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Evaluating the Effectiveness of Tree Visualization Systems for Knowledge Discovery

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Abstract

User studies, evaluations, and comparisons of tree visualization systems have so far focused on questions that can readily be answered by simple, automated queries without needing visualization. Studies are lacking on the actual use of tree visualization in discovering intrinsic, hidden, non-trivial and potentially valuable knowledge. We have thus formulated a set of tree exploration tasks not previously considered and have performed user studies and analysis to determine how visualization helps users to perform these tasks. In our study, we evaluated three systems: RINGS (a node-link representation), Treemap (a containment representation), and Windows Explorer. Our findings suggest a few ways that tree visualization helps users to perceive different aspects of hierarchical structured information. We then explain how these visual representations are able to trigger human perception to make these discoveries.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Methodology and Techniques]: Interaction techniques; H.5.2 [User Interfaces]: Evaluation/methodology

1. Introduction

Because many important applications deal with hierarchical data, a number of different tree visualization systems have been developed. These tree visualization designs focus on graphical representation and layouts, and have improved focus+context, use of space, and ease of navigation through very large hierarchies. A few user studies, evaluations and comparisons have been performed on combinations of different tree visualization systems. However, these studies have mainly focused on users performing tasks that can readily be handled by simple, automated queries. No one has yet performed a comprehensive analysis of whether tree visualization is able to yield valuable, non-trivial, hidden knowledge not easily found by non-visual methods.

Knowledge discovery is defined as the "non-trivial extraction of implicit, previously unknown, and potentially useful information from data." [FPSM92]. Keim [Kei02] promotes the use of visualization for knowledge discovery saying it combines the "flexibility, creativity and general knowledge of the human with the enormous storage capacity and computational power of today's computers." While many systems are able to represent trees visually and allow users to navigate the structure, we are interested in finding out whether tree visualization can convey the information in a way that can help users "gain insight into the data". [Kei02]

In our study, we seek answers to one very important and fundamental question that has not been sufficiently addressed before: "Does tree visualization help to discover previously unknown knowledge?" Previous studies have focused on how well tree visualization systems allow their users to navigate through the hierarchies and how quickly users can locate information. Our study, in contrast, focuses on whether certain tree visualization systems are able to visually present the data so that non-trivial, hidden information becomes visible.

In our approach, we first examined previous user studies, comparisons, and evaluations. We then conducted a user study to investigate what independent users can discover from visualizing a directory using RINGS (Ringed Interactive Navigation Graph System) [TM02] and Treemap [Shn92] tree visualization systems, compared to

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using a more common directory exploration system, Windows Explorer. We formulated non-trivial tasks that are not easily answerable through simple automated scripts. These questions focused on detecting similarities and differences in the hierarchical dataset. We then analyzed how tree visualization reveals these insights.

We separated subjects into three groups with each group exploring the same tree structure using a different directory system. We compared and analyzed the time taken for the users to answer the questions in our study. To investigate how different visual representations are better suited for discovering different insights, we investigated the differences in users' performance between the visualizations.

Because a tree is an abstract data structure with no intrinsic spatial meaning, different visualization methods transform hierarchical information into a graphical display in different ways. These transformations may or may not reveal hidden patterns. We use RINGS and Treemap in our study because RINGS uses a node-link representation while Treemap uses a containment representation. Our goal is to determine if RINGS and Treemap are able to help users in our list of knowledge discovery tasks more than Explorer can.

2. Related Work

Many different tree visualization methods currently exist. Examples include three-dimensional visualization methods such as Munzner's hyperbolic tree [Mun97] and Kleiberg's botanical tree [KvdWW01] as well as recent graph-drawing algorithms such as Kreuseler et al.'s tree [KLS00] on a hemisphere. The latter two provide good navigation and focus+context solutions. Cone Tree [RMC91] is another very well-known and commonly-used method, and an augmented version [CK95] includes a user study with tasks similar to those of other user studies (eg. find the largest file). EncCon [NH05] uses an enclosure+connection method to lay out the tree, making good use of the available space, and provides focus+context mechanisms.

