

Space-Efficient Visualisation of Large Hierarchies

Quang Vinh Nguyen

A thesis submitted for the degree of
Doctor of Philosophy in Computing Sciences
at the
University of Technology, Sydney

Faculty of Information Technology
University of Technology, Sydney
Sydney, Australia

2005

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

Date	August 05
Author	Quang Vinh Nguyen
Title	Space-Efficient Visualisation of Large Hierarchies
Degree	Doctor of Philosophy in Computing Sciences

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

Copyright © 2005

by

Quang Vinh Nguyen ()

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

Acknowledgements

I would like to take this opportunity to express my sincere gratitude to my supervisor, Dr. Mao Lin Huang, for his enormous academic guidance and financial support, encouragement, advice, and for giving me the opportunity to do a Ph.D at the Faculty of Information Technology at the University of Technology, Sydney. Mao Lin provides me not only a great academic guidance, but also a large degree of freedom in my research, for both of which I am very grateful.

I also would like to express my sincere thank to my co-supervisor, Prof. Chengqi Zhang, for his great help and useful advice.

I would like to thank Prof. Igor Hawryszkiewicz for giving me the opportunity to carry out one of my case study using the *LiveNet* system, which makes it much more valuable to my thesis. I have learnt a lot from the experiment, as well as from the discussions with Igor. I also wish to acknowledge the great support of Dongbai Xue for his eager help when I worked with the *LiveNet* system.

Great thanks are due to A/Prof. Tom Hintz and all members of Computer Vision Research Group for their generous helps, supports, and the exchange of knowledge toward the completion of my Ph.D. I would acknowledge the effort of A/Prof. Tom Hintz for the English correction.

I would like to thank Prof. Peter Eades and his Information Visualisation group members, who have given me opportunities to share and exchange the knowledge during the group meetings at the University of Sydney, Australia.

I would also thank all of my colleagues, academics and technical staffs of Faculty of Information Technology, the Graduate School and the Vice-Chancellor's Conference Fund at the University of Technology, Sydney who directly or indirectly help me on the road toward the completion of my Ph.D, especially to Ryan Heise, Robert P. Biuk-Aghai, and Ai Zhong Lin.

The author would acknowledge the appreciation to the markers of Tree-Maps and Space-Tree software (University of Maryland's Human-Computer Interaction Lab). These two softwares are very useful for my research and experiment.

Last but not least, I would like to thank my parents, my grandma, and my sisters for their continuous encouragement and support. I would also thank my girlfriend, Kim Chi Nguyen, who has always stayed side by side to make this Ph.D possible.

To my beloved parents & my loved girlfriend

Table of Contents

List of Figures	ix
List of Tables	xiv
List of Equations	xv
Abstract	xvii
Terminology	xix
Chapter 1 Introduction	1
1.1 Information Visualisation	1
1.1.1 Origins in Information Visualisation	2
1.1.2 Human Visual Perception	3
1.2 Graphs in Information Visualisation.....	5
1.3 Hierarchical Visualisation.....	5
1.3.1 Hierarchical Layout Techniques	7
1.3.1.1 Connection Approach.....	8
1.3.1.2 Enclosure Approach	15
1.3.1.3 Three-Dimensional Layouts.....	18
1.3.2 Hierarchical Navigation and Interaction Techniques.....	21
1.3.2.1 Focus+Context Techniques	22
1.3.2.2 Zooming+Filtering Techniques.....	26
1.3.2.3 Incremental Exploration.....	27
1.3.3 Other Information Visualisation Approaches	28
1.3.4 Limitations of Existing Hierarchical Visualisation Techniques	29
1.3.4.1 Limitations of the Layout Techniques	30
1.3.4.2 Limitations of the Navigation and Interaction Techniques.....	33
1.4 Challenges.....	34
1.5 Research Objectives.....	35
1.6 Author’s Contributions in the Thesis.....	36
1.7 Thesis Organisation.....	37
Chapter 2 Space-Efficient Visualisation	39
2.1 The Enclosure+Connection Visualisation Model	39
2.2 Weight Calculation	40
2.3 Space-Optimised Tree.....	43

