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Effects of Navigation Tool Information on Hypertext Navigation Behavior: A Configural Analysis of Page-Transition Data

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The effects of navigation tools in hypertext have been studied predominantly through performance measures such as speed, accuracy, number of pages accessed and recall of document elements. In contrast, the current study uses multidimensional scaling to examine differences in path data, specifically page-transition frequencies, for four navigation tool groups. Each of these navigation tools contains different combinations of spatial and conceptual information. Users' page-transition choices during an information search task in a hypertext document with hierarchically organized material were examined. The results indicate that users' page-transition patterns are heavily influenced by the type of information contained in the navigation tool but transition patterns are not totally linear.

The term "hypertext" refers to any electronic document or document collection of interconnected units of information. Many different types of hypertext systems have been designed, each consisting of its own specific structures that support the connections (links) between the user interface (the windows or pages a user views on the display terminal) and the underlying information system. A vast example of a system of hypertext documents is the World Wide Web (WWW or Web). As well, customized, constrained systems (Intranet systems) have become commonplace in work and educational environments.

Unfortunately, the cognitive processes involved in navigating through even single hypertext documents are not understood clearly. Previous research identified some of the variables that impact navigation performance in a single document. Individual characteristics such as cognitive or learning style (Andris, 1996; Korthauer & Koubek, 1994), prior domain knowledge (Ford & Chen, 2000; McDonald & Stevenson, 1998; Lawless & Kulikowich, 1998), level of interest (Lawless & Kulikowich, 1998) and gender (Beasley & Vila, 1992) all influence performance. Task demands are influential as well. For example, whether or not users are asked to search for specific material (Chen & Rada, 1996) and if users are instructed to study versus review the material (Beasley & Waugh, 1997) both affect performance. Characteristics of the document such as the inherent structure of the material, document structure cues, and the linking structure all impact performance (Korthauer & Koubek, 1994). Finally, the types of navigation tools that accompany the document can also have an effect on performance measures (Boechler & Dawson, 2002; McDonald & Stevenson, 1998, 1999; Wenger & Payne, 1994).

Much of the previous research on the effects of navigation tools looks at these effects from a performance perspective, that is, using typical measures of efficiency and effectiveness (Boechler & Dawson, 2002; Dee-Lucas & Larkin, 1995; Dias & Sousa, 1997; McDonald & Stevenson, 1998). Efficiency measures are based on speed and the number of steps taken to complete an information search. Effectiveness measures focus on the user's search accuracy as well as his/her recall and understanding of the structure of the document. Accuracy is also an effectiveness measure denoted by the number of correct answers to questions that require the user to conduct an information search.

Such performance measures have been used to investigate what types of information should be presented in navigation tools to enhance performance. Specifically, two types of information have been the focus of such research: spatial and conceptual information. Boechler and Dawson (2002) investigated the interaction of spatial and conceptual information within navigation tools and found that including both types of information in a single navigation tool did not enhance user performance over tools with either spatial or conceptual information alone. McDonald and Stevenson (1999) investigated the effects of a spatial versus conceptual map and found that a conceptual map was important for learning whereas a spatial map increases efficiency but not effectiveness. Dias and Sousa (1997) studied the effects on performance of a navigational map and found that users who visited the map frequently and /or spent more time on the map did not access more relevant screen pages or fewer unnecessary pages than subjects who used the map less frequently or for less time. Conversely, Leventhal, Teasley, Instone, Rohlman, and Farhat (1993) found that measures of navigational performance were not correlated with use of a hierarchical overview. Stanton, Taylor, and Tweedie (1992) found evidence against facilitation of navigation maps on effectiveness measures.

Although navigation tool studies using performance measures have yielded valued (albeit inconclusive) information about how navigation tools impact users' ability to find specific information in a fast and economical fashion, most don't reveal much about how different navigation tools affect the paths that users choose to access target information. This is important because, although basic performance measures indicate if users' abilities to arrive at targeted information is enhanced by a navigation tool, these measures do not indicate how users went about their search or what navigation choices were made at different decision points. How does different information presented in a navigation tool affect where groups of users generally go? To determine this, users' path data must be examined.

Prior hypertext research has examined different aspects of users' path data with different approaches. Linearity of use is a focus of some of these studies. Linearity has been operationalized in a number of ways.

Beasley and Vila (1992) used proximity matrices where each cell contained the frequency of a particular page-transition, to examine the linearity of user behavior and found that females navigated in a more linear fashion than males where linearity was defined as the choice of the next screen in a predetermined lesson sequence. It is relevant to note that, as it relates to navigation support tools, these measures of linearity did not take into account access to menu items.

Beasley and Waugh (1997) used page-transition frequencies to reveal predominant path patterns of users during learning and review. They found a strong tendency for users to navigate top-down and from left to right during initial learning but less structured navigation during review.

