomplished using perceptual processes. Perceptual processes view data values in context; that is, they enable a set of data points to be examined simultaneously. Similarly, since symbolic tasks lead to precise data values, they are best accomplished using analytical processes. Analytical processes are those used to both extract and act on discrete data values. Analytical processes are used in both symbolic information acquisition and in information evaluation, for carrying out computations on the data.

Characteristics of Cognitive Fit

According to the paradigm of cognitive fit, graphical and tabular problem representations will each facilitate certain well-differentiated tasks—those tasks that emphasize the same type of information. Spatial representations therefore best support the solution of spatial tasks; similarly, symbolic representations best support the solution of symbolic tasks. For example, determining a trend in a set of data values requires making associations among a number of data points; that is, it requires spatial information; it is therefore a spatial task. A graph is a spatial representation since it also emphasizes spatial information. Cognitive fit exists, therefore, when a trend is determined from a graph, but not when a trend is determined from a table. In this case, the processes appropriate to both using a graphical representation and supporting a spatial task are similar in nature. Detecting trends over time, comparing patterns of variables, and interpolating values, since they all involve making associations among data points, are all spatial tasks facilitated by the spatial properties of graphs, but not by the symbolic properties of tables. Fry [27] aptly summarized this relationship:

> Graphs pack a high density of information into a small area. . .are more globally visible than they are detailed, symbolic, and sequential. . .tend to show the 'big picture' or gestalt. . . . Often relationships can be seen better with a graph than with a purely verbal or numerical presentation. [27, p. 388]

Similarly, the task of extracting individual data values (a symbolic task) matches the way in which data are stored in a table of values (a symbolic representation). Hence, cognitive fit exists when individual data values are extracted from tables, but not when individual data values are extracted from graphs. With cognitive fit, the processes appropriate to both using a tabular representation and supporting a symbolic task are similar in nature. Table 1 summarizes the relationships between matching problem representations and tasks.

Note that a spatial representation does not have to be used to solve a spatial task; neither does a symbolic representation have to be used to solve a symbolic problem. Spatial tasks may be solved with analytical processes and symbolic tasks with perceptual processes (hence, the reason for dissociating process from task in this analysis). A problem solver might, for example, determine a trend from a table or extract a specific numeric value from a graph. These are instances of mismatches of representation and task. According to the theory, problem-solving performance in each instance will be less effective and efficient.

Decision Outcomes with Cognitive Fit

The decision outcomes typically investigated in graph/table research are performance (usually measured in terms of "decision quality," which is accuracy or a

Table 1: Matching information characteristics of representation and task type.

Problem Representation	Problem-Solving Task
Spatial	Spatial
Symbolic	Symbolic

surrogate for accuracy), interpretation accuracy, and confidence in the results obtained or satisfaction in decision making. Each of these dependent variables has implications for the theory. However, in this paper, the analysis is restricted to the objective performance variables (time and accuracy) and interpretation accuracy. (Note the use of terms found in the literature under review, although, more correctly, the term "precision" should be used rather than "accuracy.")

According to the analysis of performance outcomes with cognitive fit, graphs could be expected to be both faster and more accurate than tables for spatial tasks and tables to be faster and more accurate than graphs for symbolic tasks. Hence, Proposition 1 applies. Intuitively, it is clear that using graphs to solve spatial problems results in quicker outcomes than using tables—the parsimony of perceptual processes leads to faster decision making. It is also clear that tables furnish accurate (precise) values, while graphs do not. Arguments to support the fact that graphs should be more accurate than tables on spatial tasks and that tables should be faster than graphs on symbolic tasks can be developed. Ultimately, however, empirical tests must determine whether these effects are manifested in practice. Further, performance effects are not expected when the problem representation does not match the task. Hence, Proposition 2 applies.

