Information Visualisation

Course Notes

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Preface

These lecture notes have evolved over many years of giving talks and teaching short courses on various aspects of information visualisation at conferences and for industry. I taught the first dedicated course on information visualisation at Graz University of Technology in summer semester 2005 and have also taught a version of the course at FH Joanneum in Graz.

I would like to thank my students and colleagues past and present for their many suggestions and corrections, which have helped to massage these notes into their current form.

References in Association with Amazon

References with an ISBN number are linked to amazon.com (or amazon.co.uk or amazon.de) for quick, discounted purchasing. Amazon pay me a small referral fee for each item you purchase after following such a link – the item itself does not cost you any more. If you find these notes useful and would like to contribute towards their maintenance, please purchase any book you might want *after* following a specific ISBN link from here.

Thanks and happy reading,

Keith

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Chapter 1

Introduction

" The purpose of computing is insight, not numbers. "

[Richard Hamming, Numerical Methods for Scientists and Engineers, 1962.]

Information visualisation (InfoVis) is the visual presentation of abstract information spaces and structures to facilitate their rapid assimilation and understanding.

Information Visualisation

- Visualisation of *abstract* information structures.
- InfoVis $\neq$ SciVis (Scientific Vis).
- In SciVis (sometimes also called DataVis), the visual representation is usually given, suggested by geoemtry inherent in the data.
- In InfoVis, an appropriate visual representation must be (carefully) designed or "invented".
- Appropriate navigational and manipulation facilities are provided.

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- IEEE Computer Graphics and Applications. `http://www.computer.org/cga/`
- IEEE Transactions on Visualization and Computer Graphics. `http://www.computer.org/tvcg/`

Conferences

- IEEE Symposium on Information Visualization (InfoVis). Since 1995. The main conference in the field, quite low acceptance rate (23% in 2006), very focussed, high quality papers, single-track. `http://conferences.computer.org/infovis/` Proceedings published with IEEE: `http://ieeexplore.ieee.org/` TODO

- Eurographics/IEEE Symposium on Visualization (EuroVis). Formerly VisSym. Fairly high quality. `http://eurovis2010.labri.fr/` Proceedings published with Eurographics: `http://www.eg.org/EG/DL/WS/VisSym`

- International Conference on Information Visualisation (IV). Since 1997, usually in London. Broad in scope, fairly high acceptance rate (57% in 2007), papers of mixed quality, multi-track. `http://www.graphicslink.co.uk/IV10/` Proceedings published with IEEE: `http://ieeexplore.ieee.org/servlet/opac?punumber=1000370`

- Some papers at CHI, AVI, UIST.

- Knowledge and Information Visualisation 2005 (KIV 2005), Graz, Austria. `http://www.i-know.at/KIV`

InfoVis Companies

Suppliers of infovis toolkits and components:

- Inxight `http://www.inxight.com/` (bought by BusinessObjects then SAP in 2007)

- Spotfire `http://spotfire.com/` (bought by Tibco in 2007).

- Tableau `http://www.tableausoftware.com/`

- The Hive Group `http://www.hivegroup.com/`

- Panopticon `http://www.panopticon.com/`

- macrofocus `http://macrofocus.com/`

- Maya Viz `http://www.mayaviz.com/`

- OmniViz `http://www.omniviz.com/`

- AVS `http://www.avs.com/`

- Visual Insights `http://www.visualinsights.com/`

- Oculus Info `http://www.oculusinfo.com/`

- Tom Sawyer Software `http://www.tomsawyer.com/`

- ILOG `http://www.ilog.com/`

1.2 General Principles of Information Visualisation

Utilising Human Visual Perception

Humans have remarkable perceptual abilities:

- to scan, recognise, and recall images rapidly.
- to rapidly and *automatically* detect patterns and changes in size, colour, shape, movement, or texture.

Text-based interfaces require cognitive effort to understand their information content.

Information visualisation seeks to present information visually, in essence to offload cognitive work to the human visual perception system.

