Visualizing Complex Hypermedia Networks through Multiple Hierarchical Views

Sougata Mukherjea, James D. Foley, Scott Hudson
Graphics, Visualization & Usability Center
College of Computing
Georgia Institute of Technology
E-mail: sougata@cc.gatech.edu, foley@cc.gatech.edu, hudson@cc.gatech.edu

ABSTRACT

Our work concerns visualizing the information space of hypermedia systems using multiple hierarchical views. Although overview diagrams are useful for helping the user to navigate in a hypermedia system, for any real-world system they become too complicated and large to be really useful. This is because these diagrams represent complex network structures which are very difficult to visualize and comprehend. On the other hand, effective visualizations of hierarchies have been developed. Our strategy is to provide the user with different hierarchies, each giving a different perspective to the underlying information space, to help the user better comprehend the information. We propose an algorithm based on content and structural analysis to form hierarchies from hypermedia networks. The algorithm is automatic but can be guided by the user. The multiple hierarchies can be visualized in various ways. We give examples of the implementation of the algorithm on two hypermedia systems.

KEYWORDS: Hypermedia, Overview Diagrams, Information Visualization, Hierarchization.

INTRODUCTION

Overview diagrams are one of the best tools for orientation and navigation in hypermedia documents [17]. By presenting a map of the underlying information space, they allow the users to see where they are, what other information is available and how to access the other information. However, for any real-world hypermedia system with many nodes and links, the overview diagrams represent large complex network structures. They are generally shown as 2D or 3D graphs and comprehending such large complex graphs is extremely difficult. The layout of graphs is also a very difficult problem [1]. Other attempts to visualize networks such as Semnet [3], have not been very successful.

In [13], Parunak notes that: "The insight for hypermedia is that a hyperbase structured as a set of distinguishable hierarchies will offer navigational and other cognitive benefits that an equally complex system of undifferentiated links does not, even if the union of all the hierarchies is not itself hierarchical." Neuwirth et al. [12] also observed that the ability to view knowledge from different perspectives is important. Thus, if different hierarchies, each of which gives a different perspective to the underlying information can be formed, the user would be able to comprehend the information better. It should be also noted that unlike networks some very effective ways of visualizing hierarchies have been proposed. Examples are *Treemaps* [7] and *Cone Trees* [15].

This paper proposes an algorithm for forming hierarchies from hypermedia graphs. It uses both structural and content analysis to identify the hierarchies. The structural analysis looks at the structure of the graph while the content analysis looks at the contents of the nodes. (Note that the content analysis assumes a database-oriented hypermedia system where the nodes are described with attributes). Although our algorithm is automatic, forming the "best" possible hierarchy representing the graph, the user can guide the process so that hierarchies giving different perspectives to the underlying information can be formed. These hierarchies can be visualized in different ways.

Section 2 presents our hierarchization process. Section 3 shows the implementation of the algorithm in the **Navigational View Builder**, a system we are building for visualizing the information space of Hypermedia systems [10], [11]. This section discusses the application of the algorithm on a demo automobile database and a section of the *World-Wide Web*. Section 4 discusses how the hierarchies can be transformed to other forms of data organizations. Section 5 talks about the related work while section 6 is the conclusion.

THE HIERARCHIZATION PROCESS

New Data Structure

For our hierarchization process we use a data structure which we call the **pre-tree**. A pre-tree is an intermediate between a graph and a tree. It has a node called the *root* which does not have any parent node. However, unlike a real tree, all its descendants need not be trees themselves - they may be any arbitrary graph. These descendants thus form a list of graphs and are called *branches*. However, there is one restriction - nodes from different branches cannot have links between them. An example pre-tree is shown in Figure 1. Note that pre-tree is another data structure like *multi-trees* [4] - it is not as complex as a graph but not as simple as a tree. Also note that although the term "pre-tree" has not been used before, this data structure has a long history in top-down

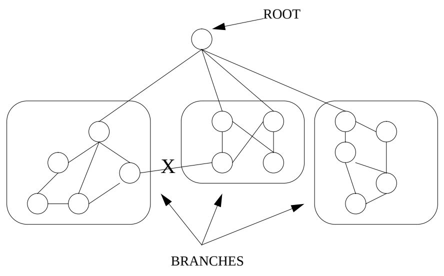


Figure 1: An example pre-tree. It has a root node which does not have any parent. The descendants of the root node are graphs. However, none of these graphs have any links between them. Our hierarchization algorithm tries to identify the best pre-tree to represent the given graph. The final tree is formed by calling the algorithm recursively for the branches.

clustering techniques [5]. Top-down clustering would often be halted when new divisions were not auspicious, leaving a final structure which is essentially a pre-tree.