Horney (1993) made the distinction between linearity of the document and linearity of user navigation. According to Horney, linearity of the document can be described through a linearity function. Path length was derived by tracing paths backwards until the probability that a certain path was taken dropped below a certain criteria. The average length of the paths gives a measure of linearity for each node and when all nodes are averaged together, for the entire document. In contrast to this, linearity of use was based on the number of visits to each node from each of it's parents where a parent node is defined as those nodes visited immediately prior to a given node. Hence, some nodes could have more than one parent node if two nodes led into the given node. The linearity function for use was calculated from path probabilities that were derived from the ratio of parent-child traversals to the total number of node visits. Using these two definitions, Horney examined the path patterns of eight hypertext authors and found that users with different skills and goals use distinctly different navigation patterns and that these patterns show little resemblance to the linearity of the document itself.

Andris (1996) also distinguished between the linearity of the document and the linearity of the user's path. He described the baseline linearity of the document as a ratio of the minimum number of linear accesses to ensure full coverage of content versus the minimum number of nodes accessed to ensure full coverage of both content and menu. The actual linearity of a given user's path was then defined as the ratio of actual number of linear accesses of content versus the actual accesses of content and menu. Finally, the linearity of the user's path was defined as the ratio of baseline to actual linearity. Based on this definition, Andris found that the different learning styles of users resulted in different degrees of linearity of use.

Given that linearity of use is an aspect of interest within total document navigation, it seems prudent to examine this issue in regards to navigation tools as well. Therefore, the purpose of the present study is threefold: (a) to investigate if there are differences during an information search task in the page-transition patterns of users who are exposed to different navigation tools, (b) to examine if page-transition patterns reveal linear use of the navigation tool, (c) to develop an alternate approach to data analysis to help shed light on the properties that guide navigation tool use.

One obstacle to such an investigation is the difficulty of making path comparisons between groups of users rather than individual users. To address this issue, the authors have taken a qualitative approach toward examining the behavioral space of multiple users. The use of multidimensional scaling (MDS) provides a means of making global comparisons between groups of users as well as reveals how the form of the navigation tool impacts the behavioral space of a given group. MDS is a statistical method for uncovering the structural regularities or pattern hidden in a matrix of data and representing that structure in graphical form for easier visual interpretation. In this case, the matrices of frequencies show how frequently a move was made between column and row elements. Based on the correlations between items in the frequency matrices, spatial coordinates are calculated and plotted in a configuration. These coordinates represent some underlying property of the data and the configuration of points they create illustrates how closely the objects under study, (in this case the page titles) are related to each other as a function of this underlying property. The dimensions that produce the spatial coordinates may be abstract such as the conceptual relatedness between pages or concrete such as the physical distances between page labels on the navigation tool. On a MDS plot, related items are plotted close together and unrelated items are plotted far apart. MDS is often used to analyze frequency, similarity, or distance data. (e.g. Borg & Groenen, 1997). MDS is related to factor analyses but is more parsimonious as the optimal multidimensional solution is constrained to five dimensions or less. Solutions of more than five dimensions create spatial configurations that are not visually interpretable.

MDS is particularly suited to the frequency data of hypertext navigation because it allows the production of a configuration that visually represents each group's path data and to partition these configurations in different ways to determine if the behavioral space of users reflects the navigation tool they used.

MDS uses measures of proximity to produce representative configurations of a data set. When MDS analysis is applied to psychological data, it is based on the assumption that measures such as similarity judgments between object pairs are equivalent to measures of proximity; and that the rating or ranking of objects constitutes the psychological distance between two objects. This approach has been used in many studies of psychological phenomenon. For example, in the case of frequency data specifically, Dawson and Harshman (1986) used a variant of MDS to reveal information about letter-perception processes. In this instance, a confusion matrix contained frequencies of how often subjects confused one letter-like symbol with another. The frequencies within each cell of the matrix were indicators of the subjects' perceptions of the similarity between two symbols. The subsequent MDS analysis on this data revealed that global characteristics such as the size and general shape of a letter guided these perceptions.

In the current study, the frequency count is a page-transition count such as that used by Beasley and Vila (1992) and Beasley and Waugh (1997), that is, the number of times a move from one particular page to another was taken. This captures a view of the data based on transitions as opposed to states. By counting the number of particular transitions one can gain a sense of which connections are important and which are not.

Each cell of the transition matrix contains the average frequency of moves from one particular page to another. Transitions that occur frequently can be assumed to be between pages that are very related on some, as of yet, unidentified dimension whereas transitions that occur infrequently can be assumed to be between pages that are less related. In this way, the frequencies of transitions are used as a measure of proximity.

Using this approach to analyzing frequency data, questions of interest are: Does the behavioral data reflect some aspect of the navigational tools? Is this representation based on different properties or dimensions for different navigation tools? If so, what does this reveal about how different navigation tools are used? Is linearity an important aspect of navigation tool use?

