Browsing Within a Multidimensional and Bidirectional Environment by Using a Hypergraph

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ABSTRACT

This paper discusses the navigation efficiency and perceived usability of a multidimensional search browser compared to a one-dimensional search browser. The central question to be examined in this paper is if data can be browsed more time efficient with the former browser than with the latter and if the former browsing method has a higher rating of usability than the latter. Performing this study involved implementing two similar, but yet different kinds of browsing systems. This paper is contributing to the topic of a possible application of a xanalogical data structure within the process of online search and the acceptance of multidimensional usage within browsers. To compare the systems, 14 (former) students participated in a within-subject experiment. The majority of these participants preferred the use of less dimensions within the implementation. On the other hand, the same system was rated higher for its functionality, which was due to the advanced usage of the xanalogical structure.

Keywords

Xanalogical structure, hypergraph, search, browsing, data structure

1. INTRODUCTION

The World Wide Web has become a highly important part of modern society. It is a system of interlinked hypertext documents accessed via the Internet. One of its developers is Theodor Holm Nelson, an American sociologist, philosopher and pioneer of information technology [14]. In the 1960's he began his biggest project, called "Project Xanadu", which was initiated by his research on a new data structure (i.e., xanalogical structure), called "Zippered Lists". The structure itself can be defined as a kind of hypergraph [10]. As Nelson stated in the 1965 paper "A File Structure for the Complex, the Changing, and the Indeterminate" [11], these the Zippered Lists would make the creation of complex and significant new media possible: the hypertext and the hyperfilm. However, the present hypertext deforms the version of Dr. Nelson. He envisioned the creation of an Internet with 'real' hyperlinks. This included the same words and phrases to be saved only on one single location, while every appearance on a web page is a reference, linking every equal phrase and word bidirectionally together. Current hyperlinks are unidirectional and words appear sequentially and redundantly on web pages within a browser. As of world wide web size's statistical data [13], the indexable web pages became at least 9.38 billion in October 2012. These pages can be found by Internet search engines, which are based on currently known hypertext as well. The results of the search are presented on two-dimensional pages, which can lead to a huge browsable and/or scrollable list of unidirectional hyperlinks. This list can usually be browsed only by one dimension. Furthermore, the search cannot be adjusted dynamically to make a constraint which is related to the already seen pages of interest. Hence, the user is responsible himself for such features by using his skills of memorizing and concatenating the elements which already occurred during the search. This research is related to the hypertext structure Dr. Nelson intended to create because it is believed, that an online search technique making use of a hypergraph structure within a multidimensional environment has the potential to have a more efficient graph representation than the conventional search technique previously mentioned [8]. One can conclude, that the traversal of a graph representation with a higher utilization factor of representable dimensions is less time consuming than with a lower utilization factor. The study contains a number of new and important insights because previous literature on xanalogical structures and similar hyperstructures mainly involves research within a one/two dimensional environment [7] [8] [9]. This raises the following main research question:

- Can data be browsed more time-efficient and more usable (i.e., having a higher rating of usability) by utilizing more than two dimensions?

Consequently, a method had to be invented, which gave the oppurtunity of answering this question. First of all, it was important to gain knowledge about the possibilities of measuring the mentioned variables (i.e., *time efficiency* and *usability*). Similar to the research of Orland Hoeber and Xue Dong Yang [6], who compared different search interfaces with each other, two different comparable systems were implemented in order to gain further insights, which might lead to an answer. Therefore, further questions were introduced:

- How to provide several dimensions within a browser?
- How can the elements of a multidimensional browser be clearly represented within a huge data space?
- How can the time efficiency and usability of both systems be tested and adequately compared with each other?

18^{th} Twente Student Conference on IT January 25^{th}, 2013, Enschede, The Netherlands.

These questions are answered first within section 3. Section 4 provides a description to the methodology of this research, including the argumentation of research design decisions. While section 5 summarizes the hypothesis, section 6 outputs the results of the experiment, including an analysis. This analysis is followed by a section discussing the outcomes of the analysis, which leads to a section of the final conclusion. After that section, some possible work for the future is presented. Now follows a section of some work, which is related to the research topic.

2. RELATED WORK

Most research on xanalogical structures and hypergraphs in general is not related to the visualization of multidimensional data. Much less related is the research on xanalogical structures to search interfaces. However, some research exists, which is marginally connected to the mentioned domains. McGuffin and Schraefel compared three hyperstructures, concluding that xanalogical structures are the most general of these structures. Therefore, they can subsume lists, 2D array, trees, and also all edge-coloured directed multigraphs [10]. The work suggested new visualization techniques and was inspiring for this research by giving examples of traversing the graphs of the hypertructures (e.g., navigating a hierarchical menu). McGuffin contributed further to the field of multidimensional data together with Balakrishnan by researching the visualization of genealogical graphs [9]. During the study dual-trees were used as the data structure because the visualization of genealogical graphs by the use of a xanalogical structure would make it difficult to see the relationship of nodes according to their generation. However, the statement must be interpreted with caution because McGuffin and Schraefel denoted, that the visualization technique is distinct from the hyperstructure itself. A new visualization technique might solve the problem of visualizing the relationship of nodes clearly. This possibility directed the research to the field of visualizing dimensions of the xanalogical structure dynamically by manual selection. Amit P. Sheth and Wolfgang Klas wrote a book over multimedia data management, which contributed to the use of similar filter actions within hypermedia for a better overview by using filter commands [12]. The topic of the book goes far beyond this research, but some general parts of the described hypermedia management and its visualization were important for the functionality of filtering dimensions. Also important was the work of Jason Eisner, Michael Kornbluh, Gordon Woodhull, Raymond Buse, Samuel Huang, Constantinos Michael and George Shafer, which decribed a system for browsing large directed graphs and hypergraphs, called *Dynasty* [7]. Further, knowledge about the construction of hypergraphs was needed in order to build a xanalogical structure for this research. As *Figure 1* indicates, Salim Jouili and Salvatore Tabbone participated to this topic by developing a construction procedure for hypergraphs [8].