A number of user experiments on tree visualization systems are conducted to compare their performances. For example, Organization chart, icicle plot, Treemap, and tree ring are evaluated in the context of decision tree analysis [BN01]. Tasks include deciding if a tree is binary or n-ary, deciding if a tree is balanced or unbalanced, and finding the deepest common ancestor of a tree. Users are also tested on their ability to memorize the location of a node.

Kobsa [Kob04] conducts a comparative experiment visualizing file directory trees using five well-known tree visualization systems, and Windows Explorer. Users are required to complete fifteen tasks, such as finding the most recently modified file, a file with ".css" extension, and the directory with the mode ".png" files. Completion times, correctness and user satisfaction are used as criteria. This study explains differences by referring to characteristics of the visualization paradigm, interface problems, and missing functionality that make certain types of tasks difficult and/or slow down users.

A controlled experiment compares SpaceTree to two other interfaces and analyzes the impact of interface features on the time to perform navigation tasks to new and already visited nodes, and topology evaluation tasks [PGB02]. Three types of tasks are used: node searches, search of previously visited nodes and topology questions.

In Pirolli et al.'s [PCW03] study, the Hyperbolic browser is compared to Windows Explorer. Users are tested on information retrieval tasks and comparison tasks, and their performance is analyzed in terms of visual search, visual attention, and "information scent".

A small user study [vHvW02], comparing Beamtree to nested Treemap and cushion Treemap, indicates that Beamtree is significantly more effective than the other two trees for the extraction of global hierarchical information such as maximum depth and balance.

We notice that all the questions posed in the above user studies can be easily answered without a tree visualization. A simple query or search can sort files by size or other attributes to accomplish some tasks. Likewise, automated scripts can find information such as the deepest sub-tree, number of descendants much more quickly than a human user can through tree visualization. The InfoVis 2003 Contest: Visualization and Pair-Wise Comparison of Trees also contains a long list of questions for the contest participants to answer using tree visualization. Many of these tasks overlap with the questions posed to subjects in the user evaluations listed above. In addition, the contest also contains a few less trivial questions, such as "Did anything change, in general, or in a sub-tree?" and "Were there small changes or major changes?" However, due to the nature of the contest, the contest entries do not provide any comprehensive study of how visualization can help answer these questions.

In our study, our goal is to investigate how visualizations can answer more abstract and less easily definable questions, so we choose questions that cannot be easily answered by automated queries. As we are interested in investigating the effect of different visual representations on the knowledge discovered, we choose two tree visualization systems with significant differences. We compare the users' performance on these two systems, as well as Windows Explorer. We give the users a set of tasks to perform, and investigate if these tasks can be more easily performed by visualization users, and if a visualization facilitate the discovery of some knowledge.

3. Directory Systems Studied

We are interested in investigating the effect of different visual representations on the knowledge discovered. RINGS