Focus-plus-Context

Focus on areas of interest, while maintaining the surrounding context (but not in as much detail).

Examples of focus-plus-context techniques:

- **3d perspective**: naturally focuses on objects in the foreground, with the context in the background.
- **Fisheye views**: geometric distortion like a magnifying glass over the area of interest [Furnas, 1981, 1986].
- **Overview-plus-detail**: two separate, synchronised windows, an overview and a detail view.

The Information Visualisation Mantra

Ben Shneiderman's information visualisation mantra:

> "Overview, zoom and filter, details on demand"

Repeated ten times, once for each project where this principle was re-discovered...

From [Shneiderman, 1996].

Visualisation + Interaction

- Interaction support is just as important as underlying visual representation.
- Smoothly animate transitions over about 1 sec. – *object constancy* eliminates the need for re-assimilation of the scene [Robertson et al., 1991a].

Guaranteed Visibility

Landmarks in the visualisation which are important to the user's understanding remain visible at all times.

Types of Information

- **Linear**: Tables, program source code, alphabetical lists, chronologically ordered items, etc.
- **Hierarchies**: Tree structures.
- **Networks**: General graph structures, such as hypermedia node-link graphs, semantic networks, webs, etc.
- **Multidimensional**: Metadata attributes such as type, size, author, modification date, etc. Items with n attributes become points in n-dimensional space.
- **Feature Spaces**: From information retrieval (IR), a *feature vector* represents each object in a collection. For collections of text documents, word frequencies are used to construct a term vectors. The feature space is projected to two or three display dimensions.
- **Query Spaces**: objects laid out according to their affinity with particular (combinations of) query terms.
- **[Spatial]**: Inherently 2d or 3d data such as floor plans, maps, CAD models, etc. Since spatial information has an obvious natural rather than abstract representation, I do not consider it to be information visualisation in the strict sense.

Chapter 2

History of Information Visualisation

References

- ++ Kruja et al; *A Short Note on the History of Graph Drawing*; Proc. Graph Drawing (GD 2001). [Kruja et al., 2002]

Online Resources

- Pat Hanrahan; *To Draw a Tree*; InfoVis 2001 keynote talk, Oct. 2001 `http://graphics.stanford.edu/~hanrahan/talks/todrawatree/`

2.1 Diderot and d'Alembert

- Denis Diderot and Jean le Rond d'Alembert, 1751.
- A taxonomy of human knowledge, called the "Figurative System of Human Knowledge".
- Inspired by Francis Bacon's taxonomy from 1620 [Bacon, 1620].
- Also known as "The tree of Diderot and d'Alembert" [Diderot and le Rond d'Alembert, 1751b].
- The top three branches are Memory, Reason, and Imagination.

Figurative System of Human Knowledge (1751)

- Produced as the table of contents for the "Encyclopedia, or a systematic dictionary of the sciences, arts, and crafts" published in 1751 [Diderot and le Rond d'Alembert, 1751a].
- Shown in Figure 2.1.

2.2 Edmund Cooper and John Snow

London Cholera Map (1854)

- In Sep 1854, a cholera epidemic hit the Golden Square area of London around Broad Street (St. James' parish).

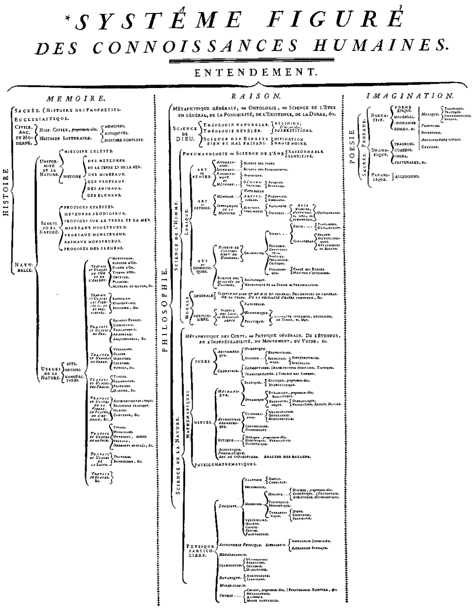

Figure 2.1: The tree of Diderot and d'Alembert. [Image from Wikimedia Commons [Diderot and le Rond d'Alembert, 1751c]]