To control for the time-accuracy trade-offs that subjects incorporate into their problem solving, time and accuracy must both be assessed [6] [63]. To fully account for the trade-off, time and accuracy should be assessed jointly. Time has been measured only infrequently in graph/table research, presumably because it is perceived to be more important to make the correct decision than to make a quick decision.

Interpretation accuracy is frequently used as a dependent variable in graphs versus tables research since it "is a prerequisite to correct problem comprehension and improved decision quality" [38, p. 147]. Interpretation accuracy is a general term encompassing any set of questions (usually multiple choice or true/false) that is used to assess subjects' understanding of material they have been exposed to, either in graphical or tabular format. The usual approach to interpretation accuracy reported in the literature is to ask a number of questions requiring either spatial and/or symbolic information and to derive just one "accuracy" score. The examples presented earlier are specific questions from a set of questions designed to assess interpretation accuracy. The majority of studies reported in the literature use some form of interpretation accuracy to assess differences in comprehension of material based on graphs and tables.

The theory presented here suggests that the questions asked should reflect the type of information that the researchers hypothesize will be affected differentially by graphical and tabular representations. From a performance perspective, interpretation accuracy is expected to behave in the same way as performance accuracy. (Note that interpretation accuracy studies may also assess time, although that approach is not common.) Hence, Propositions 1 and 2 apply here also.

TESTING THE PARADIGM OF COGNITIVE FIT

The theory presented above of the effectiveness of graphs and tables in a given decision-making task can be tested by analyzing the results of experiments reported in the literature. In what follows, the studies conducted are categorized as paradigmatic when they use "pure" problem representations and tasks and can therefore be analyzed to provide evidence to support or refute the paradigm. Studies are categorized as nonparadigmatic when they do not use pure problem representations and/or problem types.

Nonparadigmatic studies may arise in two ways. First, they may use problem representations that are not pure; the most common example is the use of bar charts that present values at the end of the bars. This approach confounds the type of information available in the graphs, making spatial and symbolic information equally readily available. An extension of the paradigm of cognitive fit would suggest that graphical plus tabular representations will outperform tabular representations on spatial tasks, while equivalent performance will result on symbolic tasks. Second, nonparadigmatic studies may use problem types that are not pure. This occurs most frequently when the interpretation accuracy instruments used contain both spatial and symbolic questions. Further disaggregation is needed before nonparadigmatic studies can be analyzed to provide evidence to test the paradigm [8] [20]. It is expected, therefore, that such studies will produce nonsignificant results. These studies can, however, be analyzed to provide indirect support for the paradigm in terms of Proposition 2.

To conduct the analysis, the type of information emphasized in the problem representation and the task solution had to be identified; that is, these major characteristics had to be determined unequivocally for the study to be included in the analysis. Two coders independently analyzed the problem representations, task types, and results of the experiments investigated in the studies. The coders achieved 100 percent agreement in characterizing the problem representations and task types. They differed, however, on the results of two experiments—those of Carter [11] [12]. The results of these experiments are difficult to extract for the purposes of this analysis since it is necessary to cross-reference across experiments. The agreement on coding the results was 92.3 percent. The disagreements were resolved jointly.

The analysis focuses on information acquisition tasks and simple studies involving information evaluation, in line with the paradigm. As stated earlier, the analysis was restricted to the objective performance variables (time and accuracy) and interpretation accuracy. Since the analysis is the same whether performance or interpretation accuracy is assessed, the results for each are presented in the same tables. The interpretation accuracy studies can be identified by observing the entries in the columns titled, Types of Questions.

Information Acquisition Studies

Table 2a presents the results of studies investigating performance on spatial decision-making tasks that largely involve information acquisition. As a general observation, all studies in this category, except that of Watson and Driver [90], showed that graphs perform better than tables on either time or accuracy of performance, or both. According to the paradigm of cognitive fit, graphs would be expected to have a natural advantage for time in performing spatial tasks. However, as noted earlier, few experiments have assessed time to perform these

Table 2: Analysis of paradigmatic spatial information acquisition tasks and paradigmatic symbolic information acquisition tasks.