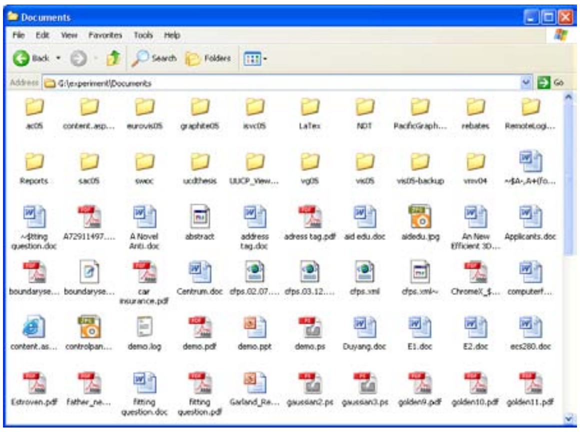

Figure 1: *Windows Explorer users found the directory "pic" very homogeneous.*

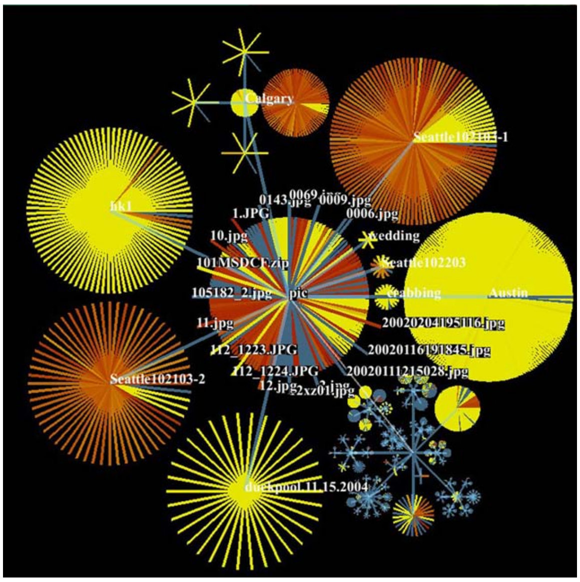

Figure 2: *RINGS users found the directory "pic" very homogeneous.*

and Treemap are two significantly different tree visualizations. We compare the users' performance on these two systems, as well as Windows Explorer.

3.1. Windows Explorer

Windows Explorer is a widely used application for file management as shown in Figure 1. In our experiment, the Windows Explorer window shows the contents of the currently selected directory, including its sub-directories and files. Each component is represented by a small icon. All directories share the same icon, and file icons are classified by the file types. Notice that Windows Explorer also provides a tree view showing the hierarchical structure of the directories. Since we want to compare a 'non-visual' system with tree visualizations, we only use the 'non-visual' features of Windows Explorer. Thus, users were not allowed to use this tree structure to look for answers except searching and opening one folder.

3.2. RINGS

RINGS is a tree visualization system with a ringed circular layout of nodes as shown in Figure 2. A node and all its children are placed in a circle. Equal-sized circles corresponding to children are placed in concentric rings around the center of the parent circle. To visualize files and directories, each folder is represented with a node, and all subdirectories and/or files are placed in the concentric circles around that node. Users can map color information to different properties, including file size, number of subdirectories, path length from root, and last modified time. In this experiment, color is selected to represent the size of files. All files less than the user-specified threshold are shown in one color, while all files above the threshold are colored according to a color gradient.

3.3. Treemap

Treemap is a space-filling tree visualization method capable of representing large hierarchies with the full hierarchy mapped onto a rectangular region as shown in Figure 3. It works by partitioning this region into a nested sequence of smaller rectangles representing the tree structure. It is particularly effective at revealing attributes of leaf nodes using size and color coding. Users can specify the presentation of both structural (depth bounds, etc.) and content (display properties such as color mappings) information. It was originally designed to visualize directories on disk with each leaf node representing one file, and the color and size of each leaf node are coded according to some particular attributes of files including file type, file size and created date. The Treemap system used in our experiment is the version 4.1.0 downloaded from http://www.cs.umd.edu/hcil/treemap/. The system maps file size to rectangle size, and color codes the files by their file extensions.

4. Experiment Design

Since there is lack of a standard directory as a benchmark to evaluate tree visualization systems, we use a directory of a graduate student researching scientific visualization as the test hierarchy in our experiment. This directory contains 48,552 files and 4,896 directories, and the maximum depth is 10. 18 users participated in the experiment. They are all students from eight different departments in the University of California, Davis. They all have at least five years

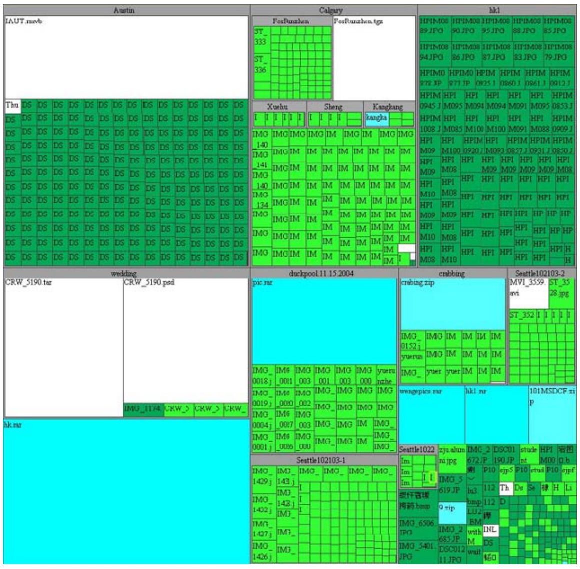

Figure 3: *Treemap users found the directory "pic" very homogeneous.*

of experience using computers. Prior to participating in the experiment, none of the users is familiar with the RINGS or Treemap tree visualization systems. Ten of the users are male, and eight are female. All have used Windows Explorer before.