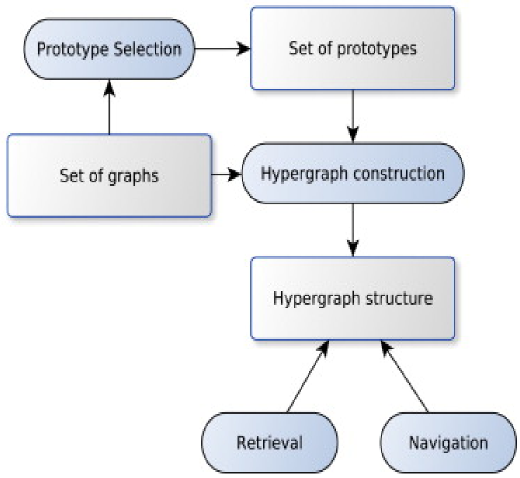

Figure 1. Construction chart of Salim Jouili and Salvatore Tabbone

3. SYSTEM DESIGN

3.1 Domain Analysis

The domain analysis involves research about the principles of multidimensional graphs, such as work on xanalogical structures. A xanalogical structure was implemented by representing the abstract functionality of such a structure within a Java application by several nested lists and maps. The principles of the xanalogical structure were obtained by the work of McGuffin and Schraefel [10]. It has to be mentioned, that the implemented data structure can only be seen as a xanalogical structure on the layer of graph traversal. The storage layer of the data structure is a component consisting of several basic data structures of the Java languages, involving hashmaps, linked lists and arrays of various types. As Berge stated [4], a hypergraph H is consisting of vertices V and edges E, so that $H = (V, E)$, where $V = (x1, x2, x3, ..., xn)$ is a finite set of vertices and $E = (E1, E2, E3, ..., Em)$ is a family of subsets of V. In this case, an element of V is equal to one element of a music database (e.g., $ARTIST$, some specific artist or some specific band), while an element of E is also equal to an element of the music database. By this behavior, multiple vertices can have several incoming and outcoming edges, which have a basic principle of xanalogical structures: Every edge of one direction may only occur once on a vertice. Therefore, if an incoming edge En contains the vertex xn, xn may not occur in another incoming edge. However, it may occur once in an outcoming edge. This led to the construction of the xanalogical structure by a modified construction procedure of Salim Jouili and Salvatore Tabbone [8]. A construction chart is shown in *Figure 2*.

3.2 Browser

In order to implement a hypermedia browser, the construction procedure of Salim Jouili was used. After the construction of the xanalogical structure, System A was developed (*Figure 3*). This system contained a Controller-View component making use of the Java OpenGL (JOGL) library (see Retrieval and Navigation in *Figure 2*) and a Model component, which consisted of the xanalogical structure (see Xanalogical structure in *Figure 2*). The browser was able to display nodes of the data structure and browsing through them by defining a start node at the time the system initialized (e.g., by defining the start node *ROOT* with all of its children, the system starts from *ROOT* and is able to browse through all of its children by the structure, which was previously defined). Additionally, if a child node became the new current node, the system could be able to retrieve all of its parent nodes and browse through these nodes. Therefore, whenever the children of parent nodes were browsed through, the parents could be retrieved and several other parents of other dimensions could be seen. It was also possible to put nodes into a list, which resulted in displaying only the nodes of choice. This list was called *Focus*. Because the system