Study	Types of Questions	Dependent Variables	Results: Accuracy	Results: Time
a. Analysis of paradigmatic spatial information acquisition tasks				
Comparing patterns of data				
Washburne [89]	Spatial	Accuracy	G>T[1]	—
Watson & Driver [90]	Spatial	Accuracy	G=T	—
Umanath et al. [82]	Spatial	Accuracy	G>T	—
Umanath et al. [83]	Spatial	Accuracy	G>T	—
Wainer & Reiser [88]	Spatial	Time	—	G>T
Recognizing trends				
Washburne [89]	Spatial	Accuracy	G>T	—
Interpolating values				
Carter [11]		Accuracy Time	G=T	G>T
Carter [12]		Accuracy Time	G=T	G>T
b. Analysis of paradigmatic symbolic information acquisition tasks				
Point/value reading				
Washburne [89]	Symbolic	Accuracy	T>G	—
Carter [11]	Symbolic	Accuracy Time	T>G	T>G
Carter [12]	Symbolic	Accuracy Time	T>G	T>G
Powers et al. [57]	Symbolic	Accuracy Time	T>G	T>G
Point/value recall				
Umanath et al. [83]	Symbolic	Accuracy	T>G	—

[1]The > sign for time means that performance is better, rather than time is greater.

types of tasks. The three experiments that report time results show that graphs result in faster task performance than tables, in accordance with the theory. Note that, in all studies, accuracy is at least equivalent for the two problem representations and frequently better for graphs than for tables. Three studies did not result in accuracy effects. Two of the studies [11] [12], however, showed effects for time, suggesting that subjects adapt the time they take to complete the tasks while keeping accuracy as high as possible (see also, [6]). The third study that did not produce significant accuracy (or time) results is that of Watson and Driver [90]. The hypotheses tested were in accordance with the paradigm of cognitive fit. It is possible that the lack of significant results may have been due to the operationalization of the study. In general, the results of the spatial information acquisition studies reported here provide substantial support for Proposition 1.

Table 2b presents the results of studies investigating performance on symbolic information acquisition tasks. According to the paradigm of cognitive fit, tables would be expected to have a natural advantage for accuracy in performing symbolic tasks. Perusal of the results shows that tables were more accurate than graphs in all five studies examined. With regard to the proposition that the representation will produce effects in both time and accuracy of performance when it matches the task, it is interesting to note that all three experiments that assessed time show tables are faster than graphs on symbolic tasks [11] [12] [57]. All three experiments used time pressure as a surrogate for time; that is, subjects were required to respond to more questions than they could complete within the time frame. These results fully support Proposition 1.

Table 3 presents the results of those studies that did not produce significant results for either graphs or tables. All studies used interpretation accuracy as the task. Five of the eight studies analyzed graphs that also presented point values [24] [45] [91]. The interpretation accuracy instruments used in four of the studies contained both spatial and symbolic questions.

One study [24], in which both representation and task type were confounded, produced nonsignificant results. The results of the four studies [45] [91] that confounded only representation and two of the three studies that confounded only task type [19] [82] also produced nonsignificant results, further supporting the cognitive fit analysis. Despite using mixed task types, one of the studies produced significant results [30]. The questions in [30] need to be examined to determine why tables resulted in greater accuracy than graphs. No examples are provided; however, the author stated: ''Half [the questions] required specific flight selection to obtain the correct answer. The other half required that data about a number of profiles be grouped to obtain the correct answer'' [30, p. 446]. It is possible that: (1) all questions required the use of analytical processes, that is, grouping required simple arithmetic operations; (2) even if 50 percent of the questions were spatial in nature, the effect may have been manifested in time, which was not assessed in the study. The results of these nonparadigmatic studies provide substantial support for Proposition 2.