2.3.1	Local Area Partition – Approach 1	44
2.3.1.1	Wedge Calculation	44
2.3.1.2	Local Region Division	45
2.3.2	Local Area Partition – Approach 2	46
2.3.3	Vertex Positioning.....	47
2.3.4	Graphical Properties for Displaying Space-Optimised Tree.....	49
2.3.5	Computational Complexity of the Algorithm	49
2.3.6	Examples of the Space-Optimised Tree’s Visualisation.....	50
2.4	EncCon Tree	55
2.4.1	An Example of the Partition.....	56
2.4.2	Local Region Partition	57
2.4.2.1	Local Region Partition - Approach 1	61
2.4.2.2	Local Region Partition - Approach 2	63
2.4.3	Graphical Properties for Displaying EncCon Tree	64
2.4.4	Computational Complexity of the Algorithm	64
2.4.5	Examples of the EncCon Tree.....	66
2.4.6	The Comparison of Different Partitioning Algorithms.....	74
2.4.7	An Experimental Evaluation	77
2.4.7.1	Edge Crossings.....	79
2.4.7.2	Angular Resolution	80
2.4.7.3	Total Edge Length.....	81
2.4.7.4	Uniform Edge Length.....	83
2.4.7.5	Experimental Results and Discussion	84
2.5	Summary	85
Chapter 3	Navigation Methods	87
3.1	The Hybrid View	88
3.1.1	Browsing Transformation	91
3.1.2	Distortion Transformation.....	92
3.1.3	The Hybrid View’s Examples.....	93
3.2	The Layering View	96
3.2.1	Layering Display.....	96
3.2.2	Interactive Navigation.....	99
3.2.2.1	Navigation in the Detail View.....	100
3.2.2.2	Navigation in the Context View.....	100

3.2.2.3	Recalling the Previous Context Display.....	100
3.3	Summary	103
Chapter 4 Case Study 1: A Visual Interface in Shared Collaborative Workspaces		105
4.1	Shared Workspaces - LiveNet.....	106
4.2	Related Works.....	108
4.3	LiveNet's Visual Interface	109
4.3.1	Relations in LiveNet Shared Workspaces.....	110
4.3.2	The Frame-Work of Visual User Interface	112
4.3.3	Combined Visualisation.....	113
4.3.3.1	Concurrent Visualisation of Multiple Relationships.....	116
4.3.3.2	Attributed Visualisation	119
4.3.3.3	Interactive Navigation Technique	122
4.4	Summary	125
Chapter 5 Case Study 2: A Visual Browser for Large-Scale Online Auctions.....		127
5.1	Product Catalogue's Navigation in Online Auctions.....	127
5.2	The Framework of Visual Online Auction Store.....	129
5.3	Dynamic Visualisation of Online Auction's Product Catalogue	131
5.4	Summary	136
Chapter 6 Ongoing Research		137
6.1	A Preliminary Three-Dimensional Extension of EncCon Tree	137
6.1.1	Motivation.....	137
6.1.2	Layout Algorithm.....	138
6.1.3	Summary	141
6.2	A Fast Focus+Context Viewing Technique for the Navigation of Classical Hierarchical Layout.....	141
6.2.1	Classical Hierarchical Layout	142
6.2.2	Technical Detail	143
6.2.2.1	The Layout	144
6.2.2.2	Interactive Navigation	146
6.2.2.3	Display Property.....	147
6.2.2.4	Complexity	147
6.2.3	Summary	148
Chapter 7 Conclusions and Future Work.....		149
7.1	Conclusions.....	149