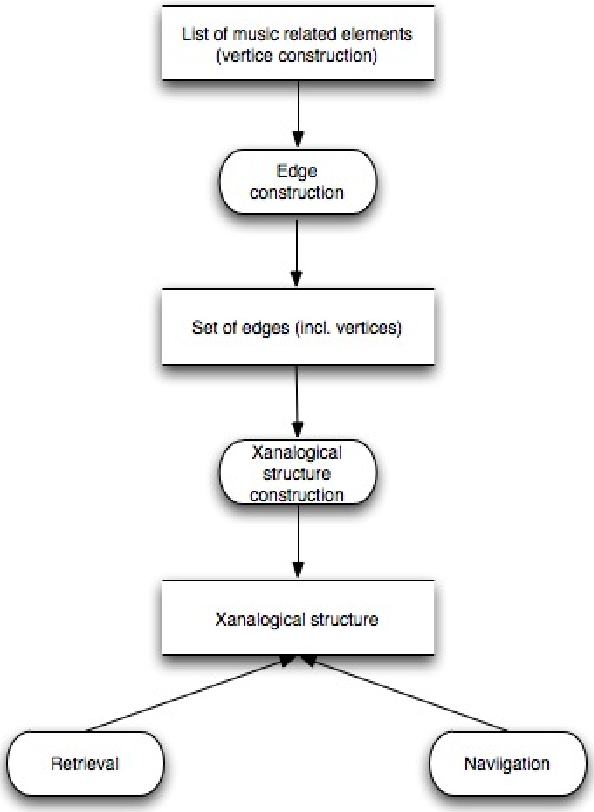

Figure 2. Modified construction chart of Salim Jouili and Salvatore Tabbone

made use of the Java OpenGL wrapper library, it was able to simulate a 3D environment. Therefore, a three-dimensional graph representation was used with an X, Y, and Z - axis. Every axis was related to one *Focus* list in order to set several filters at once for the node, which was currently displayed including its children or parents. The layout of the browser should be simple because too much information confuses the user. Therefore, System A only provides information on the Y and Z axis via the node the user is currently in (*Figure 4*).

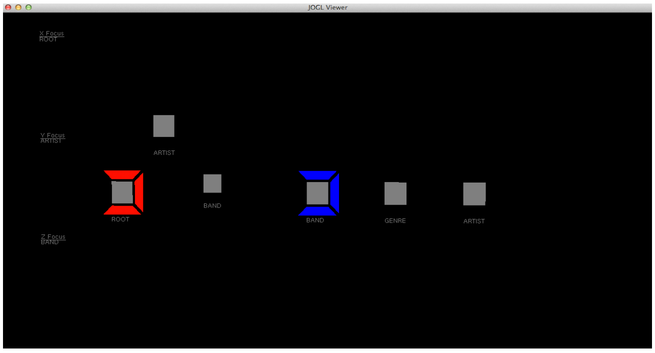

Figure 4. The Y and Z axes are only visible on the red node

The research of Eric C. Crowe and N. Hari Narayanan [5] infers, that multiple systems can be compared with each other by comparing the measurements (e.g., satisfaction and efficiency of tasks, time, etc.). This could be achieved by taking over all functionality of System A, but reducing this functionality in some aspects, while extending it in others. More about the procedure is to read in the following Methods section.

4. METHODS

The research topic is about the efficiency and usability of the 3D search browser which was developed compared with conventional 2D search browsers. However, comparing an already known consistent and stable browser to an unknown experimental browser would lead to a strong bias. The systems and their graph representations have the potential to be significantly different, but yet the participants can be functionally fixed without making use of the new features or appreciating them. Therefore, a simplified version of the 3D implementation was implemented in order to represent conventional browsers (*Figure 5*). This browser lacks the bidirectional and multidimensional functions, but provides the user with the conventional functionality of hyperlinks (i.e., give a hyperlink to a page and redirect the user from this page to an old page by another hyperlink or the "Go to previous page" feature of the browser). The two browsers were compared with each other by assigning browsing tasks to participants, which also filled out questionnaires and gave response to interviews. This data was related to the efficiency and the levels of user satisfaction. Additionally, screen capturing was performed to analyze the usage of the browsers.

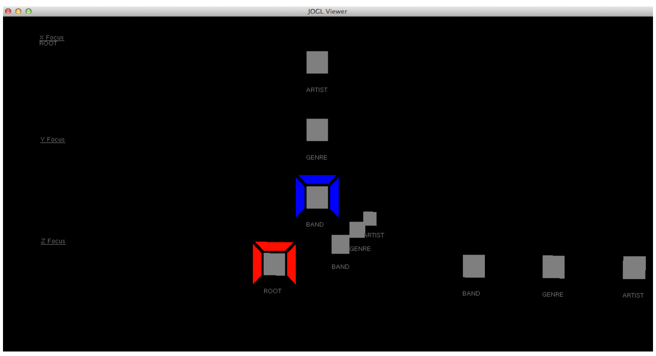

Figure 3. System A: Three-dimensional search browser

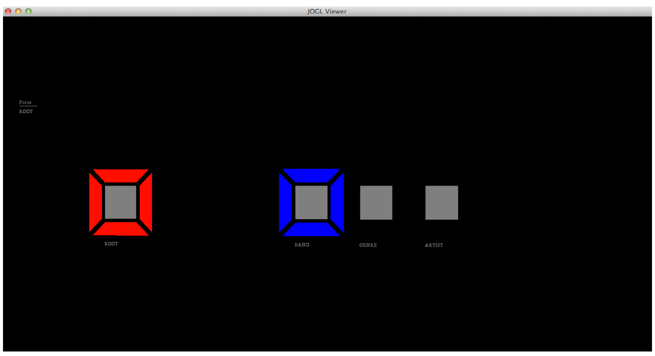

Figure 5. System B: One-dimensional search browser

Table 1. Combinations of 1st system

System	1^{st} task	2^{nd} task
System A	Task 1	Task 2
System A	Task 3	Task 4
System B	Task 1	Task 2
System B	Task 3	Task 4

Table 2. Combinations of 2nd system

System	3^{rd} task	4^{th} task
System B	Task 3	Task 4
System B	Task 1	Task 2
System A	Task 3	Task 4
System A	Task 1	Task 2

4.1 Goal

The goal consists of the retrieval of information related to the abstract level of user satisfaction and an estimate of effectiveness regarding to the completion of tasks.

