Working Paper Series
ISSN 1170-487X

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Working Paper 99/5
May 1999

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Abstract

Graphic representations of tree structures are notoriously difficult to create, display, and interpret, particularly when the volume of information they contain, and hence the number of nodes, is large. The problem of interactively browsing information held in tree structures is examined, and the implementation of an innovative tree browser described. This browser is based on distortion-oriented display techniques and intuitive direct manipulation interaction. The tree layout is automatically generated, but the location and extent of detail shown is controlled by the user. It is suggested that these techniques could be extended to the browsing of more general networks.

Key words: tree structures, visualisation, navigation, browsing, distortion-oriented displays

Introduction

This paper examines the problem of the interactive browsing of information held in tree structures, and describes the design and implementation of a tree browser. Graphic representations of tree structures are notoriously difficult to create, display, and interpret, particularly when the volume of information they contain, and hence the number of nodes, is large (Shneiderman, 1992; Lamping *et al*, 1995). To facilitate browsing and retrieving information from trees it is desirable that a simple intuitive interface be provided which automatically generates the tree layout, and which allows the user to explore the structure interactively, to identify the relationships between nodes, and to examine the data they contain in whatever level of detail is appropriate for the task in hand.

The problem of displaying large data spaces in the relatively limited areas offered by most computer display screens is one which has received considerable attention over the past 15 years (Leung & Apperley, 1994). The majority of the solutions proposed to this problem involve distorting the original space in order that a section can be viewed in detail while an overview is maintained of the entire area and the correct spatial relationships between all elements retained. One group of techniques tends to involve graphical distortion, and is rather akin to magnifying or distorting a picture. Another group involves semantic intensity distortion, in which important relationships are highlighted, while those which are of less significance move into the background or are suppressed.

The tree browser described here integrates a set of display or representation techniques based on these distortion-oriented display mechanisms, together with a set of interaction techniques which are largely intuitive or self explanatory for users of modern graphical user interfaces. A large tree can be displayed graphically and browsed within the confines of a conventional display screen using this browser. Only those nodes in which the user expresses an interest are displayed in any detail; the remainder are iconised, and in some cases whole sub-trees which are of no current interest are "pruned" or suppressed. As the user alters the view while browsing, then so the automatic layout adjusts the tree to fit best within the available space.

In the remainder of this paper, the tree browser is described using as an example the class hierarchy from the Symantec™ C++ library (Symantec, 1995). This hierarchy exhibits the classic tree properties commonly encountered; (i) the number of nodes is large (80 for the section of the library used in the example), (ii) the relationship between a node and its sub-tree is hierarchical, (iii) a user will often be interested in examining in detail two or more nodes in different parts of the tree simultaneously, and (iv) the data contained in the nodes is of interest at several different levels of detail. There are many other examples of tree structures to which these techniques could be applied, some, like this one, fixed in the computer context, and others drawn from a diverse range of disciplines such as genealogy, biology and management. It is also proposed that the display and interaction techniques incorporated in this browser could be extended for use with more general network structures; work on these extensions is currently under way.

Distortion-Oriented Display Techniques

The term *distortion-oriented display* relates to a range of techniques for providing simultaneous presentation of detail and overview in a single display. These techniques have evolved to assist in browsing, locating, interpreting and retrieving information from large and complex data spaces. Their aim is to provide the ability to examine one or more sections of the space in detail, while simultaneously maintaining an overview of the entire space.

Spence (1993) has proposed three broad categories into which these techniques can be divided. The first of these comprises the strictly graphical distortion techniques typified by the bifocal display (Apperley *et al*, 1982), the perspective wall (Mackinlay *et al*, 1991), and the graphical fisheye view (Sarkar & Brown, 1992). Leung and Apperley (1994) provide a review of these approaches, all of which involve geometric transformations or variable scaling along one or more axes in the data space. A variety of transformation functions have been demonstrated, ranging in complexity from the piece-wise constant bifocal to the polar fisheye and hyperbolic transformations.

The second category encompasses those techniques where the distortion is not geometric, but is achieved by using different encoding or representations for different objects in the information space. Thus a text document of interest would be shown in full detail, character-by-character. A similar document which was of little current interest might be encoded minimally as an icon, whose colour, shape, and perhaps label, might reflect characteristic properties of the document it represents. Such techniques are commonly used in the representation of directory hierarchies in graphical user interfaces, and indeed permeate many other aspects of window-based interfaces. Spence (1993) has described these as transformations in the *Z*-dimension, as opposed to the *X* and *Y* transformations associated with 2-dimensional geometric distortion.

The third group of techniques involve thresholding the significance of items within the data space, and the suppression of those which fall below this threshold (referred to as *W* transformations in Spence's taxonomy). Thus in Furnas's (1986) fisheye views each information element is assigned a value based on its perceived relevance with respect to the current focus of interest. A degree of interest function of this relevance and the distance from the focus is then computed, and if it falls below a specified threshold, the element is suppressed in the display.