Hierarchization Algorithm

The algorithm tries to identify a suitable pre-tree from a given graph. Thus a root node is identified and the other nodes are partitioned into branches. This root node forms the root of the final hierarchy. The algorithm is recursively called for each of the branches and the trees formed by these recursive calls become children of the root of the final hierarchy. The recursion stops if a branch has very few nodes or the required depth of the final tree has been reached. It may also happen that for certain branches, no suitable pre-trees can be formed. In these cases, the nodes of the branches become children of the parent of the branch. (This case generally occurs for branches with very few nodes).

For identifying potential pre-trees both content and structural analysis are used.

- *Content analysis:*

For content analysis, for each attribute, the nodes of the graph are partitioned into branches based on the attribute values by *Content-based Clustering*. The clustering algorithm is explained in [11]. If too many or too few branches are formed, the attribute is not suitable for forming a pre-tree. Otherwise a new pre-tree is formed with these branches. The root of the pre-tree is a *cluster* representing all the nodes of the graph.

- *Structural analysis:*

A pre-tree is formed for nodes in the graph which can reach all other nodes. These nodes are designated as the roots of the pre-trees. The branches are the branches of the spanning tree formed by doing a breadth-first search from the designated root node. [1]

Both content and structural analysis can identify several potential pre-trees. A *metric* is used to rank these pre-trees. The metric consists of the following submetrics:

- Information lost in the formation of the pre-tree: When the nodes are partitioned for forming the branches, all links joining nodes in different branches are removed. Thus valuable information is lost and a submetric calculates the ratio of the number of links remaining in the branches to the total number of links in the original graph to rank the pre-trees in order of the least amount of information lost.
- "Treeness" of the branches: Since our overall objective is to form trees, it is advantageous if the branches of the pre-tree are already close to trees. If all the branches only consisted of trees, there would be a total of n - c links where n is the total number of nodes in the branches and c is the number of connected components. Thus a submetric which calculates the ratio $(n - c)/l$ where l is the total number of links is an indication of the "treeness" of the branches.
- "Goodness" of the root: For a structural pre-tree the goodness of the root is determined by the sum of the distances of the shortest path from the root to all other nodes. A "good" root will reach all other nodes by following only a few links so that the resulting tree is not very deep. A deep tree is not desirable since it will force the user to follow a long and tedious path to reach some information. For content analysis the goodness of the root is determined by the relevance of the attribute. (For example, for an automobile database, the manufacturer of the cars is a more relevant attribute than the number of doors of the cars).

Each submetric returns a number between 0 and 1. The overall metric is calculated by a weighted sum of the submetrics where the weight is determined by the relative importance of the submetrics.

The Role of the User

By default, the entire process would be automatically forming the "best" hierarchical form for the original graph. However, the user can guide the process both during the translation of the graph to a tree and during the visualization of the tree.

- Translation phase:

– The users can control the various variables that are used in the translation process. For example, they can control the variable which specifies the maximum possible depth of the tree (the recursion stops when this depth is reached).
– The user can control the relative importance of the various submetrics in the overall metric that is used to rank a given pre-tree. For example the user can specify that the "goodness' of a root is not a useful criteria for judging pre-trees. The user can also assign different weights to different link types to influence the submetric calculating the amount of information lost.
– The algorithm generally selects the best possible pre-tree at each level. However, the user can choose the pre-tree instead. The user is shown the possible pre-trees that can be selected ranked by the metric and the user can choose one of them. The user can specify to what level of the hierarchy

[1]A detailed analysis is omitted for the purpose of brevity. The algorithm is explained with examples in the next section.