4.2 Experimental design

By the reason of letting every participant test both systems, the within-subjects design was chosen for the treatments. This design also has the advantage, that no high amount of participants is needed. First of all, this was important because due to the size of the tutorials the average time of the experiment was higher than 50 minutes and because the experiment only could take place with supervision on one computer. By making use of the within-subjects design, every participant had to perform all treatments. To prevent the negative possibility of impacting the performance and/or behavior on the next treatments, counter balancing was integrated into the design. Therefore, every treatment was done by one individual, but the combination of treatments changed for the next subject. Four different combinations were possible, which is shown in *Table 1* and *Table 2* (each row position of *Table 2* is related to its previous row position of *Table 1*).

One could argue, that there are more combinations possible. However, because of the goal of the test, the ordering of the task for one system could not change (i.e., task 1, task 2; task 3, task 4) and one system should be executed before making use of the other system by the reason of objectivity supported by the counter balancing.

Task 1 and 3 consisted of writing down the amount of bands of some specific genres, while task 2 and 4 consisted of retrieving information about all bands a specific artist played in.

4.3 Participants

The target group of the experiment consisted of 14 technical and nontechnical (former) students of various degrees, counting 4 women and 10 men. These participants were between 18 and 32 years old, resulting in an average age of 24.28 years. Every participant was or had been studying a Bachelor study or higher.

4.4 Procedures

The participants performed search tasks independently from each other. In the beginning of each session, each of them was introduced to the setup of the test: The participant had to sit down in front of a table with three stacks of papers and a 15 inch Macbook (*Figure 6*). The paper stack in the center was the introduction to the system and contained abstract information about the general struture of the database, including a graph. First, the participant had to read that paper, which usage was also adviced during the tasks. Afterwards, he had to process the paper stacks on the left and right sides sequently. The one on the left was the first system to test, while the third stack on the right was the second one. In order to introduce the participant with the systems, a short tutorial was attached to each of these stacks. After each task, the participant had to fill out a short questionnaire, which evaluated the task. When the tasks of the system were finished and the questionnaires of these tasks were filled out, the participant had to evaluate the system by another questionnaire. After finishing both systems, a final evaluation of both systems took place by a third version of questionnaire, also including the preference of the system. The tasks were split up in two tasks per system. For each system, the first task consisted of counting the number of bands within specific music genres. These genres were given in a table, which had to be completed with these numbers. The second task consisted of writing down the names of the bands one specific artist was related to. The purpose of the first task was letting the participant gain knowledge of the possibility of multidimensionality of System A, while the purpose of the second task consisted of retrieving information about the advantage of bidirectionality of System A to let the participant complete the task more efficient. Before the tasks, every participant already had performed these operations once in the tutorial of the system.

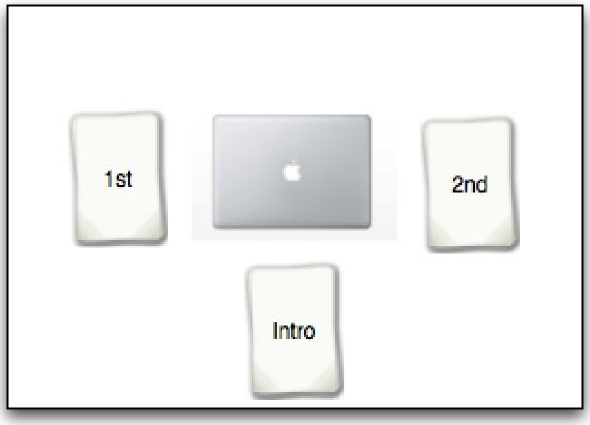

Figure 6. Experiment setup

4.5 Measures

4.5.1 Questionnaires

In order to evaluate the tasks, systems and the final system preference, three different questionnaires were made:

1. Tasks
2. System
3. Final evaluation

The final evaluation involved four open questions for the purpose of getting the preference of the system and retrieving suggestions and additional comments. The questionnaires of the tasks and the systems were combinations of closed questions gained from the Computer System Usability Questionnaire [1], the Questionnaire for User Interface Satisfaction [2] and the System Usability Scale [3]. Furthermore, one question was added by the author of this paper: "The task was (difficult - easy)". The tasks questionnaire consisted of that question, the question "Performing tasks is straightforward (never - always)" and an open field for comments. The system questionnaire contained every other question, which can be see within *Figure 13* in the Appendix section. This figure is also related to section 6. Summarized, for each system the participant had to fill out twelve closed questions and could write down additional information in six open fields.

4.5.2 Time

It was possible by the screen capture to measure the time for the following variables:

1. First tutorial
2. First task
3. Second task
4. Second tutorial
5. Third task
6. Fourth task

4.5.3 Tasks

The tasks were not directly measured by the answers to the tasks of the participants, but by the effectiveness they were answered and if the participant came to the right conclusion. Also, the Task questionnaire gives information about the situation of the participant.