To avoid the possibility of effects between systems, a between-subject method was used. We randomly divided the subjects into three equal groups of six. Each group used a different piece of software to visualize the working directory.

Since tree visualizations are used to convey hierarchical structure, we focused our tasks on directory's hierarchical information. Before starting the experiment, each subject received a short ten-minute training to introduce the visualization and interaction techniques of the tools. The subjects began the experiment by answering a short survey, and then each subject was asked to perform the following six tasks.

1. Find two or more directories that are "similar".
2. Find two or more directories that are "very similar" to one another.
3. Find two or more directories that are "slightly similar" to one another.
4. Find two or more directories that are "similar" to one another but are different from those in the first task.
5. Find five or more directories that are mutually "significantly different" from one another. Which two are the most "different" from each other?
6. List a few "very homogeneous" directories. List a few "rather homogeneous" directories. List a few "rather heterogeneous" directories. (A homogeneous directory is one where its sub-directories are similar or only belong to a few types. A heterogeneous directory is one where its sub-directories are different from one another or belong to many different types.)

The completion time of each task was recorded. Subjects were allowed to ask questions between two tasks but not while performing a task.

Unlike questions asked in other user studies, the answers to these questions are not easily found by simple automated queries. These questions are also subjective in nature, and words like "similar", "significantly different" and "rather homogeneous" allow considerable latitude in their interpretation. The intentional imprecision of language allows users more freedom, and the difference in their answers may reveal differences in the systems they use. Visual exploration is good for such open-ended tasks. "Visual data exploration is especially useful when little is known about the data and the exploration goals are vague." [Kei02]

After answering these questions, each subject was asked how difficult the questions were, from 1 (easy) to 5 (difficult). They were then asked to explore the directory for at least five minutes, and answer two questions about their insights and the most interesting findings. At the end of the experiment, groups using RINGS and Treemap were asked whether there were any features of the system which they thought were better or worse than the system usually used. Because all subjects use Windows regularly, the group using Windows was not asked this question.

5. Experiment Results

In this section, the three systems are compared according to answer classification, directory depth, and users' performance and difficulty.

5.1. Categorizing Users' Answers

In our experiment, subjects were required to give a brief explanation after each answer. After a thorough examination on the answers, we built a set of categories to classify all the answers in terms of the explanations given. The categories include name, number, type, size, content, and structure. They are all properties of a file directory. Table 1 gives the descriptions and examples of these categories.

These categories are not exclusive. One answer can possibly fall in two or more categories. For example, subject E1 in Question 1 said, "Their names are similar, and contain similar number of files and sub-folders." This answer fulfills two categories: name and number. Notice that we use two characters to represent subjects. The first character can be 'E', 'T', and 'R' to represent Windows Explorer, Treemap and RINGS respectively. The second character is the number of

Table 1: *Categories of answers based on the explanations.*

Category	Description	Example selected from user answers
Name	file and/or directory name	Folder names are similar
Number	file and/or sub-directory number	The numbers of their files and sub-directories are the same
Type	file type	One contains many .mp3 files, and the other are most document files
Size	file and/or directory size	Both of them have files from very big size to very small size
Content	contain identical or different files or sub-directories	They look like the snapshots of one project at two different times
Structure	the construction of the directory	Both these two folders contain files, sub-directories and sub-sub-directories

one subject in the group. E1 is the first subject in Windows Explorer group.

One answer category may actually have different visualization forms in different systems. For example, file and directory size are encoded with grid size in Treemap, but with color in RINGS. Type is decoded by color in Treemap, and by icons in Windows Explorer. We classify the answers based on the properties of the file directory, not on the visualization method used to discover the property. A property of a file directory can be shown by different visual properties in different visualization systems. By classifying based on directory property alone, we make sure that no matter what visualization tools are employed, the categories remain the same.

Figure 4 shows the pie graph of categories in each system. The structure category in Windows Explorer includes explanations related to whether one directory contains files and/or sub-directories, and which content, file or sub-directory, is dominant. Although Windows Explorer also provides a tree view that shows the hierarchical structure of the file directories, users did not use this tree structure to look for answers except when searching and opening a folder. No answer is based on size, probably because it is not visually displayed.