- The first spot map of cholera deaths is usually attributed to Dr. John Snow, 1854, [Frerichs, 2009], but in fact an earlier spot map was drawn by Edmund Cooper and presented on 26 Sept 1854, some 3 months earlier [Brody et al., 2000].
- Edmund Cooper was an engineer at the Metropolitan Commission of Sewers. Public complaints had linked the sewers to the cholera outbreak.
- Cooper plotted cholera deaths at addresses on a spot map, and used the map as an analytical tool to deduce that addresses near sewer holes did not exhibit higher numbers of deaths.
- Upto this time, cholera was thought to be an airborne disease, although Snow himself had long postulated a waterborne link.
- In popular retellings, such as Tufte [1997b, pages 27–37] and Henig [1996, pages 1–2], Snow *first* plotted the deaths on a spot map (see Figure 2.2), and then used the map to discover a higher clustering of deaths around the Broad Street water pump. The handle on the Broad Street pump was removed, and the epidemic subsided.
- In fact, as recounted in Brody et al. [2000], Snow first presented a spot map on 04 Dec 1854, almost 3 months *after* the outbreak.
- Snow's map was not used as an analytical tool, but rather as an illustration after the event, to illustrate his finding that cholera was a waterborne disease.
- Workers in the nearby brewery, which had its own water (and beer) supply, were largely unaffected.
- Not really infovis, more geovis, since it is based on an underlying map.

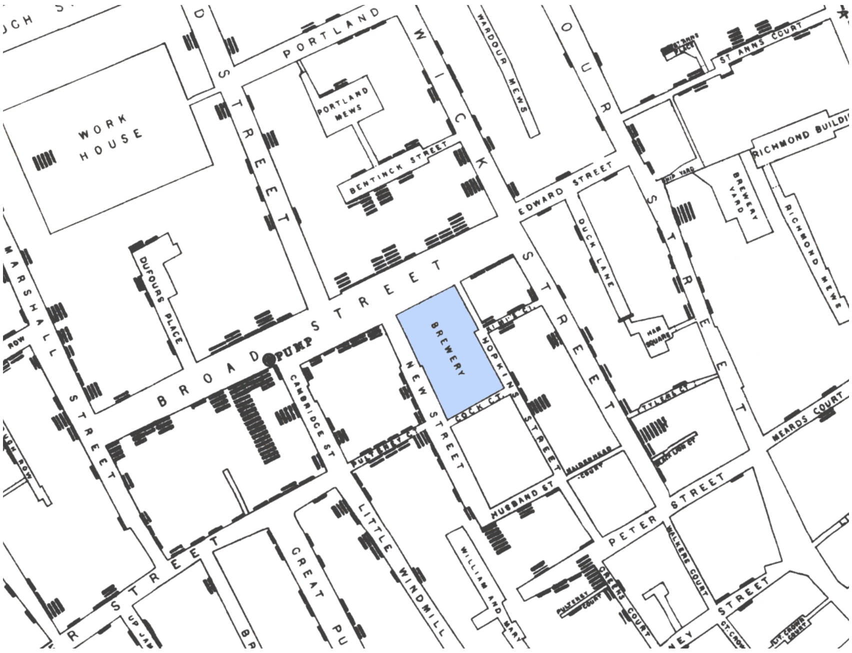

Figure 2.2: Snow's London cholera map.

2.3 Florence Nightingale

- Famous British nurse and statistician.
- She used a number of statistical graphics to illustrate her data and support her argument for health care reform [Small, 1998].