Information Evaluation Studies

The paradigm of cognitive fit can also be tested by analyzing the results of information evaluation studies for which the component subtasks can be identified. The information acquisition and information evaluation subtasks may be either similar or different in nature. With similar types of subtasks (i.e., spatial/spatial or symbolic/symbolic), one problem representation will facilitate decision making compared with the other. On the other hand, if the task is comprised of different types of subtasks, then neither problem representation may have a distinct advantage.

Table 4 presents the results of two information evaluation studies that provide sufficient information to identify the types of subtasks involved in evaluation as well as in acquisition. One of the studies [48] required similar information for acquisition and evaluation and therefore a given type of problem representation could be used to facilitate both. The acquisition and evaluation subtasks were symbolic in nature and tables led to more effective decision-making performance than graphs.

Benbasat and Dexter [3], on the other hand, provided an example of a task in which the subtasks for acquisition and evaluation are different in nature: that

Table 3: Analysis of non-paradigmatic graphs versus tables studies on information acquisition tasks.

Study	Characteristics of Representation	Types of Questions	Dependent Variables	Results Accuracy	Results Time
Point/value reading					
Lee et al. [45] Scenario B	G+T vs. T	Symbolic	Time Accuracy	T=G	T>G
Information comprehension					
Feliciano et al. [24]	G+T vs. T	Spatial & symbolic	Accuracy	G+T>T	—
Grace [30]	G vs. T	Spatial & symbolic	Accuracy	T>G	—
Dickson et al. [19] Experiment 1[1]	G vs. T	Spatial & symbolic	Accuracy	G=T	—
Umanath et al. [82][2]	G vs. T	Spatial & symbolic	Accuracy	G=T	—
Recognizing trends					
Wilcox [91] Study 1	G+T vs. T	Spatial	Accuracy	G+T>T	—
Wilcox [91] Study 4	G+T vs. T	Spatial	Accuracy	G+T>T	—
Comparing values					
Wilcox [91] Study 5	G+T vs. T	Spatial	Accuracy	G+T>T	—

[1]Some of the bar charts also presented point values.
[2]The original article [82] reported no difference between the performance of graphs and tables on specific fact recall. Further analysis [83], however, revealed that some of the tasks required the recall of specific facts, while others required comparisons, which are spatial in nature.

for acquisition is spatial, while that for evaluation is symbolic in nature. Hence, the task is composed of subtasks differentially facilitated by graphs and tables and neither problem representation is expected to have a distinct advantage. The researchers investigated the performance of tables, graphs, and graphs and tables combined on this task, as well as requiring subjects to complete their analysis within specified time limits of 5 and 15 minutes. The hypotheses of the researchers were consistent with those of the paradigm of cognitive fit. The results for the five-minute time period were not significant and are not presented in this paper. They were, however, in the correct direction according to this theory. Table 4 presents the results for the 15-minute decision-making period. Graphs were quicker than tables, although "decision quality" (in this case, profit) was not significantly different, suggesting that subjects adapted time while keeping quality at as high a level as possible. The results of this experiment, therefore, also support Proposition 1.

It is not possible to characterize the subtasks required for the solution of the majority of information evaluation studies. In effect, these studies represent decision-making tasks that are too complex to be addressed by the paradigm of cognitive fit. Many of these studies used simulated business environments (see, for example, [4] [46] [47] [59]). Here, the notion of strategy becomes important, that is, the sequence of subtasks used to solve a problem. Complex problems may be

Table 4: Analysis of paradigmatic graph versus tables studies in information evaluation tasks.

Study	Nature of Task: Information Acquisition	Nature of Task: Information Evaluation	Dependent Variable	Results: Accuracy	Results: Time
Lusk & Kersnick [48]	Symbolic	Symbolic	Accuracy (time pressure)	T>G	—
Benbasat & Dexter [3]	Spatial	Symbolic	Accuracy Time (15-minute limit)	T=G	G>T

solved using a variety of subtask combinations or strategies. Under these circumstances, it is likely that the use of uncontrolled strategies will result in nonsignificant effects for the use of either graphs or tables. Table 5 presents the results of selected graphs versus tables studies that do not support the paradigm.