The Representation of Trees

A range of distortion based techniques, and other novel representations, have been applied to the display of hierarchically related information or trees. Lamping *et al* (1995) have commented that those techniques based solely on transformations in two-dimensional space are generally unsatisfactory when it comes to representing trees because of the characteristic exponential growth in the number of nodes (see for example Figure 1). TreeMaps (Johnson & Shneiderman, 1991), another two-dimensional representation, progressively sub-divides the space available with each node containing its entire sub-tree. Although TreeMaps cope with rapid node expansion, they too suffer from the drawback that the further down the hierarchy, the less space that is available for the node. TreeMaps are, however, particularly useful for applications such as directory hierarchies, where the "size" of a node is indeed the size of its sub-tree and

is a parameter of significant interest. Furnas and Zacks (1994) have applied the notions of fisheye views to the browsing of Multitrees, providing separate views of ancestor and descendant trees, with nodes in the lineage highlighted.

Because trees tend to be pyramidal in shape, they do not map well onto two-dimensional surfaces. Cone Trees (Robertson *et al*, 1991) address this problem by mapping trees into a three-dimensional space, so that the tree spreads as a cone. Rotation of the cone can be used to bring a node of interest to the front, and so into the detail focus region. Other techniques attempt to accommodate the awkward shape of trees by mapping them onto hyperbolic surfaces (Lamping *et al*, 1995), by using fractal techniques (Koike & Yoshihara, 1993), or by using a space subdivision approach similar to TreeMaps, but with each node comprising a three-dimensional bubble (Boardman, 1995).

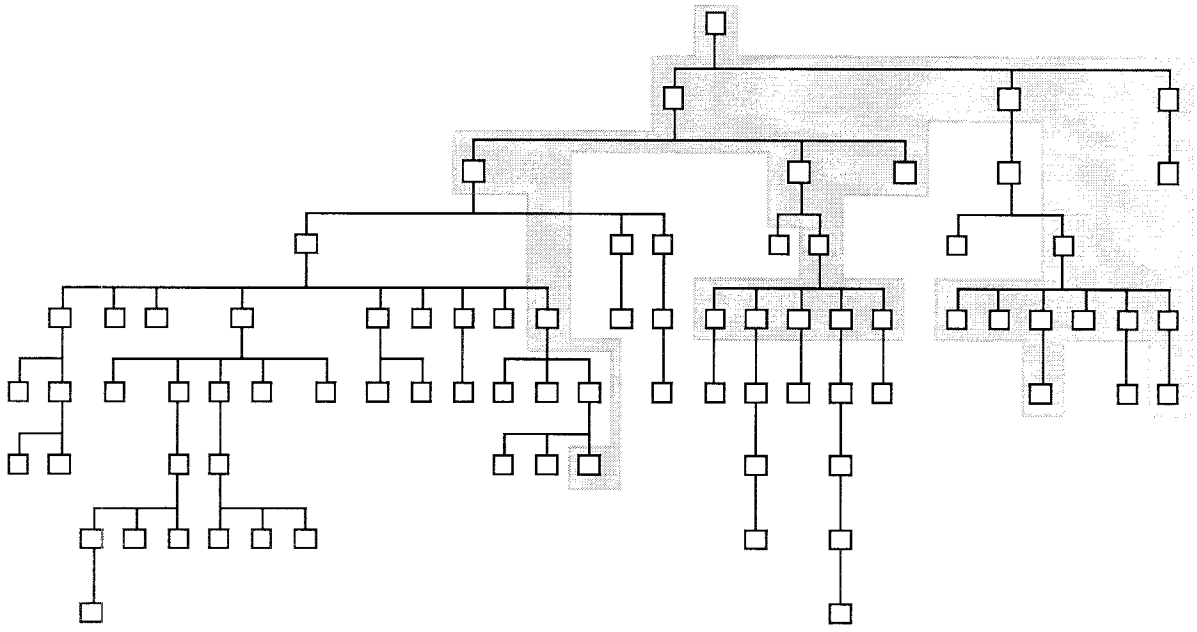

Figure 1: A section of the Symantec™ C++ Class hierarchy, showing the rapid growth in the number of nodes between levels in the hierarchy. The shaded area indicates the nodes which are explicitly represented in the browser window of Figure 2.

Although they are not directly involved with the representation of trees, other studies have examined the use of Furnas's (1986) fisheye concept in browsing hierarchically structured networks (Schaffer *et al*, 1993; Brown *et al*, 1993; Furnas & Zacks, 1994). Results suggest that the increased context information provided by the fisheye view over traditional views of such networks significantly improves user's navigation.