In Treemap and RINGS, the answers in the structure category include any knowledge gained from the arrangement and layout of grids or circles, such as whether one directory contains files and /or sub-directories, and which content, file or sub-directory, is dominant. Notice that the structure information in Treemap and RINGS provides the layout and shape in more detail, such as the contents of sub-directory, directory hierarchy. In contrast, structure in Windows Explorer is relatively shallow, since it can only show the immediate files or sub-directories of one folder but not the files and sub-directories in deeper levels. Structure is the category used most by Windows Explorer users, which indicates that Windows Explorer users mostly relied on relative shallow information compared with Treemap and RINGS users.

Another significant finding is that Treemap users, unlike Windows Explorer users, pay more attention to name than number. A likely cause is that in Treemap, files from different hierarchy levels are visible within a single display, which makes it easier to compare the names. In contrast, Windows Explorer users have to browse into directories to determine whether they are similar or different, hence users cannot remember detailed information such as name. They tend to keep in mind a general sense of previously explored folders. That is why structure and type are used most often by Windows Explorer users.

All the answers given by RINGS users fall into three categories. No answer is obtained from file name or type. Although RINGS displays the name of directories and files, no users paid attention on the file names. There are three potential reasons to explain this phenomenon. First, RINGS only shows the file and directory names of the current level. Like Windows Explorer users, RINGS users also have difficulty remembering the file names while browsing. Second, RINGS provides much information with color and shape. They are good enough to assist users to find out the answers. Third, both Windows Explorer and Treemap encode file types with visual properties, while RINGS merely shows the types as text at the end of the file names.

5.2. Directory Depth

Directory depth is the path length from the root to the current directory. The root directory has a depth of zero. For the five similar and different tasks, there are a total of thirty answers for each system. In RINGS, only two answers contain folders with different depths. However, in Treemap, eight of the answers with folders are from different depths. This implies that Treemap, compared to RINGS, shows more knowledge at different depths. This is due to the difference in layout between them. In Treemap, a file's position and size are not dependent on its depth. In contrast, RINGS uses size to encode the depth information: smaller circles represent deeper directories. This property of RINGS causes users to compare directories in the same depth.

Compared with Windows Explorer, both RINGS and Treemap provide more information in deep levels. As shown in Figures 1, 2, and 3 Windows Explorer users E4 and E5 found the "pic" directory to be "very homogeneous" , while RINGS users R2 and Treemap users T4 and T5 found it "rather heterogeneous". This may be because RINGS and Treemap users are able to see beyond the second level in the hierarchy. The RINGS and Treemap displays show that "pic" has many immediate files, and a few flat sub-directories. The immediate files in "pic" dominate the view of Windows Explorer, and the icons show that they belong to only a few

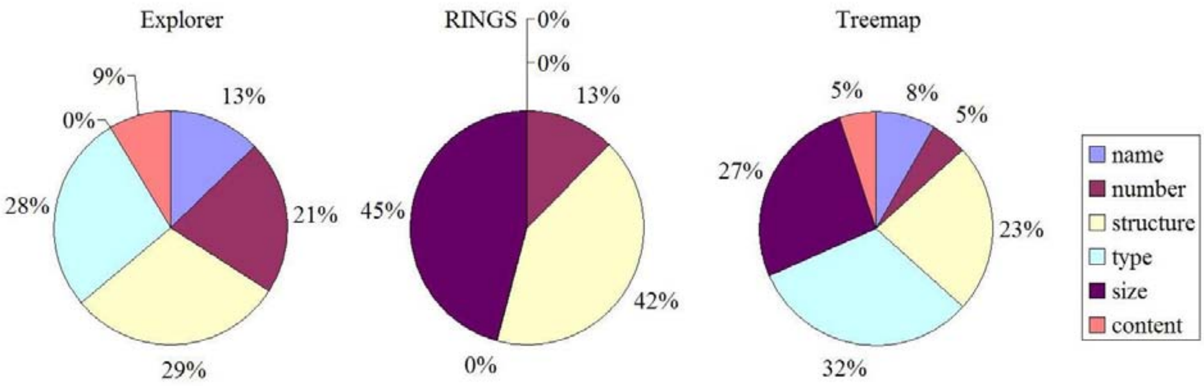

Figure 4: *The properties of the file directory each subject used to derive the answers to the questions. Users of Windows Explorer, RINGS and Treemap relied on different directory properties, indicating that each system is suited to discovering different knowledge.*

different types. Users cannot see the types, depths and numbers of files in the sub-directories from this view. The difference in opinion indicates that Windows Explorer users focus on the immediate files of the directory, while visualization users can more easily perceive information in deeper levels of the tree and hence obtain better hierarchical information.