5. HYPOTHESIS

It is assumed, that participants with advanced knowledge on graph systems and computer interfaces involving the domain of search browsers have a higher tendency to work more efficiently with System A and enjoy this system, while others will get better results on these variables with System B due to the reason of simplicity of System B. System A is assumed to take more effort and technical skills to understand. Because of the additional functionality of System A, it could be easier to get the same results regarded to System B assuming the participants will understand the possibilities of the system. Furthermore, it can be structured more clear if the system is used with an optimal utilization. That can potentially result in a higher usability rating for some or all user groups.

6. RESULTS

All participants filled out the questionnaires and wrote down at least some additional comments for both systems. Also, every participant had a preference to one specific system. In this section, the results of all questionnaires are shown and in the end the comments on the systems are summarized.

6.1 Questionnaires

Every closed question consisted of five possible answers representing an ascending scale from one to five. These answers were coded into digits (i.e. $1, ..., 5$), which could be interpreted by the IBM SPSS statistics program. Usually, 1 was the most negative and 5 the most positive answer. One of the answers of a questionnaire (i.e., $question4$ of the System questionnaire) contained a consistency check by coding the most negative answer as 5 and the most positive one as 1.

6.1.1 Reliability

The closed questions of the task questionnaire where tested for their reliability by analyzing their Cronbach Alpha values. Both questions of every task resulted in a Cronbach Alpha value higher than $\alpha = 0.7$ (*Table 3*), meaning that every question is reliable for every task.

Table 3. Cronbach Alpha for task questionnaire of both systems

Task	Cronbach Alpha A	Cronbach Alpha B
1^{st} task	0.859	0.766
2^{nd} task	0.853	0.782

Another reliability test was performed for the system questionnaire resulting in the values, which are shown in *Table 4*.

Table 4. Cronbach Alpha for system questionnaire of both systems

Task	Cronbach Alpha A	Cronbach Alpha B
Question 1	0.632	0.715
Question 2	0.596	0.710
Question 3	0.693	0.770
Question 4	0.776	0.857
Question 5	0.689	0.705
Question 6	0.597	0.697
Question 7	0.773	0.780
Question 8	0.596	0.780

The results indicate, that System A only relies on $question4$ and $question7$, while System B relies on every question with a Cronbach Alpha value $\alpha \approx \geq 0.7$. Considering that every question of one system will be compared with the question of the other one, every question is therefore relevant for the results. The questions were categorized into one variable υ (i.e., *usability*) rather than splitting them into several categories because they were a construct of different questionnaires related to the usability of system interfaces [1] [3] [2].

6.1.2 Tasks

The tasks were analyzed by two different methods. The first one involved an answer field, in which the participant had to fill in the correct answers of the task. The second one involved a questionnaire consisting of the answers described in the Questionnaires subsection of the Methods section. *Table 5* shows the results of the first set of answers: the correctness of solutions the participant performed by means and standard deviations of both systems (e.g. MA for the mean of System A and SDB for the standard deviation of System B; 1 = "correct", 2 = "incorrect"), while *Table 6* presents the retrieved data of the task questionnaires. It has to be noted that one row represents the task order of one system, which is not equal to the task number because of the counter balancing. It came out, that the first task was solved slightly more within System A than within System B. For the second task, the amount of correct solutions did not differ. However, according to a paired samples test comparing the first and second task of the same system with each other, the mean of the task correctness (i.e., MC) did not vary significantly for each system. This is measured by the 2-tailed significance of the test (i.e., P).

Table 5. Means and standard deviations of task correctness

Task	M A	SD A	M B	SD B
C. 1st task	1.21	0.426	1.29	0.469
C. 2nd task	1.14	0.363	1.14	0.363

Table 6. Means and standard deviations of task questionnaires

Question	M A	SD A	M B	SD B
Q. 1 1st task	2.79	1.424	4.07	0.829
Q. 2 1st task	2.79	1.251	4.00	1.109
Q. 1 2nd task	3.21	1.122	3.36	1.336
Q. 2 2nd task	3.14	1.167	3.79	0.975

Table 7. Comparison of correctness of first and second task

System	M C	SD	P
Sys. A: Task 1 - Task 2	0.71	0.475	0.583
Sys. B: Task 1 - Task 2	0.14	0.363	0.165

6.1.3 Systems

The results of the System questionnaires are presented within *Table 8*, giving a t-test with its means, standard deviations and the 2-tailed significance related to the comparison of the systems by the individual questions. *Figure 13* of the appendix is providing more information about the meaning of the question numbers (i.e., *Q.#*).

Table 8. Means and standard deviations of task questionnaires

Q. #	M A	SD A	M B	SD B	P
1	2.64	1.216	3.57	0.756	0.026
2	2.64	1.082	3.71	0.994	0.015
3	3.29	1.069	4.00	0.784	0.045
4	2.64	0.929	2.21	0.893	0.189
5	3.07	1.207	3.71	0.995	0.045
6	2.57	1.158	3.86	1.100	0.005
7	3.21	0.802	3.07	0.997	0.547
8	3.07	1.592	4.00	0.877	0.048

As the figure indicates, the usability was rated higher for System B by every question except the seventh one. However, a comparison of the values of both systems for this question and the fourth reveals a value $p > 0.05$. To gain more information about the total difference of the usability rating, a calculation related to the means of this figure was performed. First, the mean value of question 4 was reversed for both systems because the lowest value was equal to a positive ranking, while the highest was equal to a negative ranking. Succeedingly, the mean value of each mean value of one system was summed up, resulting in a mean value of $\upsilon = 23.86$ for System A and $\upsilon = 29.71$ for System B. These values differ significantly from each other by $t(13) = -3.174, p = 0.007$.