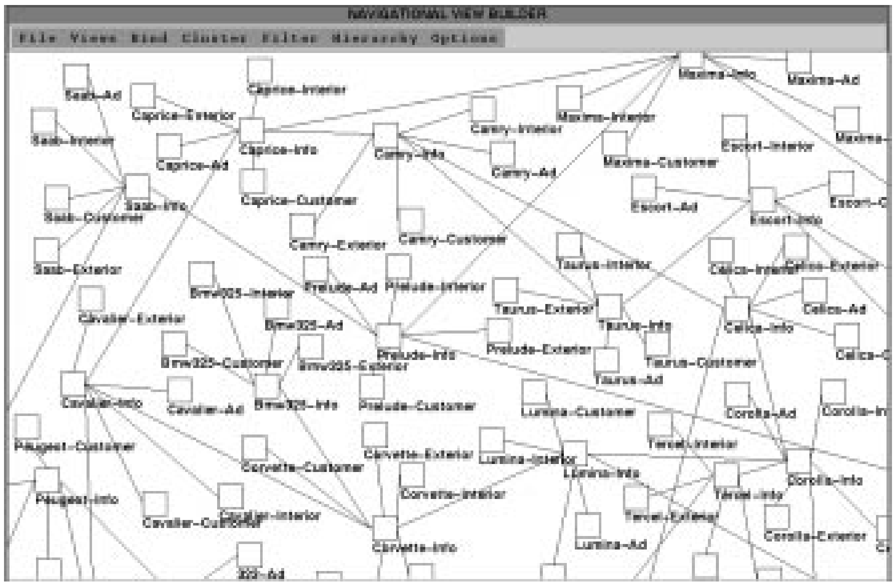


Figure 2: An overview diagram of an automobile database. The diagram is very difficult to comprehend.

the pre-trees would be chosen. By choosing different pre-trees during different runnings of the algorithm, different hierarchies, giving different perspectives to the data can be formed.

- Visualization phase:

– Besides a 2D tree, the hierarchy can also be visualized as Cone Trees, Treemaps or as a Table of Contents of a book (which is formed by listing the nodes in the order of a depth-first search).

– Different visual attributes can be bound to information attributes in the views. This is an extension of the work reported in [10].

IMPLEMENTATION

The algorithm has been implemented in the Navigational View Builder, a system for forming overview diagrams of hypermedia systems. Figure 2 represents an overview diagram of an automobile database. There are a lot of interconnected nodes showing, for example, textual information about the cars, images of the cars, TV advertisements and audio of previous buyers' comments. There are also links to other cars with similar price and other models by the same manufacturer. From this complex network a hierarchy can be formed automatically. The top-level root of this tree and its children are shown in the left hand screen of Figure 3. In this case, the attribute *Price* was used to form the initial partitioning and the root represents a cluster for all the nodes.

The user can form different hierarchies by selecting other pre-trees. For example, if the user wanted to select the pre-tree at the initial level, the dialog box shown in Figure 4 pops up. If the user wants to partition based on the attribute *Country*, the tree shown in the right hand screen in Figure 3 is formed. In this figure some of the children represents clusters for countries. For example the node labeled Japan represents all the Japanese cars and its children are shown in the left hand screen of Figure 5. Here the partitioning is done by the attribute *Manufacturer*. For some other countries the nodes in the cluster formed a tree. In these cases the roots of the tree were identified by structural analysis and they became the children of the overall root. Thus for Sweden, Saab-Info is the root of the tree for all nodes related to Swedish cars. Its children are shown in the right hand screen of Figure 5.

Color plate 1 shows a 3D Tree view of this hierarchy. In this view, the colors of the nodes represent various countries and the colors of the links represent link types. Various zooming and filtering operations that are mentioned in [15] are possible for this 3D tree. Moreover, smooth animation is used so that the view changes are not abrupt and allow the user to see the changes easily. (Note that the implementation is done using C++, Motif and Open Inventor [18].)

Forming Hierarchies in the World-Wide Web

Let us now look at an example from perhaps the most popular hypermedia system, the *World-Wide Web*. For input to the Navigational View Builder, information was automatically extracted from the WWW about the various files, their authors, their links to other files and other information by parsing the HTML documents using the method described in [14]. Figure 6 shows an unstructured overview diagram of the WWW pages about the research activities at the Graphics Visualization & Usability (GVU) Center at Georgia Tech.[2] Obviously, this information is very complicated.

The left hand screen of Figure 7 shows the top level of the hierarchy automatically created for the data by the system. The file *research.html* which lists the various research activities of the GVU Center is the root. It has branches to the major research area as well as to *gvutop.html*, a file containing general information about GVU. The right hand side of Figure 7 shows a view of a section of this hierarchy where the nodes are listed as a table of content of a book.