5.3. Users' Performance and Difficulty

Figure 5 shows the average task completion times by task and by system used. The average completion times per task of RINGS, Treemap and Windows Explorer are 3.20, 3.03, and 4.17 minutes respectively. The average time of Windows Explorer is approximately one second longer than that of the other two systems. ANOVA (analysis of variance) shows that the completion times of RINGS and Treemap are significantly shorter than Windows Explorer, with $p < .05$. Such a low p value attests to the consistency of the results.

In the last three tasks, Windows Explorer users took significantly longer than did users of the other two visualization systems. One possible reason is that the first three tasks are to find "similar" directories, and two subjects of Windows Explorer said that they just checked the structures of directories with similar names. These users did not attempt to find structural similarity. For the last three questions, Windows Explorer users were forced to find structural information deeper in hierarchy, and so they were forced to take more time.

According to our survey, compared to RINGS and Treemap users, Windows Explorer users also expressed significantly more difficulty in answering the tasks. On a scale of 1 (easy) to 5 (difficult), the mean score given by RINGS, Treemap, and Windows Explorer users was 2.5, 2.5, and 3.9 respectively as shown in Figure 6. This shows that RINGS

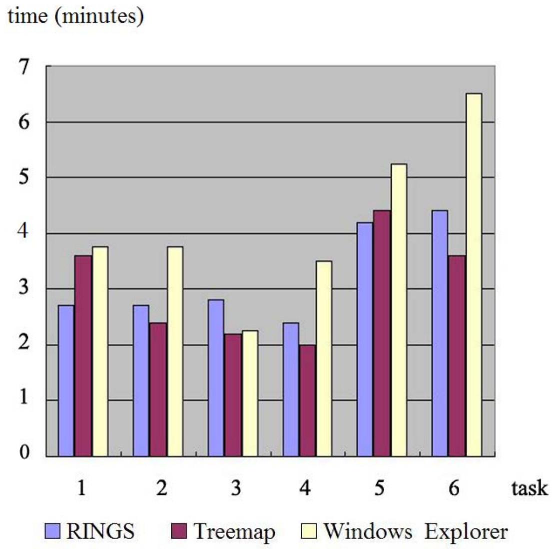

Figure 5: *The average time taken by users to complete each task using each system.*

and Treemap are able to improve users' perception of some patterns in the file directory structure and helped them discover some knowledge more easily than in Windows Explorer. In addition, the use of color in RINGS and Treemap provides a way for user to use "their primarily preattentive, parallel processing powers of visual perception." [WTP*95]

Figure 7 is an example of two similar directories found by one RINGS user. One Windows Explorer user also discovered this pair of similar directories. The RINGS screen-

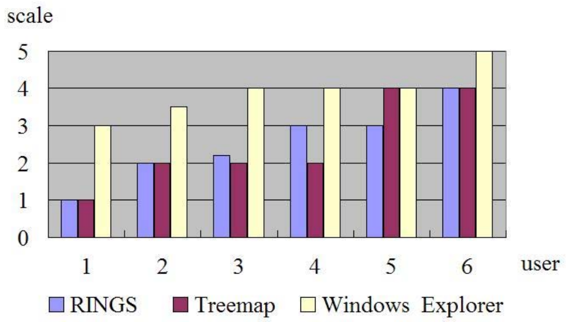

Figure 6: *The difficulty in answering the questions by the eighteen subjects with the three systems.*

shot shows the parent directory "others" of these two directories. We see a distinctly similar pattern in these two subdirectories that is different from the other sub-directories. Both "viewpolymodel" and "viewpointmodel" have many files, one sub-sub-directory with a few files, and one sub-sub-directory with two files. Furthermore, the sizes of the files contained in these two directories are similar. The result is a distinct pattern in color and shape. A Windows Explorer user would have to go into each of the directories and discover similarity in file names, sizes and number of sub-directories. Thus, Windows Explorer user experienced greater difficulty in getting this answer. The Windows Explorer user took five minutes to find this similarity, while the RINGS user took only two minutes.