The four navigation aids used in this study were constructed to approximate the most singular representation of each type of information, the absence of both types of information or a combination of both types of information. The Alphabetical navigation tool is merely a content list of the page titles organized alphabetically. It contains neither spatial nor conceptual information, as the list provides no information about how the page titles may be semantically related. The Hierarchical tool contains conceptual but minimal spatial information. It is a content list that designates the superordinate and subordinate categories in the material through the use of font size and label color. The Spatial tool contains spatial information but minimal conceptual information and the Spatial/Hierarchical tool explicitly contains both types of information. These tools were designed with the recognition that there is no representation that is purely one type of information and also with the constraint of retaining some ecological validity. For example, the spatial tool has some conceptual information embedded in the clustering of the labels rather than totally random spatial label locations as it is unlikely that a hypertext document would be accompanied by a random list or map as a navigation aid. In this case, the spatial aid has been pared down to include only one of the three methods mentioned earlier for the conveyance of conceptual information in a spatial aid (label clustering). No link designations are included in the spatial tool.

METHODS

Participants

The participants were 169 undergraduate first-year psychology students (81 males and 88 females) from the University of Alberta, Edmonton, Alberta, Canada. Students participated as part of a research participation program and received credit for their participation. The students were randomly assigned to four conditions based on the navigation aid presented: Alphabetical, n = 43 (22 males and 21 females), Hierarchical n = 41 (20 males and 21 females), Spatial, n = 41 (18 males and 23 females), and Spatial/Hierarchical, n = 44 (21 males and 23 females).

Materials

Participants were tested on a 22-page hypertext document on the topic of Fungi programmed using Visual Basic 6.0 (Professional Edition) (Boechler, Dawson, & Boechler, in press). Each hypertext page contained a short text section with similar word counts between pages and a picture to help users differentiate between pages. All users were constrained to navigating from the navigation tool only to ensure equal exposure to the navigation tool between all groups. Consequently, although the number of pages a user accessed may vary, the ratio of page visits to navigation tool visits remained constant.

Information search task. The search task began with an instruction page, followed by the navigation aid for a given condition. The Alphabetical navigation aid consisted of an alphabetical listing of the 22 page titles. The Hierarchical navigation aid consisted of a hierarchical listing of the 22 page titles, headings and subheadings delineated by different colored page titles and font sizes (Figure 1).

Anti-rejection Drug	FUNGI
Biocontrol	POSITIVE USES
Caterpillar Tonic	Medicine
Chytrids	Penicillin
Club Fungi	Anti-Rejection Drug
Conjugation Fungi	Caterpillar Tonic
Disease	Food
Food	Morels
Fungi	Truffles
Heart	Yeast
Lichen	Biocontrol
Medicine	TYPES
Morels	Club Fungi
Negative Aspects	Sac Fungi
Penicillin	Conjugation Fungi
Poisonous Mushrooms	Chytrids
Positive Uses	Lichen
Sac Fungi	NEGATIVE ASPECTS
Skin	Diseases
Truffles	Skin
Types	Heart
Yeast	Poisonous Mushrooms
(a)	(b)

Figure 1. (a) Alphabetical content list (b) Hierarchical content list

The Spatial navigation aid was a map of the page titles. This map was derived by counting the number of steps between titles in a hierarchically-ordered tree diagram of the material. The resulting “distances” were transformed into a matrix of correlations that was analyzed using MDS. The configuration produced by this analysis provided the positions for the page labels on the map. The spatial map did not provide explicit information about the semantic relatedness of pages but the process described created a configuration with some implicit information about relatedness given that the clustering of page titles reflected to some degree the levels of the tree diagram (Figure 2).

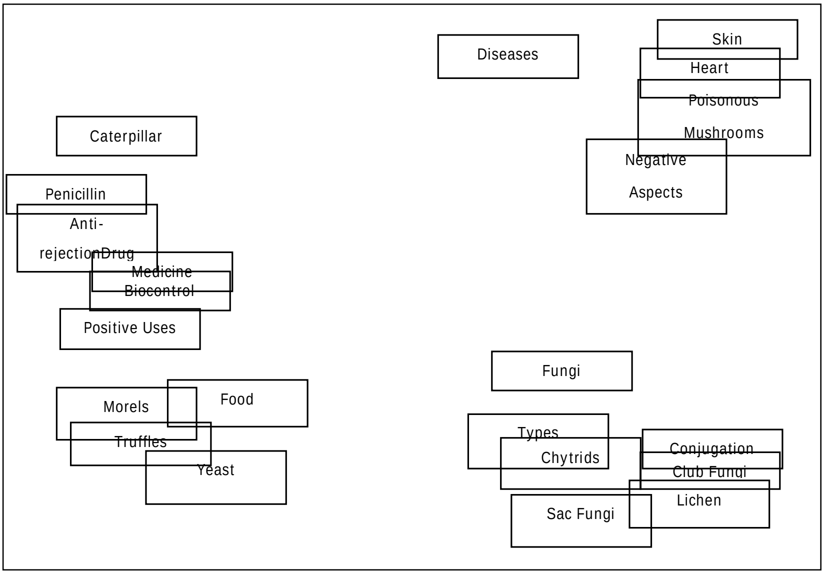


Figure 2. Spatial navigation tool

The fourth navigation aid, the spatial/hierarchical aid, was the previously mentioned tree diagram, consisting of four levels of page titles with subordinate and superordinate categories along with connecting lines (Figure 3).