Further results of the questionnaire could be retrieved by an independent variable called *knowledge*. Some participants had knowledge about graph traversal, while others did not. Also, some participants stated not to understand the system after the tutorial, while others did understand it well. This information was summarized before the first task of each system began and two possible values were introduced: *yes* and *no* (i.e., *yes* = "the participant has knowledge about both systems", *no* = "the participant does not have knowledge about both systems"). By calculating the individual results of the independent variable and performing and independent samples test, participants with knowledge rated System A with $\upsilon = 25.25$ and System B with $\upsilon = 27.25$ resulting in $t(13) = -1.070, p = 0.306$. Participants with less to no knowledge rated System A with $\upsilon = 22.00$ and System B with $\upsilon = 33.00$ resulting in $t(13) = 2.445, p = 0.031$. Performing for both systems an independent samples test with the mentioned independent variable gave the outcome represented by *Table 9*. The application of an OANOVA test revealed the significance of each question, which indicated, that given the independent variable, $question1$ and $question2$ of System A have a signicant difference with $t(13) = -3.611, p = 0.004$ for $question1$ and $t(13) = -2.188, p = 0.049$ for $question2$. Two different questions also indicate significance for System B: $question5$ with $t(13) = 2.338, p = 0.038$ and $question7$ with $t(13) = 2.202, p = 0.048$.

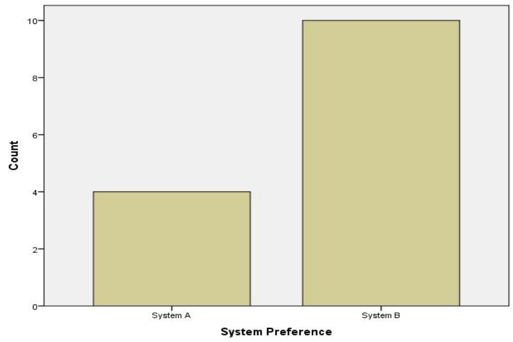

Figure 7. Result of system preference

Table 9. Means and standard deviations of task questionnaires related to knowledge on both systems

Q. #	Knw.	M. A	SD A	M. B	SD B
1	No	1.67	0.516	3.83	0.408
	Yes	3.38	1.060	3.38	0.916
2	No	2.00	0.894	4.00	0.894
	Yes	3.13	0.991	3.50	1.069
3	No	3.17	0.753	4.33	0.516
	Yes	3.38	1.303	3.75	0.886
4	No	2.33	1.033	1.83	0.753
	Yes	2.88	0.835	2.50	0.926
5	No	3.00	1.414	4.33	0.817
	Yes	3.13	1.126	3.25	0.886
6	No	2.33	1.367	4.33	0.817
	Yes	2.75	1.035	3.50	1.195
7	No	3.50	0.548	3.67	0.516
	Yes	3.00	0.926	2.63	1.060
8	No	2.67	1.633	4.33	0.516
	Yes	3.38	1.598	3.75	1.035

6.1.4 Preference of browser

In general, 10 out of 14 participants preferred System B, which can be seen in *Figure 7*. On the other hand, *Figure 8* indicates, that the knowledge group is related to the preference group. Analyzing these values with a chi-square test reveals, that they have a marginal significance with $p = 0.07$. While participants without knowledge only preferred System B, the half of the participants with knowledge preferred System A.

Understood Both Systems * System Preference Crosstabulation

			System Preference		
			System A	System B	Total
Understood Both Systems	No	Count	0	6	6
		Expected Count	1,7	4,3	6,0
	Yes	Count	4	4	8
		Expected Count	2,3	5,7	8,0
Total		Count	4	10	14
		Expected Count	4,0	10,0	14,0

Figure 8. Crosstabs of Knowledge and System

6.2 Screen captures

The screen captures were mainly performed to reveal the time related to the completion of the tutorials and tasks. Additionally, the efficiency could be analyzed during the performance of tasks. The amount of steps to complete a task can be seen within *Table 10*. The efficient steps (i.e., ES) are the optimal path for the solution, while the conventional steps (i.e., CS) are the solution of solving the task by a conventional order of reading the instructions from top to bottom. Only two participants were near the values of the conventional orders. Every other participant came to a value at least twice as high.