Bat's Wing Diagram (1858)

- Shows changes over time for a small number of variables.
- In this case, the number of deaths from three different causes over a 12-month period.
- The time points are shown by 12 equally spaced radial lines (one for each nonth).
- The length of the radial line is proportional to the number of deaths.

Wedge Diagram (1858)

- Florence Nightingale, 1858.
- I will use the name wedge diagrams following Small [1998].
- Sometimes called polar area diagrams.
- Sometimes *incorrectly* referred to as coxcomb diagrams [Small, 1998].

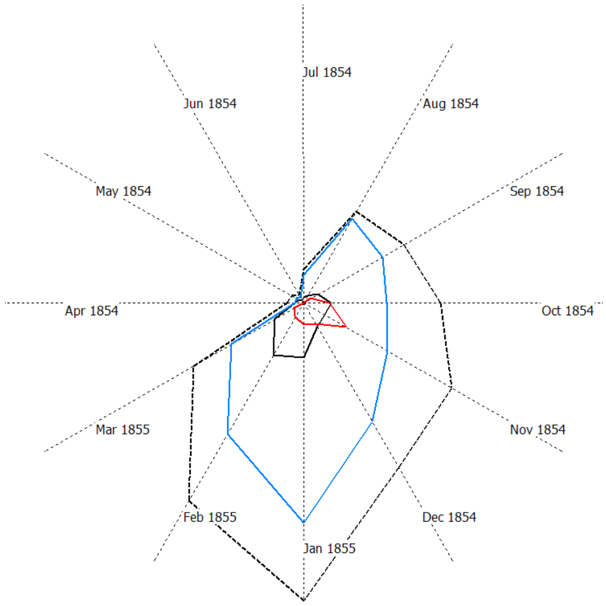

Figure 2.3: Bat's Wing Diagram.

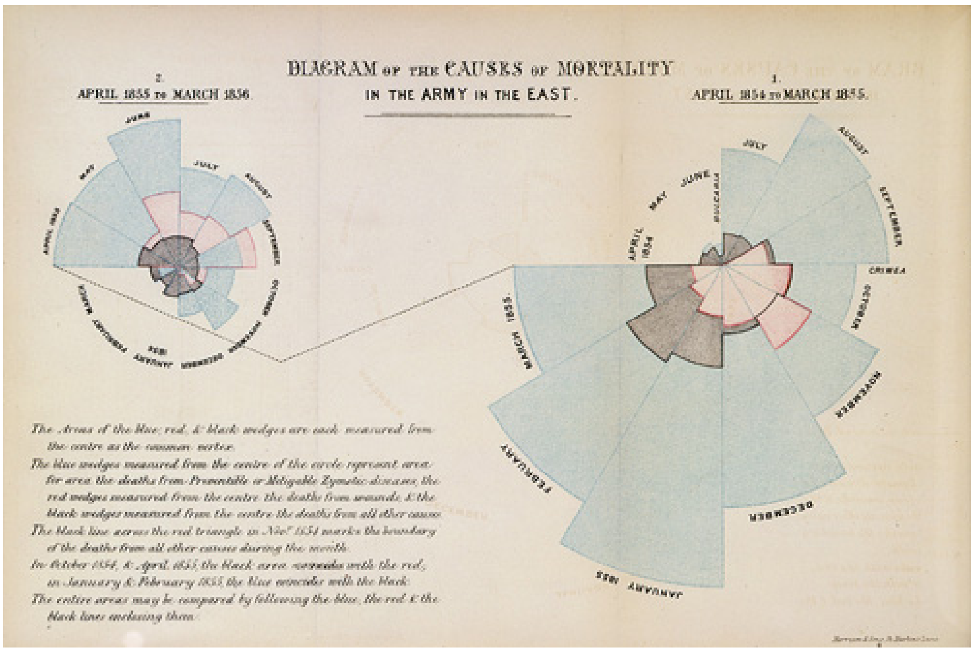

Figure 2.4: Florence Nightingale's original polar area diagram. [Image from Wikimedia Commons [Nightingale, 1858]]