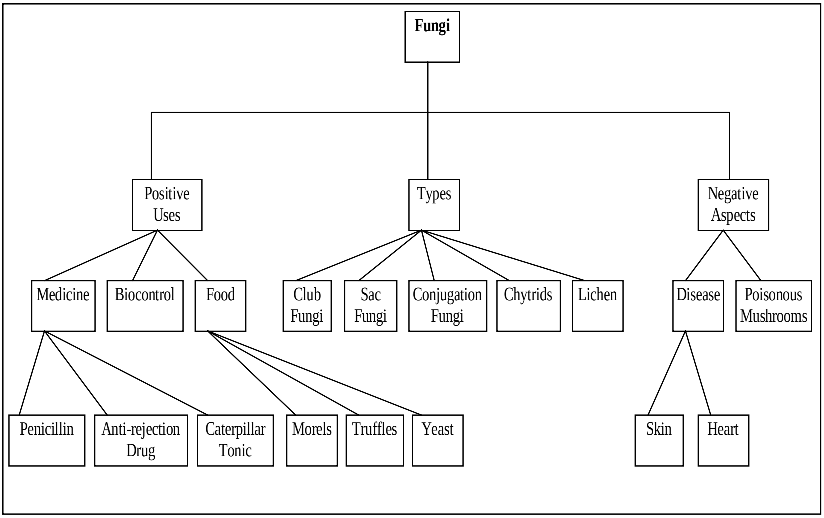


Figure 3. Spatial/hierarchical navigation tool

The organization of the navigation aids did not reflect the linking structure of the document but only served as a representation to help the users mentally organize the document material. All page labels on all four navigation aids were linked to the corresponding page; therefore, the users could always navigate directly to any page from the navigation aid without having to access intermediary pages. Hence, the optimal route to a given page was always a direct selection of a particular page label from the navigation aid.

Procedures

At the beginning of the test session, participants were given brief instructions on the function of icons and the use of the mouse. Participants were then told they were required to complete two tasks related to a document that they would be viewing. It was explained that Task 1 would involve searching through the document for the answers to 10 questions and that once this task was complete the program would provide instructions for the following task. To begin the information search task, participants were presented with a login page where they submitted their name and student number by typing in the necessary information into textboxes and clicking on a command button labeled “Submit.” This initiated the appearance of the instruction page, which students could view as long as they chose before clicking on a command button labeled “Continue.” The navigation tool for that condition then appeared in a new window with the first question of the information search task listed at the bottom of the browser frame. The timer for the first question was initiated when the navigation tool page appeared. Also, on the bottom of the browser frame was a command button labeled “Found it”. When the participant had located the answer to the question they were to click on the “Found it” button and the timer would stop. The “Found it” label then changes to “Submit.” When the student was sure of the answer he/she had selected they would then click on the “Submit” button and the program recorded their answer. This event also prompted the return to the navigation tool page and the appearance of the next question. This process was repeated until all ten questions were answered.

RESULTS

For each subject in all four navigation tool groups, a matrix was constructed of the frequencies for a move from one particular page to another. Subject matrices were then averaged to create a group matrix of averaged frequencies for each of the four navigation tool groups.

Initially, an analysis of variance was conducted on the frequency matrices for the four groups which revealed a main effect of group, $F(3, 1936) = 4.053$, $p = .007$. Tukey’s post hoc tests (HSD) indicated this result was attributable to a difference between the Alphabetic group and the Hierarchical group, Alphabetical versus Hierarchical, $p = .005$.

The averaged frequency matrices were then transformed into correlation matrices and analyzed using MDS. The optimal solutions (number of dimensions) for each group were determined using several criteria typically used in MDS analyses (Borg & Groenen, 1997). The most common measure that is used to evaluate how well a particular configuration reproduces the observed distance matrix is the stress measure. Stress is a goodness-of-fit measure for the entire MDS representation based on the error between the observed proximities and the reproduced proximities that comprise the configuration. The stress criteria adopted in this study was based on the stress norms proposed by Kruskal and Wish (1978), who suggested a value of .20 or less was acceptable to define the optimal number of dimensions. Scree plots of the stress versus number of dimensions were also examined. Viewing scree plots, the optimal number of dimensions is suggested by the sharpest elbow in the curve which represents the solution where further increases in dimensions does not improve the stress statistic (Kruskal, 1964). Changes in R^2 values are also used to evaluate the precision of solutions. The optimal solution typically results in a more drastic increase in the R^2 value from the previous dimension than between any other two dimensions. For instance where two solutions were very close, Shepard diagrams, which are scatter plots that plot the proximities on the *x*-axis and the corresponding MDS distances on the *y*-axis, were also examined. The solutions that produced diagrams with the least scatter and no obvious outliers were chosen as the optimal solution. These criteria were judged collectively to determine the appropriate number of dimensions for the MDS solution.