Table 10. The amount of steps for both systems

Task	ES A	ES B	CS A	CS B
Task 1	25	31	47	53
Task 2	10	27	10	27
Task 3	24	34	39	48
Task 4	14	28	14	28

6.3 Time

As already mentioned, the time was measured by analyzing the screen captures. The beginning of the first tutorial could be measured by recognizing a specific point of the tutorial, where the participant had to open the tutorial (e.g., "Open 1.jar on the Desktop"). The end of the tutorial could be recognized by coming to the last step of the tutorial. After this moment, the participant terminated the program and initialized the first task, which was related to the tutorial. That could be task 1 or task 3. As in the tutorial, the end of the task could be recognized by coming to a solution. The solution could be incorrect, but the end of the task was still recognizable because no action was performed after a specific step. This property held for every task and tutorial. Figure 9, 10, 11 and 12 indicate, that the time is related to the knowledge. According to an independent samples test with the knowledge as independent variable, the participants with knowledge performed task 1 of System A marginal significantly faster than the other group: $t(13) = 2.020, p = 0.066$. On the other hand, the mentioned figures indicate, that the group with knowledge as well as the one without both had a higher efficiency within System B. However, the the time values of the first task of System A and the second task of System B do not differ significantly with $t(13) = 1.504, p = 0.157$. The differences for the second task are even much less significant with $t(13) = 0.478, p = 0.641$.

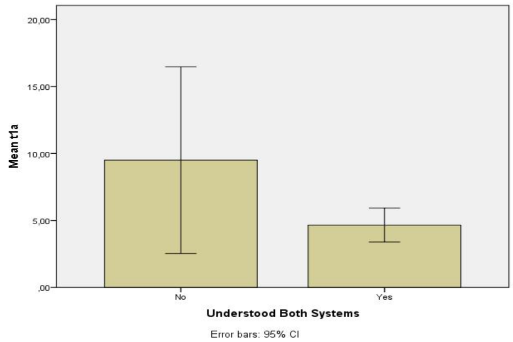

Figure 9. Mean time of first task of System A compared to knowledge

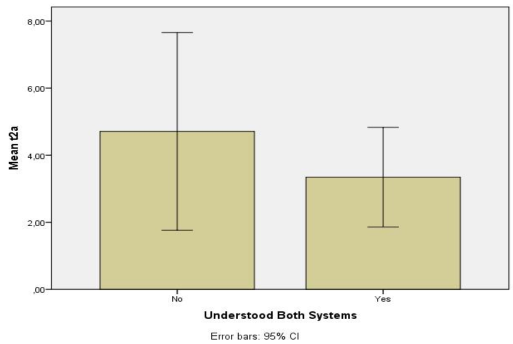

Figure 10. Mean time of second task of System A compared to knowledge

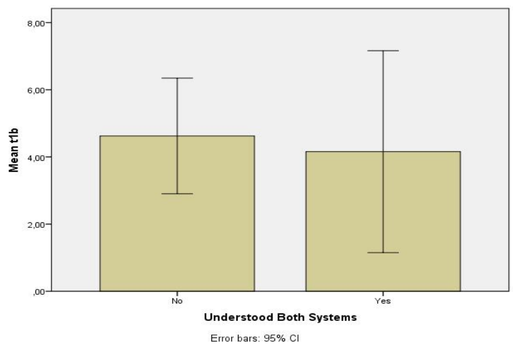

Figure 11. Mean time of first task of System B compared to knowledge

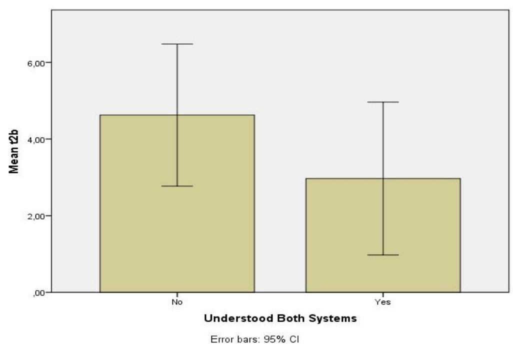

Figure 12. Mean time of second task of System B compared to knowledge

6.4 Comments and interviews

Some participants gave useful comments and after finishing the tasks and filling out the questionnaires, they where interviewed. In general, participants mentioned, that System A was more difficult to learn than System B. Also, the layout of System B was easier to be introduced with. On the other hand, the majority of participants stated, that System A has more possibilities to layout the system more effectively for specific tasks, although it was more difficult to browse through. Some participants issued, that they would like to use a threedimensional grid within System A instead of fixed axes. Others did not see the use of three axes for the tasks they had to perform.