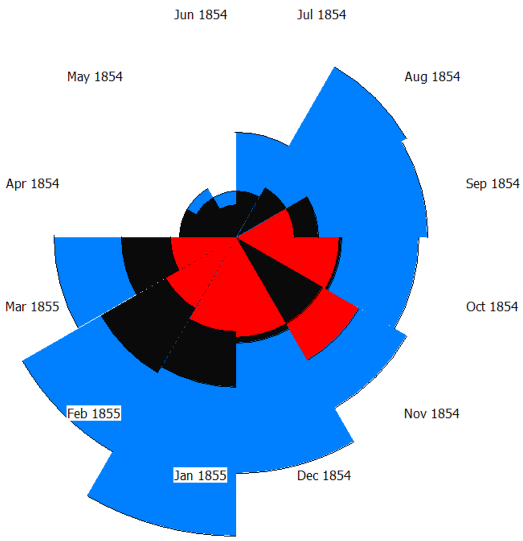

Figure 2.5: Polar Area Diagram.

2.4 Charles Minard

Diagram of Napoleon's Russian Campaign (1861)

- Charles Joseph Minard, 1861.

2.5 Jaques Bertin

Reorderable Matrix

- Jaques Bertin created a physical device for reordering matrices called Domino, see Figure 2.7.
- It is decribed in more detail by Henry [2008, page 78].

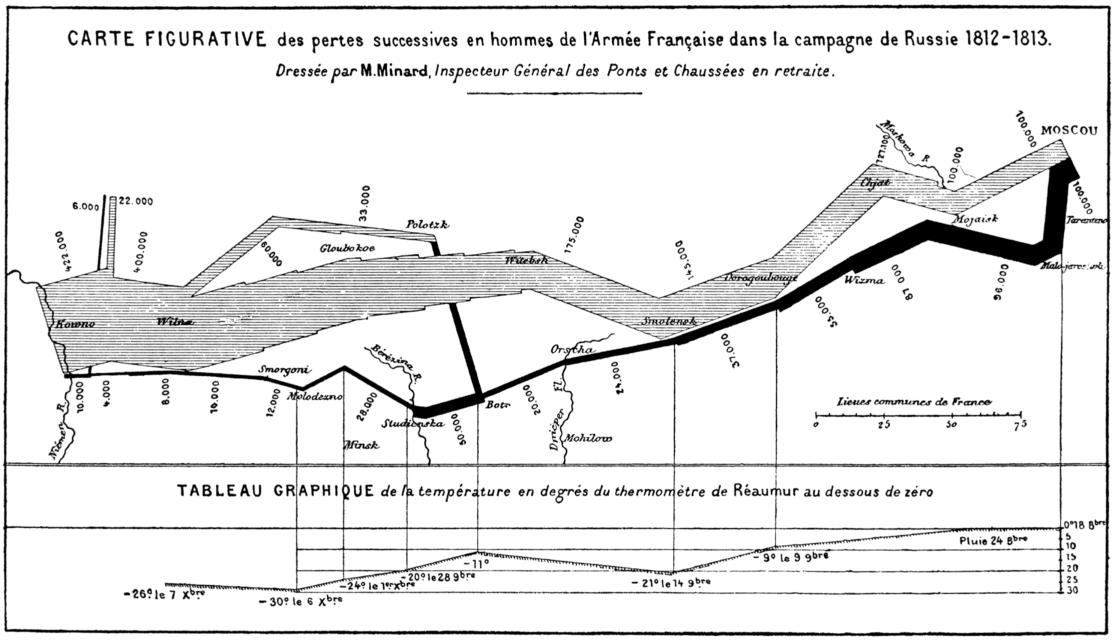

Figure 2.6: Minard's Map

Figure 2.7: Bertin's reorderable matrix. [Photograph used with kind permission of Jean-Daniel Fekete.]