Alphabetical. The Alphabetical tool consisted of the 22 page titles in a vertically organized alphabetical list. The list contained a beginning structure where the top label was adjacent to only one other label below it, a middle structure where labels had two adjacent neighbours and an end structure where the last label had only one adjacent label above it. No conceptual information was contained in this tool.

According to the previously described criteria, the optimal solution for the Alphabetical group data was a three-dimensional solution which accounted for 75% of the variance with an acceptable stress value, Stress = .156. A scree plot of the stress values and the dimensions shows a sharp elbow at the three-dimensional solution suggesting this is the appropriate solution. The MDS configuration for the three-dimensional solution appears in Figure 4 and can be partitioned into three distinct ordered regions (for further information on regional partitioning see Borg & Groenen, 1997).

These regions represent the Alphabetical listing divided approximately into thirds in an ordered fashion; beginning, middle, and end (from right to left). Although the MDS plot reflects the general form of the navigation tool in an ordered way, the order of individual points within the three regions do not precisely follow the alphabetic sequence of the list.

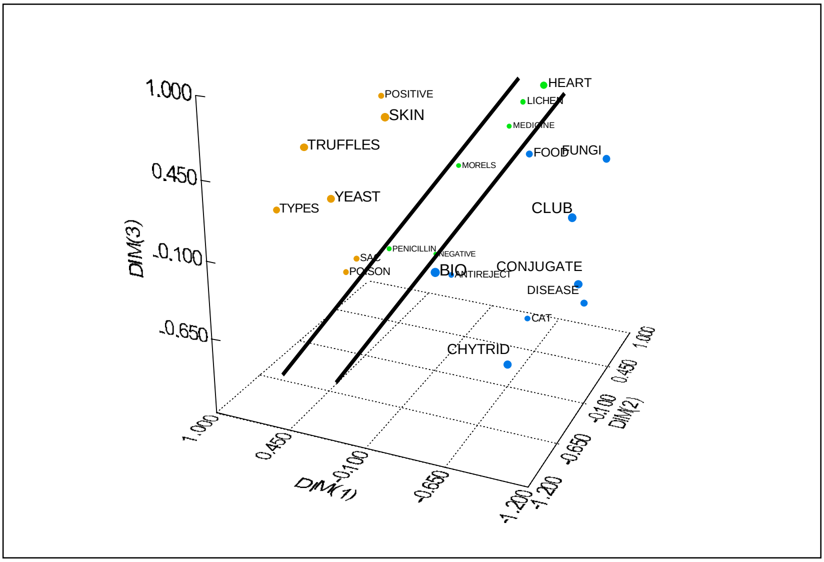


Figure 4. Three-dimensional solution for the Alphabetical Group—Axial Partitioning based on the divisions of the alphabetical list into thirds

To determine if the precise alphabetic order was possibly obscured by the three-dimensional representation, each facet of the three-dimensional plot was projected onto a two-dimensional configuration (facet diagram). Out of these 3 diagrams, the plot of Dimension 1 and Dimension 2 shows an obvious alphabetical organization into clusters of the thirds, ordered in a counterclockwise fashion (Figure 5). The plot of Dimension 1 and Dimension 3 shows a very clear axial partitioning of the space into the three alphabetical portions of the list. This facet is an ordered facet as well, the first third of the alphabet appearing on the right, the second third in the middle and the last third on the left. However, neither of these plots shows absolute correspondence to the order of labels on the list. The final plot of Dimension 2 and 3 shows no obvious organization based on the dimension of alphabetical order. To investigate if the third facet diagram was possibly organized by way of another dimension, we attempted to partition the behavioral space according to the frequency of a given page being accessed, rather than the transition frequency. Frequency of access for individual pages did not appear as a clear dimension in any of the facet diagrams for the Alphabetical group.

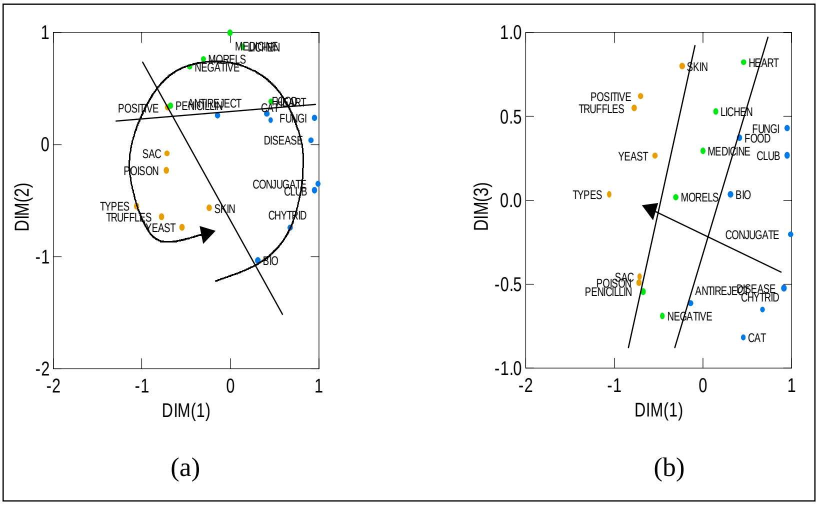


Figure 5. Alphabetical facet diagrams: (a) Dimension 1 and 2, (b) Dimension 1 and 3