All of these techniques share a common disadvantage in that the distortions make the underlying structure (the tree) less than recognisable, and produce gross dynamic shape changes as the focus of interest is moved.

The Tree Browser Display

The tree browser described here attempts to utilise the best features of the three different approaches to distortion-oriented displays described by Spence (1993); geometric distortion (*X* and *Y*), semantic intensity distortion (*Z*), and thresholding (*W*). While it is recognised that these display features have almost all been seen in tree browsers before, this browser leaves the user firmly in control of the distortion parameters, and automatically maintains the tree in a recognisable fashion. Simple and intuitive user interaction with the tree is seen as being vital, so the display and interaction techniques are tightly integrated.

Figure 2 shows an example tree browser display, a representation of the section of the Symantec™ C++ class library illustrated in Figure 1. Remember that Figure 1 contains 80 nodes; Figure 2 shows in detail only those sections of the class library contained within the shaded area of Figure 1. Nevertheless, the user retains an overview of, and access to, the entire tree. The user could have started with the view of Figure 1, and by a series of interactions, have arrived at Figure 2. In this example the user is attempting to find an appropriate class from which to begin building a new interaction button, and so requires simultaneous access to several nodes in different parts of the tree.

Automatic layout generation for trees has been addressed by others (Di Battista *et al*, 1994; Eades & Sugiyama, 1990). However, of particular concern in this application is the need to maintain consistency of node position and relationships and overall tree shape as browsing proceeds. As will be seen from the description that follows, entire sub-trees may disappear or reappear with a single button-click. A layout algorithm has been developed which provides good consistency and minimal positional change (Chester, 1996; Hodge, 1998) and is described in more detail in a later section.

There are a number of different node representations included in Figure 2, as well as some arc constructions which require explanation. Figure 3 illustrates the Z-transformations, or semantic intensity distortions which can be carried out on nodes, giving rise to the differing node appearances in Figure 2. Figure 3(a) shows a minimised node; there is no label or descriptive information provided, although different icons can be used to represent different types of node in a non-homogenous tree. In Figure 1,