A major drawback of the World-Wide Web is that very few useful semantic attributes are defined for the pages. To create some other meaningful hierarchies, attributes like the topic

[2]URL: http://www.gatech.edu/gvu/gvutop.html

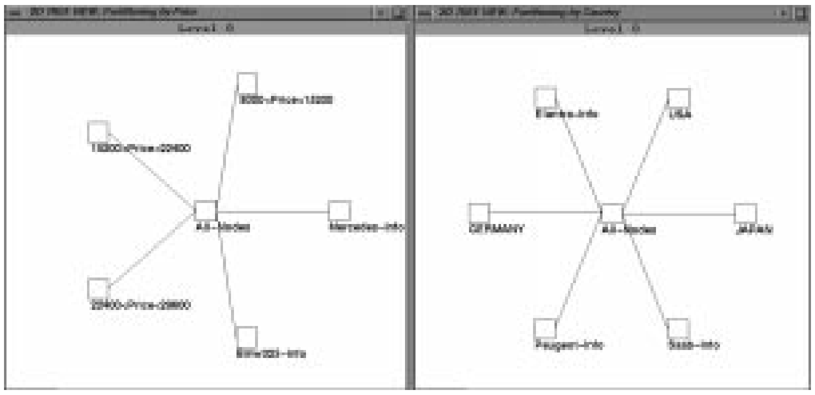
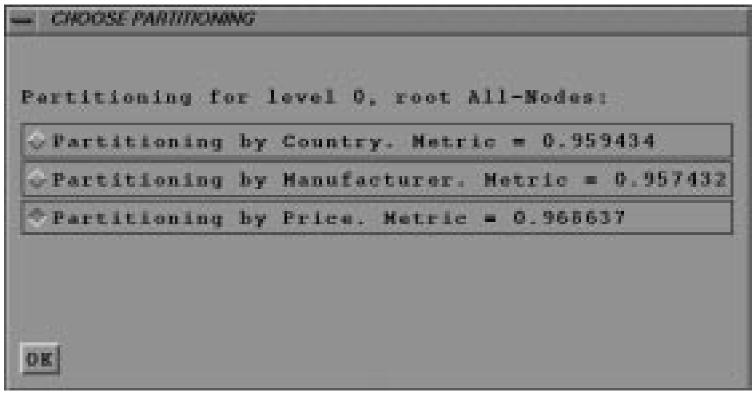


Figure 3: The left hand screen shows the default tree formed for the automobile database. The top-level partitioning is by the attribute *Price*. The right hand screen shows the tree formed if the top-level partitioning is done by the attribute *Country*.



Partitioning for level 0, root All-Nodes:

Partitioning by Country. Metric = 0.959434

Partitioning by Manufacturer. Metric = 0.957432

Partitioning by Price. Metric = 0.966637

Figure 4: At each level various pre-trees can be used. A metric ranks these pre-trees. By default the pre-tree with the best metric is selected. However, the user can select others using the above menu.

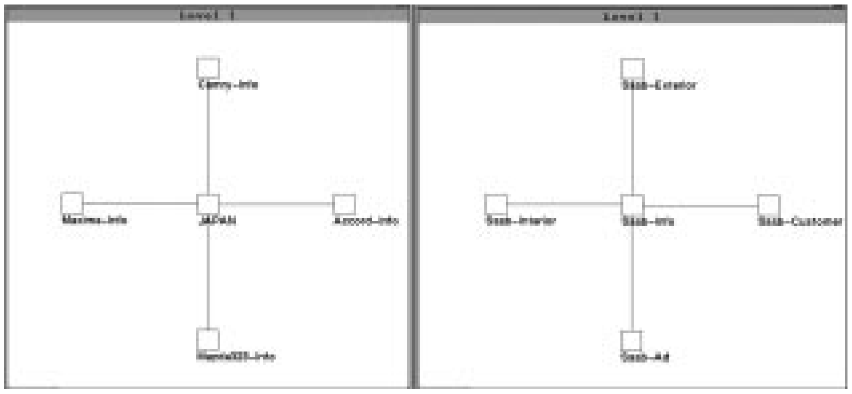


Figure 5: Examples of Content and Structural analysis for forming pre-trees. The left hand screen represents the nodes for Japan. The root is a cluster representing all Japanese cars. The nodes are partitioned by the attribute *Manufacturer*. The right hand screen is for Swedish cars. These nodes form a tree with the node Saab-Info as the root.