Chapter 3

Visualising Linear Structures

Linearly structured information:

- alphabetical lists
- program source files
- chronological lists
- ranked search results

3.1 Perspective Wall

- Xerox PARC, 1990.
- 3d perspective technique for linear information.
- Focus on the front panel and context in the side panels.
- CHI'91 paper [Mackinlay et al., 1991] and video [Robertson et al., 1991b].
- US Patent 5339390 [Robertson et al., 1994b].

3.2 Seesoft

- AT&T Bell Labs, 1992.
- Focus + context technique for large amounts of source code.
- Lines of code are compressed down to rows of pixels. See Figure 3.2.
- Like hanging program listings on a wall several metres away.
- Zooming window supports several levels of zoom, from overview to lines of code.
- Articles [Eick et al., 1992; Ball and Eick, 1996] and InterCHI'93 video [Steffen and Eick, 1993].
- US Patent 5644692 [Eick, 1997].

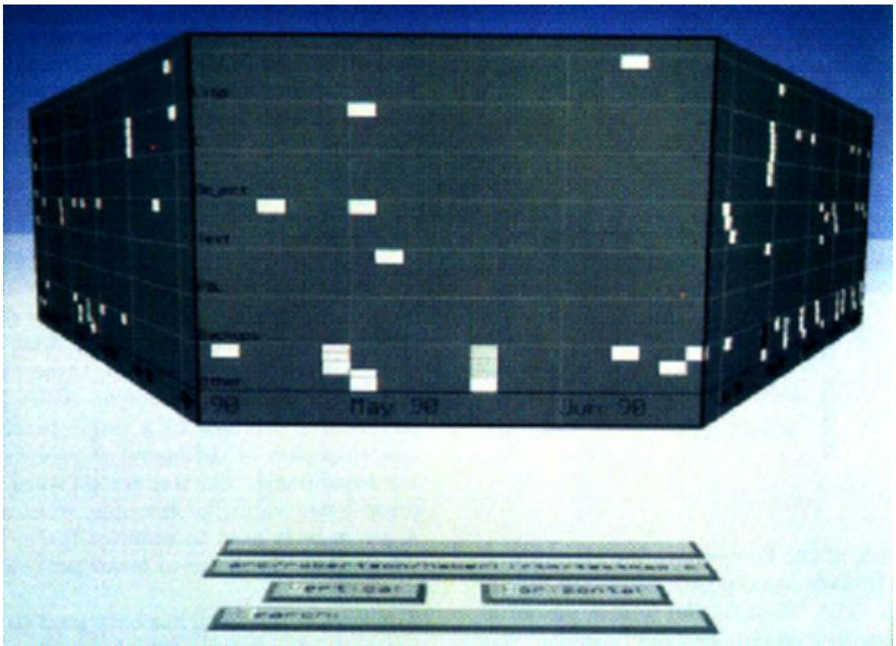

Figure 3.1: The perspective wall spreads linearly structured information across a wall from left to right. 3d perspective provides focus on the central segment of interest. [Copyright © by the Association for Computing Machinery, Inc.]