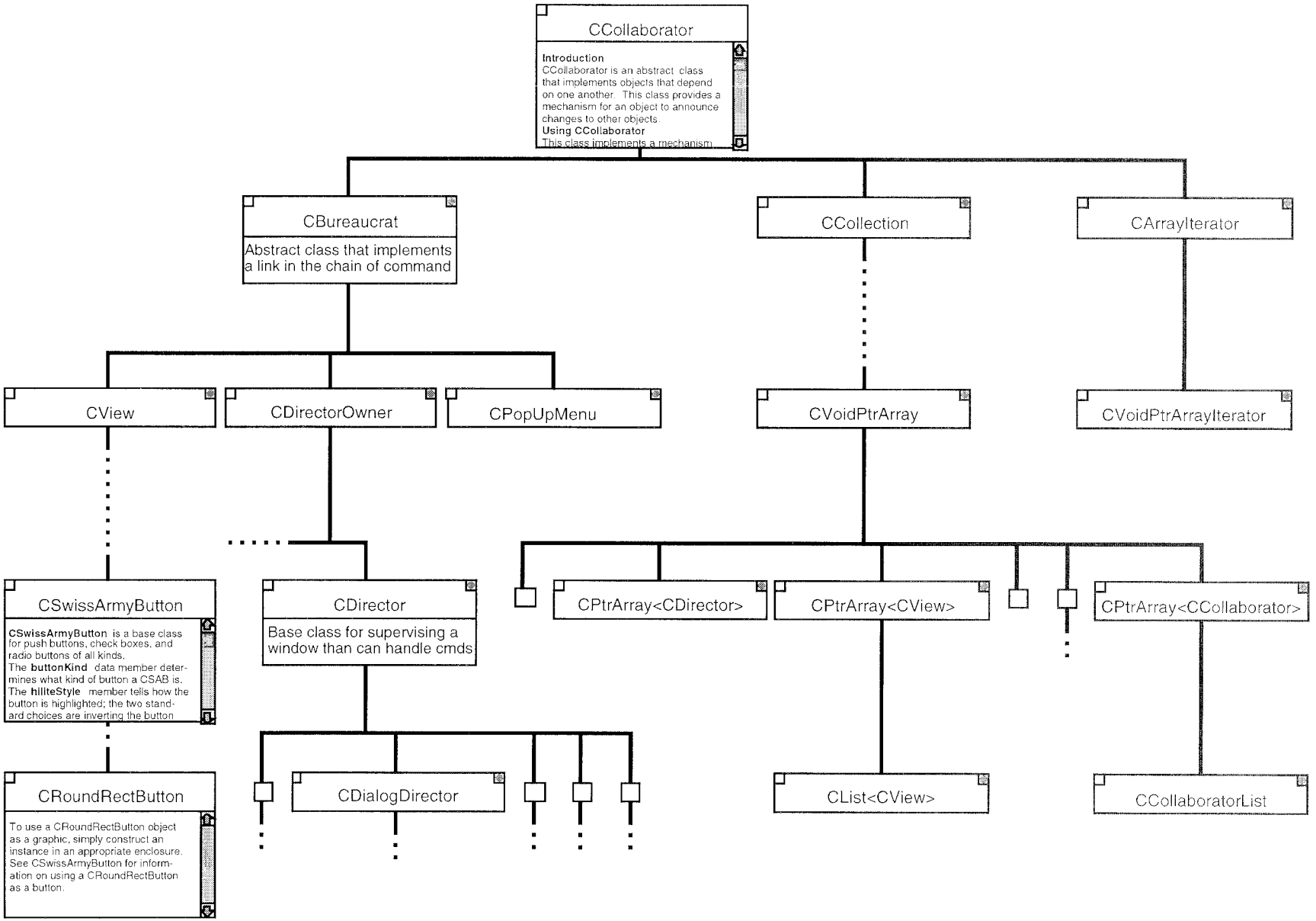

Figure 2: A tree browser display of the section of the Symantec™ C++ class library illustrated in Figure 1.

only minimised nodes were used, and because of the space saving, the entire tree could be represented on the display.

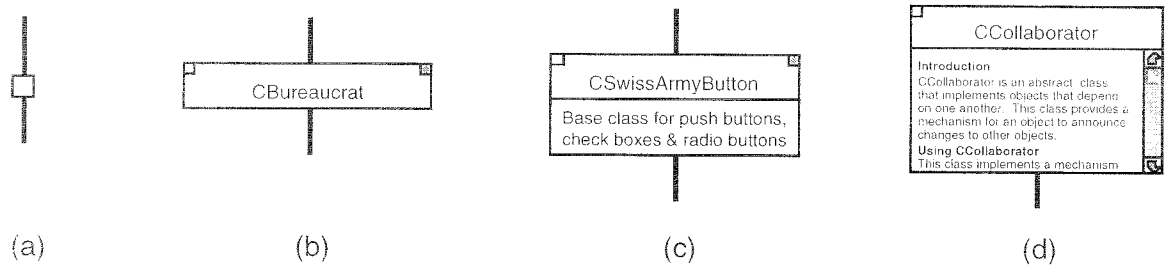

Figure 3: The hierarchy of node detail or semantic intensity provided by the tree browser.

Figure 3(b) shows a labelled node; at the expense of screen space, a unique identifying label for a node can be displayed. At the next level of detail, Figure 3(c), the label is augmented by a brief abstract, in this case describing the purpose of the class represented by the node, and finally at the highest level of detail, Figure 3(d), a comprehensive description of the node is provided in a small scrolling window.

It should be noted that these four representations are just views of a node at different levels of detail. Any node can be moved between these levels of detail under user control; the appearance of the node changes *in situ*, with all tree relationships remaining intact. As a consequence of one of these changes, all or part of the displayed tree may have to be redrawn to accommodate the new node dimensions, but the overall shape or form of the tree will remain unchanged.

There is one further representation of a node which the tree browser provides. At any of the above four levels of detail, a node can be "opened". In this case a new window is opened for the node, and the most detailed descriptive information is displayed. The node window so created is superimposed on the browser window, but it is an independent window that can be moved, scaled or closed under user control; the original node symbol in the tree remains.

Thresholding or suppression of parts of the tree is also evident in Figure 2; not all of the original 80 nodes are represented. Those parts of the diagram which represent or suggest suppressed items are reproduced in Figure 4. Figures 4(a) and 4(b) show "stumped" versions of minimised and labelled nodes respectively. These result from sub-tree pruning; the entire sub-tree emanating from the node in question has been flagged as being of little interest to the user at the present time, so is not displayed. It is better to consider the sub-tree as having been collapsed into the root rather than cut off; it still exists, but is not displayed. Pruned sub-trees can be easily restored by the user at any time; considerable savings of screen real estate can be achieved through this means, as is evident from Figure 2.