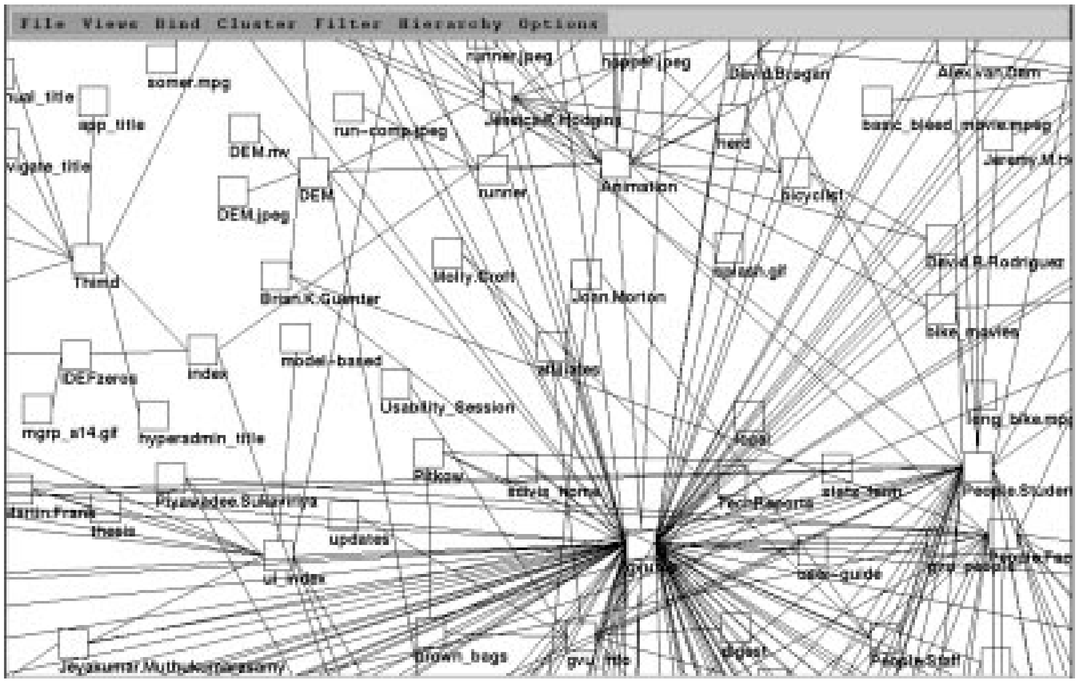
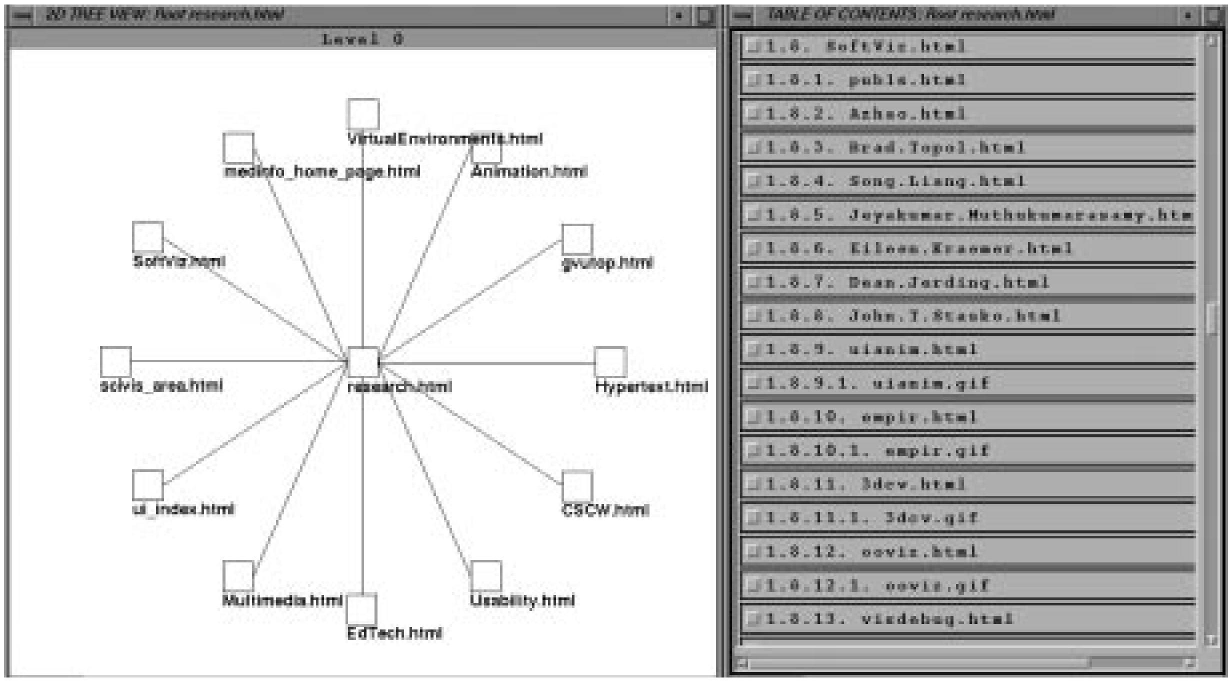