5.4. Other Findings

In our questionnaire included after the user tests, several RINGS users (R1, R2, R3 and R4) liked its ability to display global structural information, and Treemap users (T1, T2, T4 and T5) liked its ability to display size information. User R2 mentioned that it is sometimes difficult to find the parent directory in RINGS. R3 commented that it is sometimes difficult to see the names of the directories. Treemap user T3 mentioned that after clicking on a sub-directory, it opens and takes up the whole plane, but being able to browse without losing track of the current position would be preferable. This comment indicates the need for more focus+context solutions to this particular implementation of Treemap file directory visualization. User T5 mentioned that the hierarchical relations between the directories are not clear, which is a well-known weakness of this implementation of Treemap.

6. Conclusions and Future Work

We have performed a study to find the effectiveness of tree visualization methods in aiding knowledge discovery. Existing user studies and analysis have focused on answering simple search or identification questions whose answers can

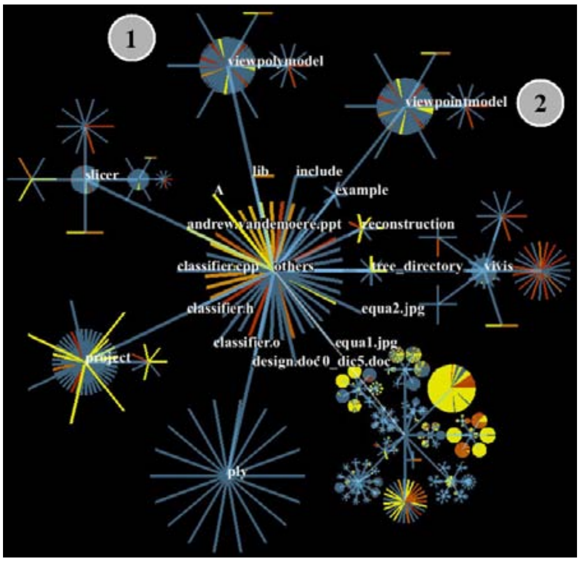

Figure 7: *An example of two similar directories ("viewpolymodel" and "viewpointmodel", labelled 1 and 2 respectively in the figure) found by both RINGS user and Windows Explorer user.*

by found more efficiently by automated queries than by visualization. Our study, is unique as we have formulated questions which are not easily answered by simple algorithmic searches so that we can determine whether the visual perception of file hierarchies can help discover deeper, non-trivial knowledge.

From our experiments, we find that the tree visualization systems, RINGS and Treemap, tend to help users make certain types of discoveries in the file directory tree. First, the ability of RINGS and Treemap users to use the "shape" and "arrangement" of the tree structure to answer questions is an important finding because they are properties not easily described and conveyed by algorithmic methods yet they have directly led to discovery of useful knowledge. Our experiments show that this ability is one of the key contributions of tree visualization to the discovery of knowledge in hierarchical data. Second, we find that visualization users are better able to perceive the number, depth and arrangement of subdirectories and files in several depths within one directory, whereas Windows Explorer users tend to focus on the immediate files and sub-directories in the top level. Third, we find that Windows Explorer users took significantly longer than did RINGS and Treemap users to complete their given tasks. Windows Explorer users also expressed that they found the tasks more difficult than did the RINGS and Treemap users.

Differences in visual representation of trees also lead to differences in information gained. Our experiment results show that Treemap can show the names and sizes of files better. RINGS is very effective at presenting the depth information of files and sub-directories in the hierarchy. Using icons, Windows Explorer users can quickly perceive the types of files in a directory. In other words, the users should choose the visualization method according to their goals.

RINGS and Treemap are not the only ways to map a hierarchy to graphical forms. Other techniques could facilitate different discoveries. On the other hand, it is also necessary to study a variety of different types of tree data such as the tree of life.

Acknowledgements

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