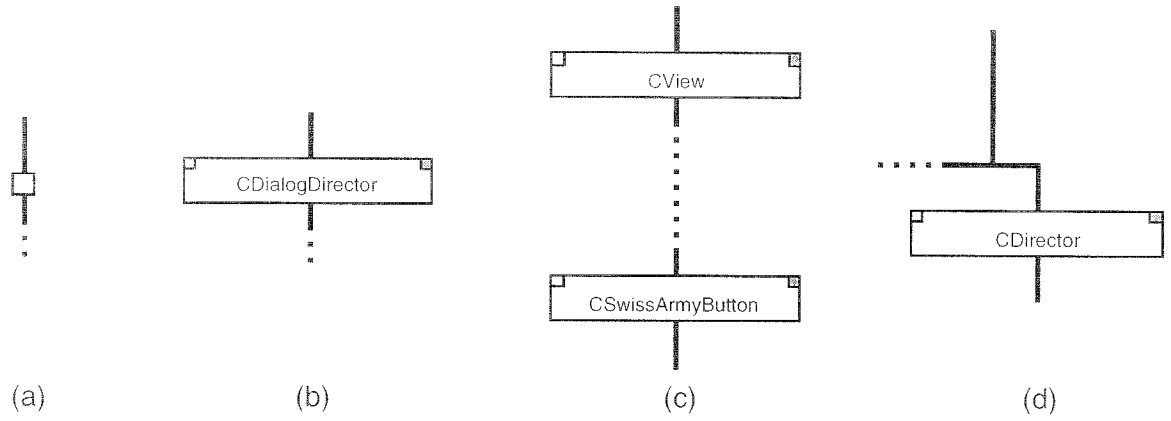

Figure 4: The representation of thresholding or suppression in the tree. Stumped nodes are shown in (a) and (b), (c) represents vertical telescoping, and (d) horizontal telescoping.

Stumped nodes allow for the suppression of entire sub-trees. Often, however, the user does not wish to suppress a sub-tree, but the detail that comes between a node and one of its descendants. This is the situation described as "vertical telescoping" and represented in Figure 4(c). In this case, all nodes between the two in question are suppressed, including the siblings of the suppressed nodes (and their sub-trees) and the siblings of the target descendant node. Any children of this latter node will still be shown, unless suppressed by pruning.

A further form of suppression is required when some but not all of the children of a given node are of interest. This "horizontal telescoping" is represented in Figure 4(d). Here there is just one child node which is to be followed; its siblings (and their sub-trees) are suppressed.

Interacting with the Tree

As much as possible, interaction with the tree is provided with simple and intuitive mouse actions, directly on the nodes or arcs of interest. For example, movement between the four levels of node representation is achieved via expand and contract boxes in each of the icons. The smallest minimised node (Figure 3a) is expanded to a labelled node (Figure 3b) by simply clicking on it; it can only get bigger. A labelled node has both an expand box (top right) and a contract box (top left) as shown in Figure 5. Display of the full window for a node is achieved by a double-click action on any of the four node forms; the window is removed by a conventional close action.

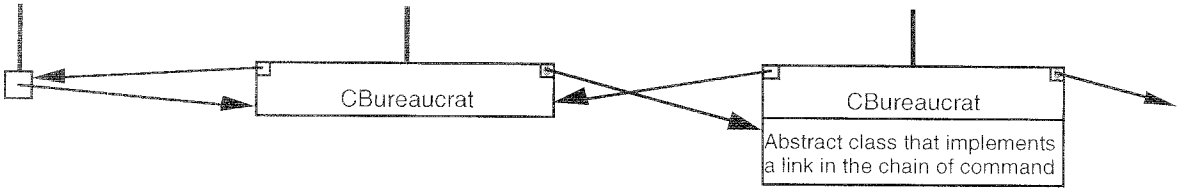

Figure 5: A single mouse-click is required to move a node from one level of detail to another.

Pruning is also achieved through a mouse action. In the normal browse mode, when the cursor is over an arc, its appearance changes to that of a pair of snips. With the cursor in this state, clicking on the descending arc from a node causes that node's sub-tree to be pruned. With the same cursor, clicking on the vestigial arc causes the sub-tree to be redisplayed.

Vertical telescoping, as shown in Figure 4(c), is achieved by a simple dragging action between the two nodes. The cursor is placed over the lower of the nodes, the mouse key pressed, and the cursor dragged to the ancestor node. As the dragging takes place, then so those parts of the tree that will be suppressed are greyed as the cursor crosses each node (see Figure 6a). When the target ancestor node is reached, and the mouse key released, then the unwanted part of the tree disappears, as shown in Figure 6(b). The vertical distance between the two selected nodes is reduced and a dotted arc appears between them. The suppressed section of the tree can be restored to view by clicking on the dotted arc. Three different restoration modes are provided. If the centre (dotted) portion of the arc is clicked, then the entire suppressed section of the tree is restored. If, however, the vestigial top or bottom solid section of the arc is clicked, then the suppressed portion is restored incrementally from the top or bottom respectively. Incremental restoration from the lower node is demonstrated in the transition from Figure 6(b) to Figure 6(c).

Horizontal telescoping, where a number of sibling nodes and their descendants are suppressed, is handled in a similar fashion. However, in this case it is not a simple dragging action between two nodes that is required, but the tracing of a path which passes through each of the nodes to be suppressed. Figure 7 shows an example where a path is traced through three non-adjacent nodes. When the mouse button is released, the sub-tree reduces to the one shown in Figure 7(b), with the three selected nodes suppressed. Restoration of the suppressed nodes is achieved by clicking on the vestigial dotted stump extending to the left in Figure 7(b).