7.1.1	Space-Efficient Visualisation.....	150
7.1.2	Navigation Methods.....	151
7.1.3	Case Studies.....	152
7.1.4	Ongoing Research.....	153
7.2	Future Work.....	153
7.2.1	Usability Study – Topology of Tree.....	154
7.2.1.1	Type of Layouts.....	154
7.2.1.2	Criteria for Evaluating Layouts - Topology of Tree Visualization.....	154
7.2.1.3	Design.....	155
7.2.1.4	Participants.....	155
7.2.1.5	Tasks.....	155
7.2.1.6	Procedure.....	155
7.2.1.7	Measurement.....	156
7.2.1.8	Questionnaires.....	156
7.2.2	Usability Study – Navigation and Topology of Tree.....	156
7.2.2.1	Type of Tree Visualisation Systems.....	156
7.2.2.2	Criteria for Evaluating Tree Visualisation Systems.....	157
7.2.2.3	Design.....	157
7.2.2.4	Participants.....	157
7.2.2.5	Tasks.....	157
7.2.2.6	Procedure.....	158
7.2.2.7	Measurement.....	158
7.2.2.8	Questionnaires.....	158
	Author’s Publications for the Ph.D.....	160
	Bibliography.....	162

List of Figures

Figure 1.1. An example of good information visualisation.	4
Figure 1.2. An example of bad information visualisation.....	4
Figure 1.3. A visualisation of classical hierarchical layout.	9
Figure 1.4. A visualisation of radial view.	10
Figure 1.5. A visualisation of balloon view.	11
Figure 1.6. A visualisation of disk-tree.	12
Figure 1.7. A Visualisation of hyperbolic browser.	13
Figure 1.8. A visualisation of internet mapping.....	14
Figure 1.9. A visualisation of NicheWorks.....	15
Figure 1.10. A visualisation of tree-maps.	17
Figure 1.11. A visualisation of sunburst.	18
Figure 1.12. A visualisation of cone tree.	20
Figure 1.13. A visualisation of botanical visualisation.	20
Figure 1.14. A visualisation of information cube.	21
Figure 1.15. The bifocal display.	24
Figure 1.16. The perspective wall.....	25
Figure 1.17. Fisheye views.....	26
Figure 1.18. An example of semantic zooming of classical hierarchical layout.....	27
Figure 1.19. An example of incremental exploration of huge graph.	27
Figure 1.20. A visualisation of spring-mass model.....	28

Figure 1.21. A structure induced by hierarchical clustering.....	29
Figure 1.22. The inefficiency of space utilisation techniques in <i>connection</i> approach. ...	32
Figure 1.23. The traditional <i>focus+context</i> concept.	33
Figure 2.1. An example of <i>space-optimised tree</i> 's area partitioning.....	42
Figure 2.2. An example of <i>EncCon tree</i> area partitioning.	42
Figure 2.3. A wedge $wg(v)$	44
Figure 2.4. A local region $R(v)$	45
Figure 2.5. An example of partitioning v_i 's local region into four sub-regions.	46
Figure 2.6. An example of positioning a vertex in its local region.	48
Figure 2.7. An example of a medium large dataset of approximately 170 nodes.	51
Figure 2.8. An example of a file system with approximately 3,700 nodes.	52
Figure 2.9. An example of a uniform dataset of approximately 22,000 nodes.	53
Figure 2.10. An example of a huge dataset of approximately 50,000 nodes.	54
Figure 2.11. Diagram of partitioning direction.	56
Figure 2.12. An illustrated example of the partitioning process.	57
Figure 2.13. An example of the partitioning on the left side of the rectangle.	61
Figure 2.14. An example of <i>EncCon tree</i> visualisation using approach 1.	62
Figure 2.15. An example of <i>EncCon tree</i> layout using approach 2.	64
Figure 2.16. An example of a file system with approximately 2,750 nodes.	68
Figure 2.17. An example of a file system with approximately 11,000 nodes.	69
Figure 2.18. An example of a file system with approximately 900 nodes.	70