The studies by Davis [16] and Ghani [28] used simulated environments and hence are not analyzable using the paradigm. Ghani, for example, stated: "The information evaluation task of actually deciding how much to order and take out, was the more complicated aspect of the task, since it required the subject to consider the joint probabilities of the weather and the demand forecasts" [28, p. 89]. Hence Ghani's task was much more complex than simply acquiring data and performing readily characterizable evaluation. With currently available information, the subtasks necessary for task solution cannot be determined. Further, in such a complex task, it is likely that subjects used a variety of strategies for task solution, composed of different combinations of subtasks. Hence, it is not surprising that neither graphs nor tables had a significant advantage.

Tullis' [76] study used interpretation accuracy. Tullis' subjects responded to "questions which ranged from simple identification to complex integration and decision making" [76, p. 543]. The lack of specificity in the questions used precludes analysis using the paradigm of cognitive fit. Further, the study used formats that were not "pure." For example, the graphical formats attempted to present a concrete model of the domain under investigation. They contained pictorial as well as "graphical" elements.

Note that each of these studies produced nonsignificant results supporting the notion that testing did not occur at a sufficiently detailed level to permit analysis using the paradigm, thus supporting Proposition 2.

DISCUSSION

This research investigates the performance of graphs and tables on information acquisition and relatively simple information evaluation tasks. This section discusses the findings and the implications of the findings from a theoretical, methodological, and a practical perspective.

Discussion of Findings

This analysis of research into the performance of graphical and tabular representations on information acquisition tasks shows that matching the problem representation to the type of task to be solved results in improved decision-making

Table 5: Analysis of non-paradigmatic graphs versus tables studies in information evaluation tasks.

Study	Characteristics of Representation	Types of Questions	Dependent Variables	Results	
				Accuracy	Time
Forecasting					
Davis [16]	G vs. T		Decision cost Time	G=T	G=T
Decision making					
Ghani [28]	G vs. T		Profit Time	G=T	G=T
Troubleshooting					
Tullis [76]	Mixed	Spatial & symbolic	Accuracy Time	G=T	G=T

performance. The link between these factors is the mental representation formulated. The processes necessary to formulate the mental representation play the key role in mediating the dual matching process—matching problem representation to mental representation and mental representation to task—and are therefore the critical factors in determining the performance of the two types of representation on a given type of task. In effect, cognitive fit encourages the use of consistent (and therefore optimal) problem-solving processes in the solution of a specific task, resulting in performance advantages. The paradigm and its application to the information presentation domain is largely successful in explaining the significant findings of the graphs versus tables experiments involving information acquisition and simple information evaluation tasks that report sufficient details to analyze. Further, it can also explain the majority of nonsignificant findings reported in the literature.

Implications of the Findings

What, then, are the implications of these findings for theory, methodology, and for practice? Although the analyses conducted in this paper provide compelling evidence in support of the theory presented, the theory should be tested explicitly. In particular, the role of processes should be assessed directly. Basic research should also be conducted to assess empirically the relationships in the model (Figure 1). Future research, for example, might address the effects on performance of problem solving in mismatched contexts, the relative importance of the problem representation and the task in the formulation of the mental representation, and the nature of problem solving in more complex tasks.

The theory presented here can be extended in at least two ways. First, cognitive fit is not restricted to the graphs versus tables domain. It can be applied to any domain where there is sufficient information to permit analysis of the tasks to be performed. It has, for example, been identified in the systems development domain [73] [87]. Within each domain, the information characteristics of the particular task under investigation must be identified. Then the available problem representations must be examined to identify those that have information characteristics that support task solution.