In general, interactions with the tree browser follow very simple and intuitive rules. Most actions are reversed by the same means as they were created; actions on a node controls the displayed detail of that node; and actions on an arc controls the displayed detail of the tree structure.

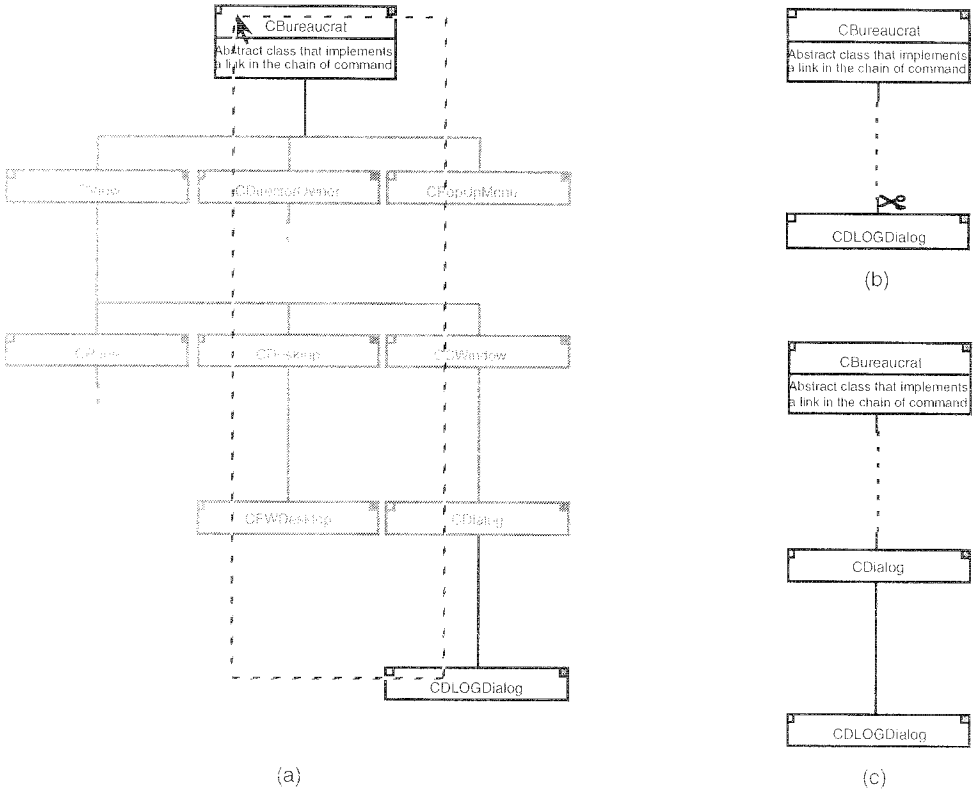

Figure 6: (a) & (b) Vertical telescoping is achieved by dragging from the descendant node of interest to the ancestor; (b) & (c) incremental restoration is achieve by clicking on one of the vestigial arcs.

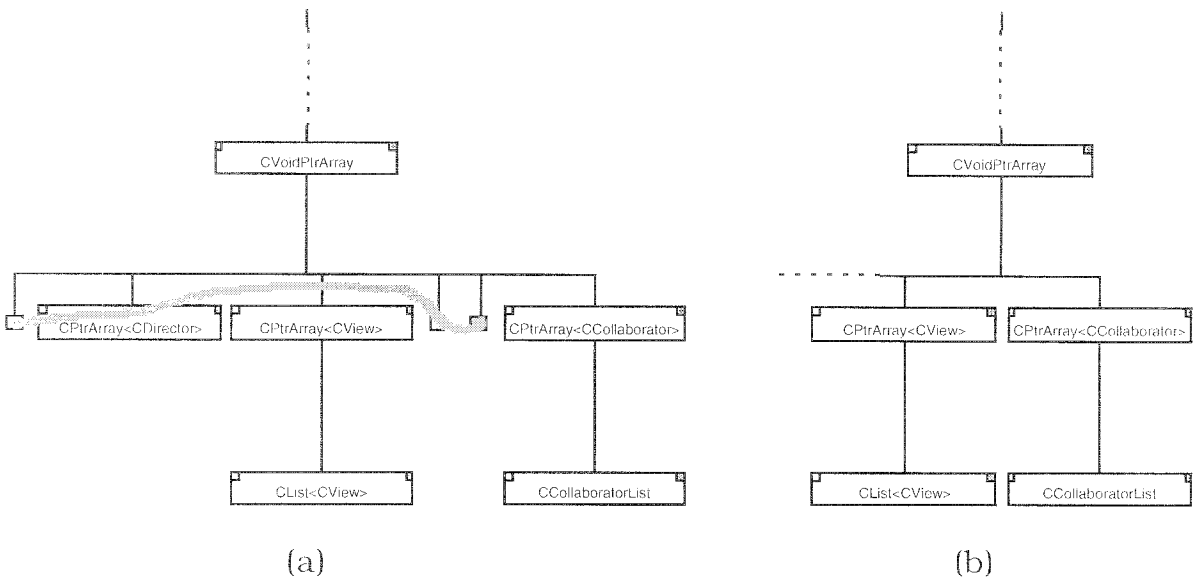

Figure 7: (a) A path is traced though a group of sibling nodes, (b) resulting in their suppression.