Figure 2.19. An example of a file system with approximately 3,600 nodes.....	71
Figure 2.20. An example of the entire Java v.1.4.1 documentation with approximately 9,500 nodes.	72
Figure 2.21. An example of a huge dataset of approximately 50,000 nodes.	73
Figure 2.22. An example of node-link diagram at different type of rectangles.	75
Figure 2.23. The layouts of a tree generated by four area partitioning algorithms.	76
Figure 2.24. The layouts of the 2 nd experimental dataset.....	77
Figure 2.25. The layouts of the 3 rd experimental dataset.	78
Figure 2.26. The layouts of the 4 th experimental dataset.	78
Figure 2.27. The layouts of the 5 th experimental dataset.	79
Figure 2.28. A summary of the experimental evaluation results.	85
Figure 3.1. An example of semantic zooming when a sub-tree is selected to be viewed in detail.....	89
Figure 3.2. An example of the movement of points.....	91
Figure 3.3. Graph of the distortion transformation.	93
Figure 3.4. The visualisation of an entire tree layout.....	94
Figure 3.5. The visualisation of a sub-tree of the entire tree shown in Figure 3.4 when semantic zooming is applied.	94
Figure 3.6. The same visualisation as shown in Figure 3.5 when a <i>browsing</i> transformation is applied.....	95
Figure 3.7. The same visualisation as shown in Figure 3.6 when a <i>distortion</i> transformation is applied.....	95
Figure 3.8. Layering display.	97

Figure 3.9. An example of focus+context viewing of a file system using semi-transparency technique.....	98
Figure 3.10. Examples of viewing, interactive navigation and animation in <i>layering display and interactive navigation</i>	102
Figure 4.1. An example of the current text-based LiveNet’s interface.....	107
Figure 4.2. The framework of the visualisation system.....	112
Figure 4.3. An example of the visualisation of a particular user’s shared workspace....	115
Figure 4.4. An example of the display where the <i>categorising</i> and the <i>accessing</i> relations are at the active state.....	117
Figure 4.5. An example of the display where the <i>participating</i> and the <i>sharing</i> relations are at the active state.....	117
Figure 4.6. An example of the display or a workspace with a normal view.....	118
Figure 4.7. An example of the display of a workspace with a clustered view.....	118
Figure 4.8. An example of the attributed visualisation of a large workspace.....	120
Figure 4.9. An example of a detail look from the attributed visualisation when a subsection is enlarged during the navigation.....	121
Figure 4.10. An example of the attributed visualisation when nodes are represented as icons corresponding to their types.....	121
Figure 4.11. An example of the display when the view at Figure 4.3 is switched to iconic mode.....	123
Figure 4.12. An example of the display when the node ‘My Activities’ is selected.....	123
Figure 4.13. An example of the interaction when the user is pointing the mouse over a node.....	124
Figure 4.14. An example of the interaction when the view is held and the user can interact with more information through linked nodes.....	124

Figure 5.1. An example of the traditional text-based interface for online auction.	128
Figure 5.2. The framework of a visual online auction store.	130
Figure 5.3. An example of the visual navigation window and the main window of the online auction's prototype.	132
Figure 5.4. The global view of the entire product catalogue.	134
Figure 5.5. The display of all subcategories and auctioned items belonging to the category "Computer".	134
Figure 5.6. The display when the global-view is switched to active state.	135
Figure 5.7. The display when the mouse is over a product. The system pop-ups a layer to show more detail of the auctioned item.	135
Figure 5.8. An example of the display of both visual navigation and the main window when the bidder double-clicks on the item "JavaScript 3" from categories "Computers-Computer Books".	136
Figure 6.1. An example of three-dimensional extension of the <i>EncCon tree</i>	139
Figure 6.2. The same visualisation as shown in Figure 6.1 with modified representation of edges.	140
Figure 6.3. The Reingold and Tilford algorithm.	144
Figure 6.4. An example of displaying a tree layout using <i>RT</i> algorithm.	145
Figure 6.5. An example of the layout where (a) $M = 0.02$ and (b) $M = 0.04$	146
Figure 6.6. An example of the navigation and interaction.	147

List of Tables

Table 1. Edges Crossings of the Top Three Levels.	80
Table 2. Angular resolution.	81
Table 3. Average edge length (the size of display is: 700x700 pixies).....	83
Table 4. Average length variance (the size of display is: 700x700 pixies).....	84

List of Equations

Equation 2.1	41
Equation 2.2	44
Equation 2.3	47
Equation 2.4	59
Equation 2.5	59
Equation 2.6	59
Equation 2.7	60
Equation 2.8	60
Equation 2.9	60
Equation 2.10	80
Equation 2.11	80
Equation 2.12	81
Equation 2.13	82
Equation 2.14	82
Equation 2.15	83
Equation 3.1	90
Equation 3.2	91
Equation 3.3	92
Equation 3.4	93
Equation 6.1	138

Equation 6.2	145
Equation 6.3	146

Abstract

Relational information visualisation concerns viewing relational data, where the underlying data model is a graph. Hierarchical visualisation is one of hot topics in graph visualisation in which the data is organised in a hierarchical structure. As the amount of information, that we want to visualise, becomes larger and the relations become more complex, classical visualisation techniques and hierarchical drawing methods tend to be inadequate.