Second, the theory is not restricted to matching problem representation to task. It can be extended to include problem-solving techniques, tools, or aids. The study by Vessey and Weber [87] serves to illustrate both types of extensions to the paradigm. The study examined which of three structured analysis tools (structured

English, decision trees, and decision tables) recommended for specifying the content of primitive processes derived from structured analysis result in superior performance in specification (design) and coding of nested conditional statements. The first experiment examined the effects on performance of matching the problem-solving tool to the task at hand, while the second experiment matched problem representation to task. The results provided substantial support for the paradigm of cognitive fit for matching both problem representation and problem-solving tools to tasks in the systems development domain.

The paradigm of cognitive fit demonstrates, therefore, that a general theory of tasks is not essential to develop a problem-solving paradigm. A theory can be developed for particular research contexts that will, with accumulated findings, help pave the way to a general theory of problem solving, as well as to a general theory of tasks. To be able to progress in this direction, however, the details of processes must be reported as well as details of tasks and problem representations.

The paradigm of cognitive fit presented in this paper is useful for examining fairly simple decision-making tasks. Now, an examination of the effect of information presentation on more complex decision-making tasks, where strategy is key, is needed. Two studies that addressed the role of strategy in decision making are Jarvenpaa [36] and Blocher, Moffie, and Zmud [9]. Jarvenpaa examined strategies used for both information acquisition and information evaluation, based on graphical formats, while Blocher et al. highlighted the relationship between strategy and task complexity, based on a graphs versus tables study (also, see [18]). Kleinmuntz and Schkade [41] and Vessey [86] provided theoretical foundations and reviews of the role of strategy in this context. Two methodological approaches for examining performance on more complex tasks are described later in this section.

The current research touches on several issues of methodology. First, most of the research on graphs and tables to date has been based on the assumption that decision-making performance will be manifested in accuracy alone. Among the studies that measured both time and accuracy, albeit separately, are those by Carter [11] [12], Tullis [76], and Benbasat and Dexter [3]. Although the limitations of studies that assess only accuracy have been acknowledged for some time, researchers have not yet recognized the need to assess time and accuracy jointly. Time data is now frequently collected, although time and accuracy are still most often analyzed separately. To control for simple time-accuracy trade-off, time and accuracy should be evaluated simultaneously. The study by Davis [16] is the only one identified using this approach.

Second, analyzing the results of studies that used interpretation accuracy as the dependent variable reveals that care should be exercised in devising a suitable test instrument. Many of the studies analyzed here used mixed spatial and symbolic questions, confounding the nature of the decision making "task." Note that the results of all interpretation accuracy studies, where the questions matched the information characteristics of the problem representations, were significant and those where the questions asked were both spatial and symbolic in nature were not significant. Researchers can use one of two approaches to develop a test instrument. First, they can use just one type of question showing a well-defined purpose in conducting the study (see, for example, [48]). Alternatively, they could use just one instrument with well-defined questions to measure performance on each of spatial and symbolic dimensions (see, for example, [89]).

Third, if the objective of the research is to examine the performance of graphs versus tables, then researchers should ensure that they use "pure" graphical constructs. A number of studies reported in the literature, for example, place figures at the end of horizontal bar charts resulting in combined graphical and tabular representations. As noted earlier, such problem representations provide both spatial and symbolic information and cannot, therefore, be regarded as purely graphical in nature. The study of combined problem representations is legitimate, of course, but not if the aim is to study the performance of graphs and tables.

Fourth, the theory developed in this research emphasizes the importance of processes and the formulation of the mental representation in decision making. This suggests the use of qualitative research strategies to investigate these two aspects of problem solving. Anderson [1] suggested it is currently difficult to distinguish between processes and mental representations. The difficulty lies in the fact that they are really two sides of the same coin: one is static while the other is dynamic; one is declarative while the other is procedural [68]. Processing strategies can be investigated by using a process tracing technique such as protocol analysis [22] [23] [61] [75]. The protocol analysis procedure involves externalizing problem-solving behavior by "thinking aloud" while solving a problem (the dynamic or procedural aspect). Mental representations can be investigated by inducing an external representation of the intermediate mental representation (the static or declarative aspect). Using both these techniques could provide powerful insights into the problem-solving process.