The Tree Drawing Algorithm

Algorithms for generating 2-dimensional pictorial representations of trees and graphs abound (Di Battista *et al*, 1994). These algorithms are designed to meet a variety of constraints and requirements for appearance, readability and understandability. Amongst the criteria proposed by different authors are the following:

- All arcs should be directed away from the root;
- nodes should be centred upon their immediate sub-nodes;
- nodes should be distributed evenly over the page;
- edge crossings should be avoided;
- edges should be as straight as possible;
- nodes should not overlap;
- nodes should conform to the idea of symmetry; and
- the display space should be minimised.

Not all of these constraints are necessarily compatible, nor do they relate to the dynamic environment of the tree browser. Not only does the concept of the browser require that trees be aesthetically pleasing, but it also imposes the following additional constraints:

- As the user alters the level of detail of nodes and structure to be displayed, then so the general form and spatial relationships in the tree should shift smoothly and not dramatically; and
- the algorithm should execute sufficiently rapidly to be effective in an interactive environment.

The algorithm that has been developed is a relatively simple one, which operates in a single bottom-up pass (Chester, 1996; Hodge, 1998). The operation of the algorithm can be described in a simplified form with reference to Figure 8. Initially, only the bounding boxes of the individual nodes in the tree are known (Figure 8a), and the sub-node bounding box for each non-terminal node is set to be degenerate. The collision-resolution algorithm is applied recursively to the root (P), addressing each of its children in turn, from left-to-right.

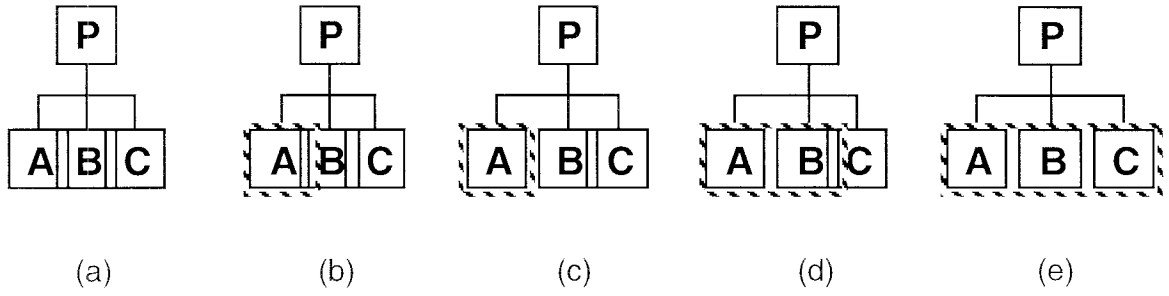

Figure 8: The operation of the tree-drawing algorithm. The dotted rectangle is the sub-node bounding box.

After resolving any collisions within the sub-tree A, the sub-node bounding box for P is set to the bounding box of A (shown by the dotted rectangle in

Figure 8b). Sub-tree B is then considered, and any node collisions within B are resolved. B is then checked against P's sub-node bounding box, and it is seen that a collision occurs (Figure 8b). To resolve this, a search is carried out to establish which sub-node is causing the collision (in this case, A), and the two sub-nodes are separated (Figure 8c). The sub-node bounding box is recalculated, a further check is carried out against this box, and as no further collisions occur, the bounding box is updated to include B, as shown in Figure 8(d). The operation is then repeated with sub-tree C, resulting in the situation illustrated in Figure 8(e).

The initial layout algorithm normally ensures that sibling nodes do not collide. For this reason, collisions that need to be resolved by the drawing algorithm tend to occur at a depth of two or more in the sub-trees in question.

Extension to General Graphs

The tree browser described in this paper has established display and interaction techniques which allow a user to effortlessly navigate and examine information held in large, but nevertheless well-organised, tree structures. Much of the information we deal with, however, is held in network or general graph structures, which are rather more complex, and for which it is not so obvious how they might best be represented or displayed. Of particular interest and complexity, is the representation of the information space of the World-Wide Web. One approach to improving navigation in the Web is to consider direct interaction with an effective visualisation of the space under consideration.