Hierarchical. The Hierarchical tool was a list with the levels of the hierarchy denoted by different font sizes and label colors. This tool contained conceptual information with a minimum of spatial information. The optimal solution for the Hierarchical group was a two-dimensional solution, which accounted for 74% of the variance in the data. The stress value for this solution was adequate for defining an optimal solution (stress = .20). The scree plot showed a distinct elbow at the two-dimensional solution. A plot of the two–dimensional solution showed that three distinct regions could be axially partitioned (Figure 6). These three regions represent the three subheadings of the 2nd level of the hierarchy (Positive uses, Types, and Negative aspects) grouped with the fourth and fifth level labels below that correspond to each. This reflects the depth of the hierarchy of the material. Partitioning of the behavioral space based on breadth (the horizontal levels of the hierarchy) did not produce any clear representations. This is not surprising as the information based on the breadth of the hierarchy was embedded in the list, denoted by font size and label color, and, therefore, was not as salient as the depth information. Frequency of access for individual pages was not reflected in the behavioral space either.

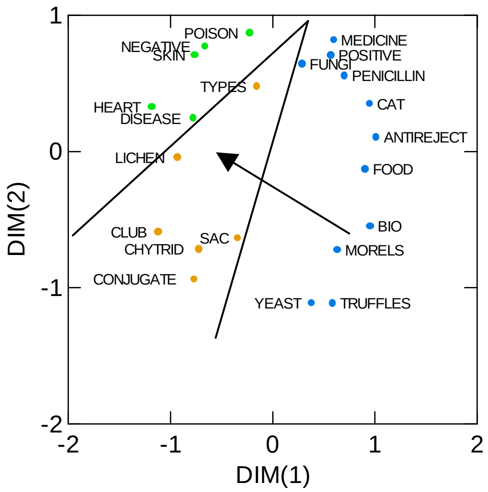


Figure 6. Two-dimensional solution for the Hierarchical group axially partitioned by depth of hierarchy

Spatial. The Spatial tool was a map with no explicit links and no information about conceptual relatedness except for that suggested by the general clustering of the labels. The best solution for the Spatial group is also a two-dimensional solution, R^2 = .870, stress = .183, with a scree plot elbow at the two-dimensional mark. The two-dimensional plot for the Spatial group showed similar groupings to the hierarchical group and could be partitioned in two different ways, axially and in clusters The axial partitioning of the space clearly delineates the three depth subheadings of the hierarchy (Figure 7) but cannot be partitioned clearly into the horizontal levels of the hierarchy. The clustering of regions also reflects the vertical levels, although the cluster regions do not take into account the FUNGI label. These clusters closely resemble the clustering of the page titles on the Spatial navigation tool but the individual points do not adhere to the vertical order of the labels.

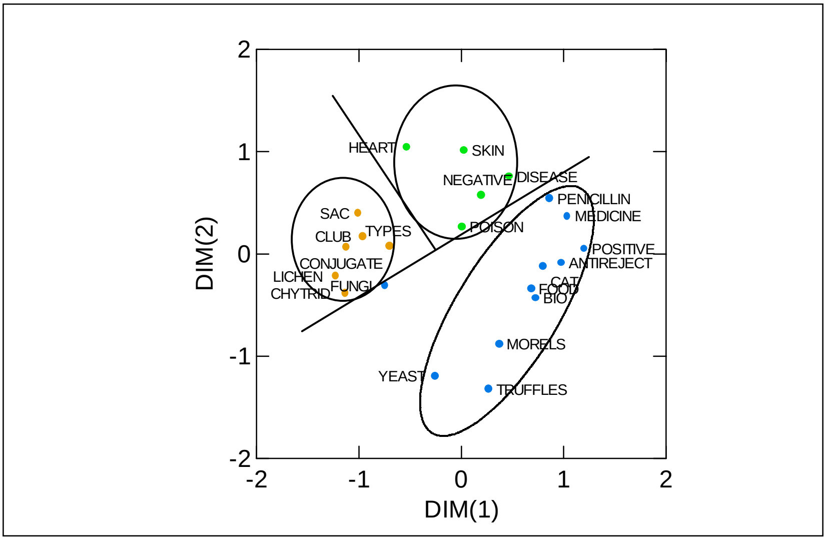
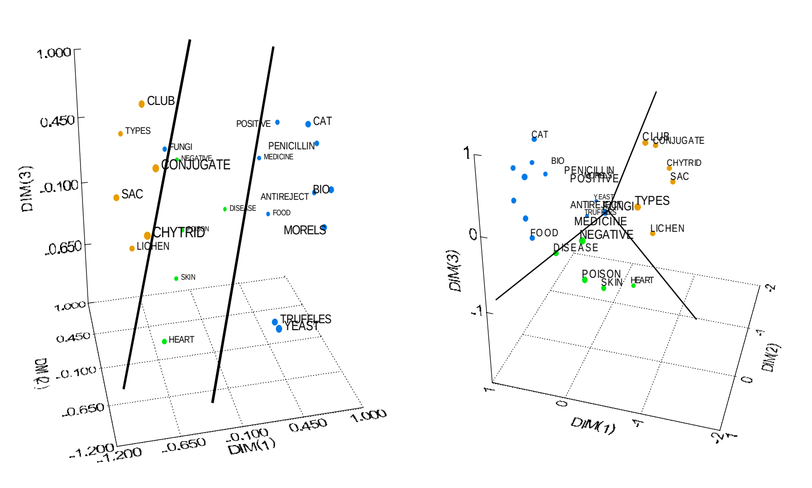