Fifth, the notion of cognitive fit presented in this paper applies to fairly simple tasks. Examination of more complex decision-making tasks might take two forms. First, the notion of fit can be extended to more complex decision-making environments. Venkatraman [85], for example, presented the theoretical and statistical implications associated with each of six types of fit characterized on the basis of the degree of specificity of the fit relationship (micro to macro) and the presence or absence of a criterion of fit. Some of the macro concepts of fit offer a way of viewing decision making on more complex tasks (see also, [84]). Second, the notion of elementary information and perceptual processes could be used to characterize the diverse processing strategies that may arise when a number of possible subtasks are involved in problem solving [13] [14] [15] [51] [55] [56] [67] [81].

Sixth, from the viewpoint of the methodology used to conduct the analysis presented here, an alternative approach, meta-analysis, could be considered. Meta-analysis is an approach commonly used to determine significant effects in an area in which a number of studies report inconclusive results [35] [92]. It is a data-pooling approach appropriate for overcoming the low power of a number of related experiments. What is needed to analyze the graphs versus tables studies is not, however, statistical manipulation, but insight into the fundamental reasons for the inconclusive results. In other words, the distinction between spatial and symbolic tasks must be made prior to conducting a meaningful meta-analysis. Hence, the first step was to conduct a "qualitative" meta-analysis. Following this theoretical insight, meta-analysis would have been recommended had the power of the experiments analyzed been insufficient to reveal the underlying theory.

From the viewpoint of practice, the paradigm of cognitive fit developed here suggests that decision makers will perform better when they receive the appropriate support for a specific task. Note that this analysis suggests, therefore, that permitting decision makers complete freedom in choosing their own problem representation(s) will not necessarily lead to improved performance. Further, these results also suggest that problem solvers will not necessarily perform better when the problem representations they use support their natural problem-solving strategies (see also, [73]). From the viewpoint of practice, it is advocated, therefore, that systems designers examine the nature of the task to be performed. They should then support the task by providing the problem solver with the problem representation that matches the task.

CONCLUSIONS

The primary purpose of this research was to develop a theory to explain the performance of graphs and tables in decision making and to examine the validity of the theory from an empirical viewpoint. The theory highlights the importance of considering the type of task under investigation. The empirical evidence demonstrates that the theory is successful in explaining the results of the majority of graphs versus tables experiments reported in the literature that provide sufficient details to analyze, namely, information acquisition and simple information evaluation tasks.

The central theme that runs throughout this paper is the need to develop theories on which to base research. There are two approaches; each may be equally applicable, although one approach may be preferred, depending on the timing of theory development. One approach suggests that a field cannot advance until sufficient knowledge of the area has accumulated [43]. This is the approach taken currently in the graphs versus tables area. It is an inductive approach to theory development. Areas that are ripe for the development of theory can be identified by searching for statements such as: "DeSanctis identifies 29 studies that have compared graphics to tables. Twelve of the 29 studies found tables to be better than graphics, ten found no significant difference between the two modes of presentation, and seven found graphics better than tables" [37, p. 764].

The second approach suggests that theories on which to base research might be found by investigating appropriate reference disciplines. This is a deductive approach to theory development. To use this approach effectively for developing theories, relevant reference disciplines must be thoroughly investigated. [Received: August 10, 1989. Accepted: February 15, 1990.]

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Iris Vessey is Associate Professor of MIS at The Pennsylvania State University. She earned her Ph.D. degree at the University of Queensland. Dr. Vessey is a member of the Society for Information Management, The Institute of Management Science, the Association for Computing Machinery, and the Institute for Electrical and Electronic Engineers. Her current research interest is in problem solving for both systems design and systems development.