Others have applied distortion-oriented display principles to the navigation of information held in graph structures (Schaffer et al, 1993; Brown et al, 1993). Multitrees (Furnas & Zacks, 1994) conveniently partition general graphs into hierarchical trees, providing for their simple representation. It is now proposed that the techniques just described in this paper, in particular those relating to the interactive control of detail through pruning and telescoping, be combined with a graph layout programme, to provide a highly interactive graph browser. A prototype browser developed in this way is currently being implemented.

Implementation

Two demonstration prototypes of the tree browser have been implemented. The first, in Symantec™ C++ on a Power Macintosh™ computer (Chester, 1996), successfully demonstrated the principles of display and interaction and provided for the development of the tree-drawing algorithm. However, this implementation was found to be too slow to be effectively usable. A second implementation using the X Window System™ OpenGL library, together with a refined version of the tree-drawing algorithm (Hodge, 1998), has provided a very smooth demonstration with trees of up to 100 nodes.

Conclusions

This paper has described the implementation of a tree browser based on distortion-based representations, automatic tree layout, and well-known and intuitive interaction techniques. Although the demonstration prototype system has not yet been fully evaluated, experience shows that tree browsing rapidly becomes intuitive and effective, and users are able to locate items and information of interest more quickly than with conventional undistorted tree representations.

The extension of these display and interaction techniques to more general network structures is currently under way.

Acknowledgments

Part of the research described in this report was carried under a sub-contract to the Massey University FRST-funded project "Advanced Information Technologies Through CASE".

References

Apperley, M.D., Tzavaris, I. & Spence, R. (1982): A bifocal display technique for data presentation. *Proceedings of Eurographics '82*, 27-43.

Boardman, R. (1995): *Visualisation of information trees.* ISE3 Individual Project Report, Information Engineering, Imperial College.

Brown, M.H., Meehan, J.R. and Sarkar, M. (1993): Browsing graphs using a fisheye view. *INTERCHI '93 Proceedings*, 516.

Chester, Michael (1996): *The display and manipulation of abstract trees.* 0657.420 Report of an Investigation, University of Waikato, Department of Computer Science.

Di Battista, G., Eades, P., Tamassia, R. & Tollis, I.G. (1994): Algorithms for drawing graphs: an annotated bibliography. *Computational Geometry Theory and Applications*, **4**, 235-282.

Eades, P. & Sugiyama, K. (1990): How to draw a directed graph. *Journal of Information Processing*, **13**(4), 424-437.

Furnas, G.W. (1986): Generalised fisheye views. *CHI '86 Proceedings*, 16-23.

Furnas, G.W. & Zacks, J. (1994): Multitrees: Enriching and reusing hierarchical structure, *CHI '94 Proceedings*, 330-336.

Hodge, Stephen (1998): *Browsing Trees and Graphs.* MSc Thesis, University of Waikato, Department of Computer Science.

Johnson, B. & Shneiderman, B. (1991): TreeMaps: A space-filling approach to the visualisation of hierarchical information. *CHI '91 Proceedings*, 401-408.

Koike, H. & Yoshihara, H. (1993): Fractal approaches for visualising huge hierarchies. *Proceedings of 1993 IEEE Symposium on Visual Languages.*

Lamping, J., Rao, R. & Pirolli, P. (1995): A focus+context technique based on hyperbolic geometry for visualising large hierarchies. *CHI '95 Proceedings*, 401-408.

Leung, Y.K. & Apperley, M.D. (1994): A review and taxonomy of distortion-oriented presentation techniques. *ACM Transactions on Computer-Human Interaction*, **1**(2), 126-160.

Mackinlay, J.D., Robertson, G.G. & Card, S.K. (1991): The perspective wall: Detail and context smoothly integrated. *CHI '91Proceedings*, 173-179.

Robertson, G.G., Mackinlay, J.D. & Card, S.K. (1991): Cone trees: Animated 3d visualisations of hierarchical information. *CHI '91 Proceedings*, 189-194.

Sarkar, M. & Brown, M.H. (1992): Graphical fisheye views of graphs. *CHI '92 Proceedings*, 83-91.

Schaffer, D., Zuo, Z., Bartram, L., Dill, J., Dubs, S., Greenberg, S. & Roseman, M. (1993): Comparing fisheye and full zoom techniques for navigation of hierarchically clustered networks. *Proceedings of Graphics Interface 93*, 87-97.

Shneiderman, B. (1992): Tree visualisation with tree-maps: 2-d space-filling approach. *ACM Transactions on Graphics*, **11**(1), 92-99.

Spence, R. (1993): A taxonomy of graphical presentation. *INTERCHI '93 Adjunct Proceedings*, 113-114.

Symantec (1995): *SYMANTEC C++ development system for Power Macintosh: User's guide and reference.* Symantec Corporation, Cupertino, CA.