Traditional hierarchical visualisation algorithms are more concerned with the readability of the layouts. They usually do not consider the efficient utilisation of the geometrical plane for the drawings. Therefore, for most hierarchical layouts, a large portion of display space is wasted as background. The aim of this research is to investigate a space-efficient approach to handle the visualisation of large hierarchies in two-dimensional spaces.

This thesis introduces a new graph visualisation approach called *enclosure+connection* for visualizing large hierarchies. This approach maximises the space utilisation by taking advantages of the traditional enclosure partitioning approach, while it retains the display of a traditional node-link diagram to hopefully provide users a direct perception of relational structures.

The main contribution of this thesis is layout and navigation algorithms for visualising large hierarchies. Two layout algorithms, the *space-optimised tree* and the *EncCon tree*, have been developed to achieve the space-efficient visualisation. Both algorithms use the enclosure concept to define layout of hierarchies, which ensure the efficient utilisation of display space. Two *focus+context* navigation and interaction methods have been proposed to cooperate with the visualization of large hierarchies. Several advanced computer graphics approaches, such as *graphic distortion* and *transparency*, are used for the development of these navigation methods.

Two case studies have been implemented to evaluate the layout algorithms and the associated navigation methods. The first case study is an application of a shared collaborative workspace which aims to provide users with a better assistance for visual manipulation and navigation of knowledge-based information. The second case study is a visual browser for navigating large-scale online product catalogues.

Although the case studies have provided some useful evaluation, formal usability studies would be required to justify fully the effectiveness of these layout and navigation methods. Although this task has not carried out in this research, the author has presented his usability study's plan as a future work.

Terminology

- **A graph $G = \{V, E\}$:** is defined as a pair (V, E) , where V is a set of vertices, and E is a set of edges between the vertices $E = \{(u, v) \mid u, v \in V\}$.
- **A tree:** is a connected graph without a cycle.
- **A rooted tree:** consists of a tree $T(r)$ and a distinguished vertex r . The vertex r is called the root of T . In other words, T can be viewed as a directed acyclic graph with all edges oriented away from the root. If (μ, ν) is a directed edge in T , we then say μ is the father of ν , or ν is a child of μ . If T contains vertex ν , then the sub-tree $T(\nu)$ rooted at ν is the sub-graph induced by all vertices on paths originating from ν .
- **A leaf vertex:** is a vertex with no children.
- **A node:** represents a vertex with its displaying properties.
- **Weight $w(\nu)$:** represents the weight of vertex ν .
- **Wedge $wg(\nu)$:** is defined by a vertex μ , line l goes through μ , and a clockwise angle $\alpha(\nu)$; where μ is the father of ν . Thus, we have $wg(\nu) = \{\mu, l, \alpha(\nu)\}$ (see Figure 2.3).
- **Local region $R(\nu)$:** is an area which contains the drawing of a sub-tree $T(\nu)$.
 - At the Space-Optimised Tree model: $R(\nu)$ is a polygon that is defined by the wedge $wg(\nu)$ and one (or more) cutting edges (boundaries of other local regions) that cross the line l in $wg(\nu)$ (see Figure 2.4).
 - At the EncCon model: $R(\nu)$ is a rectangle.
- **Layered visualisation LV :** consists of two graphical layers L_1 and L_2 of the information that are appeared in an overlapped manner in the visualisation, $LV = L_1 + L_2$ (see Figure 3.8). Each layer is the medium for the drawing of graph G or a sub-graph $G_i \in G$. At any time, a graph G_i drawn in L_1 is always a sub-graph of G_j drawn in L_2 . Thus, we constantly have $G_i \in G_j \in G$.