Figure 7. Spatial two-dimensional solution: Axial partitioning and clustering according to three depth levels of hierarchy.

Spatial/hierarchical. The spatial/hierarchical tool was a tree-diagram which explicitly showed the hierarchical categories and their relations to one another. This tool contained both conceptual and spatial information. The best solution for this group is a three-dimensional one, R^2 = .83, stress = .135 with a scree plot elbow at the three-dimensional mark. The three-dimensional plot (see Figure 8) could be partitioned both axially and radially into the three subheadings of the hierarchy.



(a) (b)

Figure 8. Three dimensional MDS solution for the Spatialhier group—(a) Axial partitioning based on depth of hierarchy, (b) Radial partitioning by depth from Fungi center point

This type of partitioning illustrates users' reliance on information provided by the depth of the material. The dimension of breadth is also discernible in the three-dimensional plots for this group as illustrated in Figure 9, which shows a distinct partitioning of the behavioral space into the three horizontal layers of the hierarchy. However, this partitioning is not absolute as the point "Biocontrol" is outside the appropriate region, yet inspection of the "Biocontrol" label on the spatial/hierarchical tool provides no obvious reason for this.

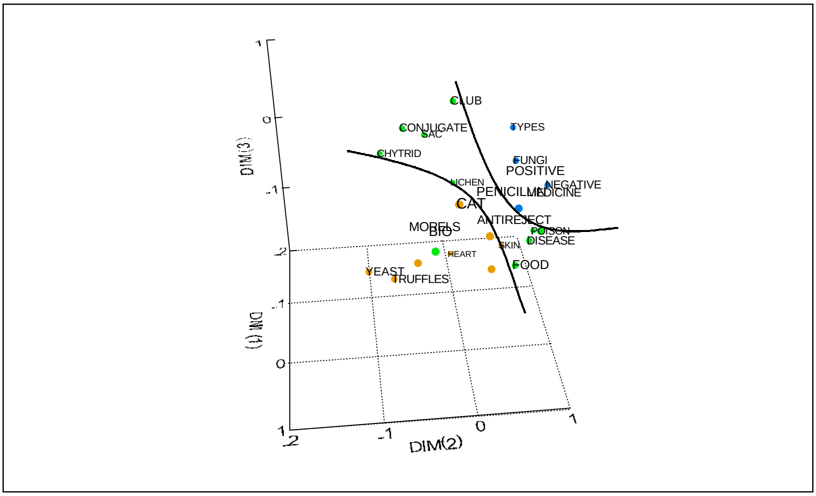


Figure 9. Three dimensional MDS solution for the Spatialhier group—Axial partitioning by breadth of the hierarchy

In the case of the spatial/hierarchical tool, both depth and breadth are explicitly presented in the navigation tool and both types of information are also evident in the users' transition choices.

Linearity of use. Because the page-transition frequencies so obviously mirror the navigation tool structures, it is tempting to deduce that users are merely moving through the navigation tools in a linear fashion. However, a purely linear usage of the navigation tool would result in the one-dimensional MDS solution being the most optimal for describing the data. This would be particularly true for the two lists which users are limited to traversing vertically. Consequently, if there is a significant difference between the one-dimensional solution and the optimal solution chosen for each group, this would suggest that another property, potentially in conjunction with linearity, was guiding tool use. To ascertain if users moved solely in a linear manner, F tests were conducted on the variance for the one-dimensional solution versus the variance for the optimal solution for each group. For all four groups a significant difference was detected between the R^2 values, (Alphabetical, $F(3,18) = 12.05$, $p < .05$, Hierarchical, $F(2,19) = 24$, $p < .05$, Spatial, $F(2,19) = 25.14$, $p < .05$, and Spatial/hierarchical, $F(3,18) = 5.22$, $p < .05$). Therefore, linearity is not the sole dimension that influences how users traverse the navigation tool.