7. DISCUSSION

The result shows, that participants without advanced knowledge about both systems had difficulties performing some tasks. For example, one participant without knowledge had a strong preference for System B by reasoning that it was much more comfortable to work with. However, the same participant also mentioned, that System A could be more efficient if he knew more on how the system works. Both systems were prototypes with functionality, which were in development. Because System A had more functionality, the system also had more potential for inconsistencies. Some controls were designed too uncomfortable to work with for persons having less to no technical skills. The gained knowledge after the tutorial was also relevant to work efficiently with System A. Participants with knowledge executed the tasks significantly faster, but were not more efficient with System A than with System B as hypothesized. It has to be mentioned, that nearly every participant (i.e., 12 out of 14) had a solution measuring paths twice as long as the conventional path, which was considered as solving the task by trial and error. Instead of performing the task in the same manner as described within the tutorial, most participants performed unnecessary operations. That suggests, that the tutorial was not clear enough. Further, System A had only one question, which was rated slightly higher than the one of System B: "This system has all the functions and capabilities I expect to have". The mean time for the second task of System B did not vary much regarded to the preference of the system. The task consisted of looking for all related bands of an artist. A node $RELATEDBANDS$ was added within an artist node for this task. This node was added intentionally in the end of a list counting twelve elements to force the participant to browse through this list. After the participant arrived at $RELATEDBANDS$, he could enter the node to get to the result for the task. For System A, the participant only had to enter the artist and press the backspace key. Therefore, it was obvious for all participants, that System A had at least one more feature than System B. This feature represented two of the main properties of the xanalogical structure: multidimensionality and bidirectionality. Thus, this property had a slight favor to the conventional placement of a "link". Although the property of the multidimensionality was embraced, it was not appreciated to be visualized within three dimensions. The reason of this result can vary: as mentioned in the Results section, it could be a low appreciation of using fixed axes instead of a whole threedimensional grid or a poor choice of tasks, which could be solved too easily with System B without the need of another system. Another possibility is, that visualizing three dimensions on a two-dimensional screen could be not clear enough for some applications, which would verify the argument of McGuffin and Balakrishnan [9].

8. CONCLUSION

In general, System B had a higher usability than System A. In contradiction to the hypothesis, the first task within System A was not seen as more usable by most participants with knowledge and they also did not perform the second task more efficient within this system. The research question can only be answered for this study because the difficulty of understanding the tutorial was a bias for the research. The time efficiency has no significant difference for both systems. Both user groups preferring System A and System B liked the idea of a bidirectional browsing environment, but generally did not like the idea of a graph representation using more than two dimensions. This research also showed, that most people with less to no technical skills prefer having a system with less functional options.

9. FUTURE WORK

Besides the performance of the tasks and filling out the questionnaires, some participants were also interviewed for their opinion of using an improved version of System A in the future after explaining the participants the purpose of this research. The majority of participants embraced the idea of bidirectional links, but stated, that the functions of such a system had to be simple and yet more advanced. Also, there should be a manual, which is easy to read. Another variable (i.e., *space efficiency*) may be measured also to gain more knowledge about the amount of steps, which was deleted within this research due to the high amount of participants performing the tasks by trial and error. Furthermore, involving more participants within a future study is suggested because the standard deviation can potentially be decreased. Further work should also include the perceived satisfaction of the participants, which would introduce yet another variable (i.e., *user experience*). More participants could not be tested due to the lack of time, which also caused an unequal number for the counter balancing. A future study should have a multiple amount of four participants, considering the study is related to the number of tasks performed within this research. In order to come to a clear conclusion if people can experience a higher level of efficiency and user experience within a bidirectional multidimension environment, more research should be done within this field. Another important topic, which came up during the interviews was the suggestion of using an advanced version of System A for the traversal of databases by the introduction of different operations and input fields. By the input fields the system could search for specific nodes, while by the definition of a specific operation (e.g., a join or distinct operation for a set of nodes) the axes could be used for more purposes than actually. In case that future work comes to a positive result for a multidimensional and bidirectional search system, it could be possible to extend it further for the use of online search. This extension involves further development of the placement of nodes on directions within a threedimensional visualization by not only making use of linear axes, but placing the nodes of the same dimension on a specific vector. The probability for the likeliness of chosing one path is important for that method to reach a destination node efficiently. Such work would also involve research in data mining.

10. ACKNOWLEDGMENTS

My thanks to my project group and my tutors Betsy van Dijk and Manja Lohse, which reviewed my work and were very helpful with suggestions!

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APPENDIX

		System A		System B	
#	Question	Mean	Std. Deviation	Mean	Std. Derivation
Closed questions of system questionnaire					
1	Organization of information (1: Confusing – 5: Very clear)	2.64	1.216	3.57	0.756
2	Learning to operate the system (1: Difficult – 5: Easy)	2.64	1.082	3.71	0.994
3	I found the various functions in this system were well integrated (1: Strongly disagree – 5: Strongly agree)	3.29	1.069	4.00	0.784
4	I thought there was too much inconsistency in this system (1: Strongly disagree – 5: Strongly agree)	2.64	0.929	2.21	0.893
5	I can effectively complete my work using this system (1: Strongly disagree – 5: Strongly agree)	3.07	1.207	3.71	0.994
6	It was easy to learn to use this system (1: Strongly disagree – 5: Strongly agree)	2.57	1.158	3.86	1.010
7	This system has all the functions and capabilities I expect it to have (1: Strongly disagree – 5: Strongly agree)	3.21	0.802	3.07	0.997
8	Whenever I make a mistake using the system, I recover easily and quickly (1: Strongly disagree – 5: Strongly agree)	3.07	1.592	4.00	0.877
Closed questions of task questionnaire (1st task)					
9	Performing the task was straightforward (1: Never – 5: Always)	2.79	1.424	4.07	0.829
10	The task was (1: Difficult – 5: Easy)	2.79	1.251	4.00	1.109
Closed questions of task questionnaire (2nd task)					
12	Performing the task was straightforward (1: Never – 5: Always)	3.21	1.122	3.36	1.336
13	The task was (1: Difficult – 5: Easy)	3.14	1.167	3.79	0.975

Figure 13. Results of closed questions