Figure 6: An overview diagram of the World-Wide Web pages about the research activities at GVU. It indicates clearly why traditional overview diagrams are useless for real-world hypermedia systems.



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1.8. SoftVis.html
1.8.1. pubIs.html
1.8.2. Azhso.html
1.8.3. Brad.Topol.html
1.8.4. Song.Liang.html
1.8.5. Jeyakumar.Muthukumarasamy.htm
1.8.6. Eileen.Kraemer.html
1.8.7. Dean.Jerding.html
1.8.8. John.T.Stasko.html
1.8.9. uianim.html
1.8.9.1. uianim.gif
1.8.10. empir.html
1.8.10.1. empir.gif
1.8.11. 3dev.html
1.8.11.1. 3dev.gif
1.8.12. ooviz.html
1.8.12.1. ooviz.gif
1.8.13. vizdebug.html
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Figure 7: The left hand screen shows the top level of the default hierarchy formed for the GVU WWW pages. *research.html* is the root and the major research areas are shown. The right hand screen shows a book view of a portion of this hierarchy showing research in Software Visualization.

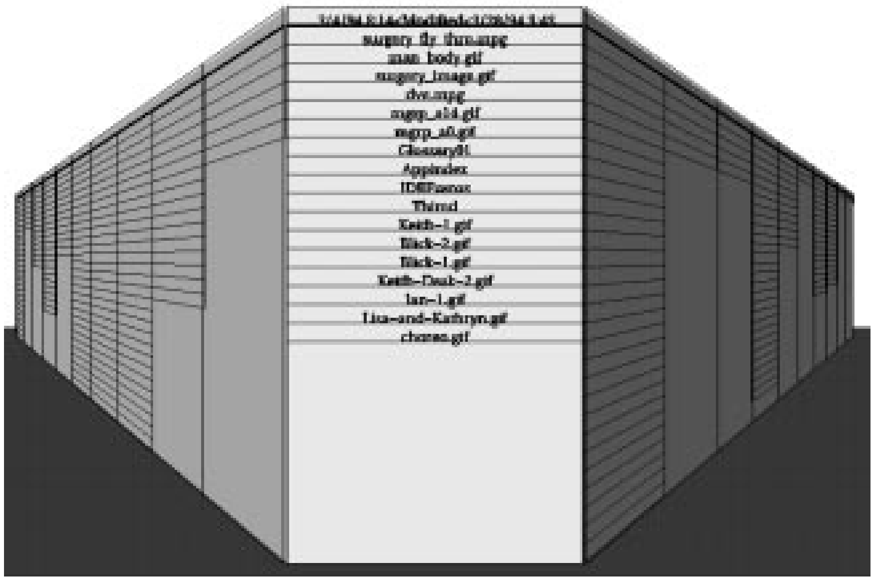

Figure 8: A Perspective Wall view showing a linear arrangement of the files based on the last modification time. The different walls show files which were last modified in different time frames. Only some walls are in the focus at a given time.

of the page (whether it is a research page or a personal page, etc.) were inserted manually. (Efforts are underway to incorporate metadata into WWW and hopefully in the near future we can extract all useful information from the WWW automatically.) The left hand screen of Color plate 2 represents a treemap view of a hierarchy formed when the initial partitioning is done by the topic of the page. The colors are used to represent the kind of users who created the pages. Green is used to represent Phd students and the color plate indicates that the Phd students are the primary authors of the pages.