DISCUSSION

The structure of the navigation tool heavily influences the transition choices that users make as indicated by the relationships found between the spatial configurations derived from the page-transition frequencies and the organization of the navigation tools. The MDS configurations for each group can be clearly partitioned into dimensions that reflect the elements contained in each of the four navigation tools demonstrating that different navigation behavior was produced by presenting different navigation tools to users. Even though users were unconstrained by the linkage structure of the pages, they still relied heavily on the structure of the tool to guide their choices. This was true even for the three groups that used the two lists and the spatial tool, which did not contain any explicit linkage suggestions within the tool. With these tools, there were no elements to suggest some pages were linked while others were not. Hence, users were free to access any page title without any suggestion that certain pages were not directly accessible from other pages. This allows them the freedom to make choices based solely on the potential content of a page rather than on the link connections between pages. However, the results show that users did not exploit this freedom but rather were guided substantially by the order and structure of the navigation tool.

Looking closely at the MDS solutions, there is a difference in the number of dimensions for an optimal solution in the alphabetical and spatial/hierarchical groups versus the hierarchical and spatial groups. This difference suggests that users' are making different transition choices between the four navigation tools. The optimal solution for the Alphabetical tool group was a three dimensional solution where the most identifiable dimension was alphabetic order. For the hierarchical group, a two-dimensional solution produced the clearest organization of the data, the important dimension being depth of the hierarchy. The spatial group data was best represented by a two-dimensional solution as well where the depth of the hierarchy was clearly identifiable as a guiding dimension. Finally, the optimal solution for the spatial/hierarchical group was three-dimensional with the depth and breadth of the hierarchy both represented in the facet diagrams. For this last group, if the breadth representation was just a matter of users accessing the lowest level of the hierarchy infrequently relative to the other levels, this would also be reflected in the plots partitioned by the frequency of access for individual pages for the other navigation tools. This is not the case. Therefore, this suggests that, for the spatial/hierarchical group, users rely on the breadth information in the tool to make navigation decisions as well as the depth information.

Generally, users' navigation transitions appear to reflect the most prevalent organization in a given navigation tool whether that is conceptual, alphabetical, or spatial. However, there are two different lines of evidence to suggest this is not totally linear usage of the tool. First, if use of the navigation tool were absolutely linear then the MDS analyses would reveal a one-dimensional solution as optimal; this is not the case for any of the groups. Secondly, inspection of the plots of the optimal solution for each group should reveal not only partitioning based on salient features of the navigation tool (e.g., the three depth subheadings) but also all of the individual points lying within certain regions should precisely correspond to the order of the labels in the navigation tool as well. Again, this is not the case. For example, with the Spatial tool, linear navigation would result in the "column" on the left side of the tool being traversed from top to bottom, followed by a move to the right to the top of the next "column" (Figure 2). The order of navigation would then be Caterpillar, Penicillin, Anti-rejection Drug, Medicine, Biocontrol, Positive Uses, Food, Morels, Truffles, Yeast. However, the two-dimensional-solution plot of where users actually went (Figure 7), illustrates that, in the cluster that contains these particular labels, the previously described order of navigation is not represented. These two lines of evidence indicate that, although the property of linearity may contribute to navigation, it does not function in isolation but rather in conjunction with other guiding dimensions such as the conceptual layout of the material.

Summarily, information contained within the structure of the navigation tool and linearity of use explain much of the observed navigation behavior. A remaining question is, does the inherent organization of the content affect navigation, that is, are users relying on content to make any navigation decisions? The data from the alphabetic group provides an opportunity to speculate on this issue. Besides random choices, users of the alphabetic navigation tool are limited to reliance on three sources of information for navigation choices: (a) alphabetic order, (b) linear order, or (c) content as suggested by the page titles. If the alphabetic group was navigating only linearly or only alphabetically, the best MDS solution would be one-dimensional. Because this is not the case, a conceivable explanation is that users must be making some transition choices based on content as well, that is, a best guess from the labels or previously visited pages as to what would be an appropriate page to find the target information.

CONCLUSIONS

In summary, three conclusions are suggested by the results of this configural analysis of page-transition data. First, users' transition choices are heavily influenced by the types of information presented in the navigation tool. Second, users' do not adhere strictly to a linear usage of the navigation tool. Third, in an unfamiliar document, even with a navigation tool that presents limited content information (only the page titles themselves), users seem to make some page-transition choices based on suppositions of content. These are important findings because, although previous research has shown influences on performance measures of navigation tool information, the impact on path data is not as clearly understood.

This article also illustrates that the use of MDS on page-transition data is a viable approach toward investigating the properties that guide navigation tool use. In this study, MDS analysis of page-transition data revealed highly systematic and interpretable regularities in the flow of user transitions. While other commonly used statistical methods, such as analysis of variance, may fail to capture all the differences between groups of users' page-transition patterns, MDS represents the data in a configural manner that highlights these differences and allows for the detection of theoretically relevant properties that underlie the data.

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