Multiple hierarchies, each giving a different perspective to the underlying information space can be formed. If a user selects a node in one view, its positions in the other views are also highlighted. Thus, these views help the user in comprehending the data. It should be also noted that the user can go directly to the corresponding WWW page for the selected node. Thus in the Treemap view, the node *visdebug.html* is highlighted. The corresponding WWW page is shown on the right hand screen of Color plate 2.

GENERATING OTHER VIEWS

Once a hierarchy is formed from the original graph structure, the hierarchy can be transformed to other data organizations as well. Visualizations can be formed for these data organizations also. For example, if the original partitioning for forming the hierarchy was done by a quantitative attribute, a linear structure sorted by that attribute can be formed from the subtrees of the root node.

Figure 8 represents a perspective wall [9] view of a linear arrangement of the GVU WWW pages sorted by the last modification times of the files. From the hierarchy whose initial partitioning was by the attribute *last-modified-time*, the files were divided into partitions based on the time when they were last modified. These partitions were arranged on walls. Only some walls are in the focus at a given time. The user can easily control the walls which are in focus through a scrollbar. Similarly, for the automobile database a Perspective Wall view can be formed where the cars are sorted by the attribute *Price*.

Other views can also be generated. For example, a tabular view showing information like average price, mileage, etc. for various car models and also such useful statistics for different manufacturers of the cars can be formed by a depth-first traversal of the hierarchical structure whose partitionings are done by the attributes *Manufacturer* and *Car-Model*.

RELATED WORK

Our structural analysis is similar to that described in [2] for identifying hierarchies from hypermedia structures. Although using just structural analysis to identify hierarchies works for hypertext systems with simpler underlying structures, identifying meaningful hierarchies by structural analysis alone is difficult for real-world systems. Content analysis is also essential as is evident from the paper. [6] describes a method to linearize complex hyper-networked nodes to facilitate browsing using a book metaphor. However, this work also uses structural analysis only.

This paper is also related to systems that deal with graphical presentation of information automatically or semi-automatically. Examples include APT [8] and SAGE [16]. However, our information domain is different from these systems - these systems deal with highly structured information. The views that we want to develop are also different. The previous systems generally produced bar diagrams, scatter plots and such graph views.

CONCLUSION

One of the best ways to comprehend a large complicated information structure is to form multiple simpler structures each highlighting different aspects of the original structure. Our work tries to use this philosophy to make a complex hypermedia system understandable to the user. We believe that by forming various effective views of the underlying space, we would allow the user to better understand the complex information. We give examples of the hierarchization process from two complicated hypermedia systems to illustrate our point. These examples show that our algorithm was able to extract meaningful hierarchies which gave better insights into the complex information spaces.

Future work is planned along the following directions:

- *Visualizing Larger Databases:* Although a detailed complexity analysis is beyond the scope of this paper, it can be shown that the major bottleneck of the algorithm is the structural analysis to identify roots. [2] uses an $O(n^3)$ algorithm to identify roots. On the other hand we use $O(n^2 + nl)$ algorithm to identify roots (by calling the breadth-first search for each node). Although in the worst case $l = O(n^2)$, on average $l = O(n)$ and our algorithm will perform better. For the WWW database with about 400 nodes and 800 links our algorithm took about 7 seconds on a SGI reality engine. Although this is acceptable, we will face problems for larger databases. We are investigating ways to enhance the performance by improving the efficiency of the code and using probabilistic algorithms to identify roots. Moreover, even cone trees and treemaps are not able to visualize larger databases effectively. New visualization techniques are needed.
- *Usability Studies:* A limitation of our system is that no evaluation of how useful our views really are have been done so far. We plan to do serious usability studies in the near future. These studies may give us new insights that will help to improve our system.

ACKNOWLEDGEMENT
This work is supported by grants from Digital Equipment Corporation, Bell South Enterprises, Inc. and Emory University System of Health Care, Atlanta, Georgia as part of the Hypermedia Interface for Multimedia Databases project. We would also like to thank the reviewers of this paper for their useful comments.

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