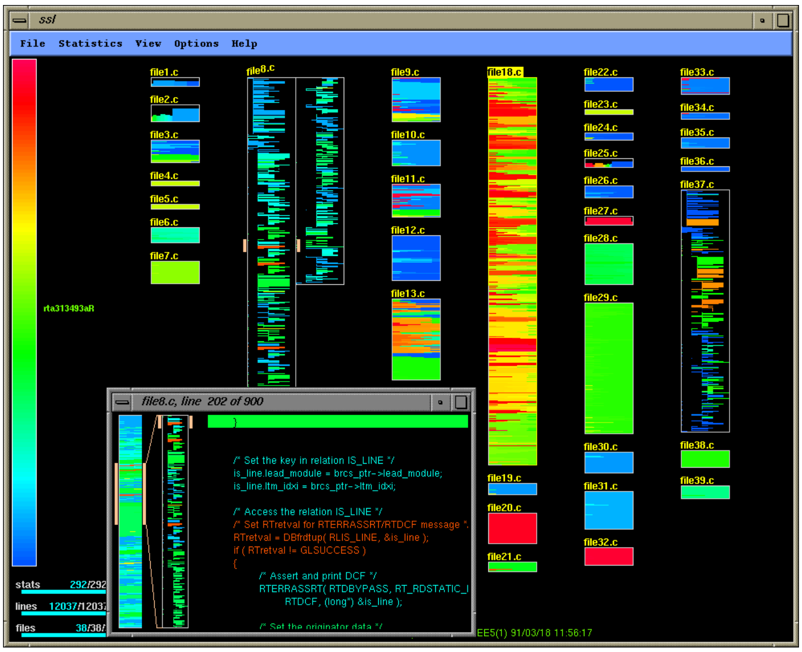

Figure 3.2: Seesoft visualising software consisting of 38 files comprising 12037 lines of code. The newest lines are shown in red, the oldest in blue, with a rainbow colour scale in between. [Image used with kind permission of Steve Eick, Visual Insights.]

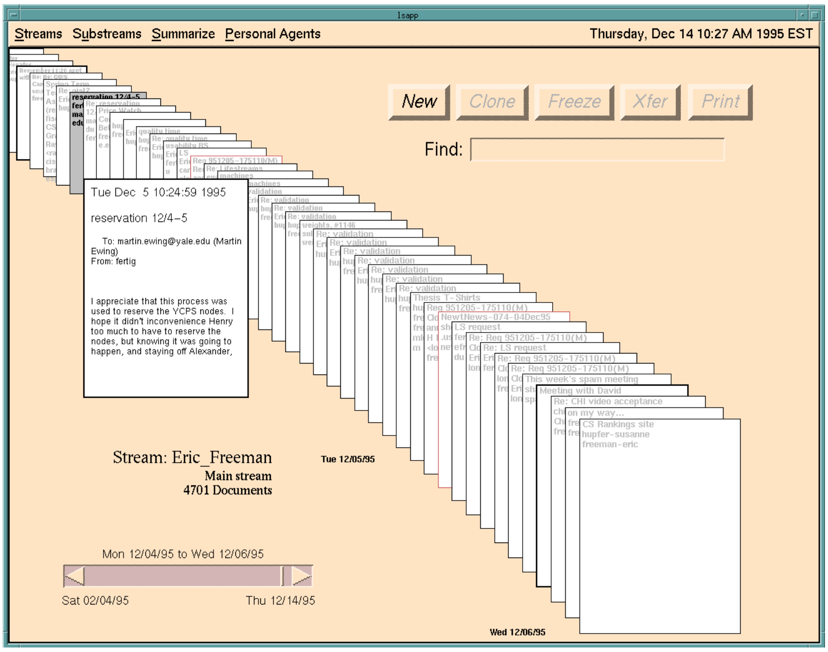

Figure 3.3: Lifestreams orders streams of item chronologically. It is possible to filter items into substreams. [Copyright © by the Association for Computing Machinery, Inc.]

3.3 Lifestreams

- Yale University, 1995.
- Streams of chronologically ordered items.
- AAAI 1995 paper [Freeman and Fertig, 1995], CHI'96 video [Fertig et al., 1996], Wired article [Steinberg, 1997].

3.4 Spiral of Ranked Items

- A spiral is a compact way of displaying a list of ranked items.
- GopherVR used a spiral to display search results. See Figure 3.4.
- 1994 draft version of paper for ED-MEDIA 95 [McCahill and Erickson, 1994].

JUCS Spiral of Authors

- Journal of Universal Computer Science (JUCS), Graz University of Technology, 2009.
- High-profile authors in a sub-field of computer science are visulaised in a spiral (in decreasing order of number of publications in that sub-field). See Figure 3.5.
- FIT 2009 paper [Afzal et al., 2009].

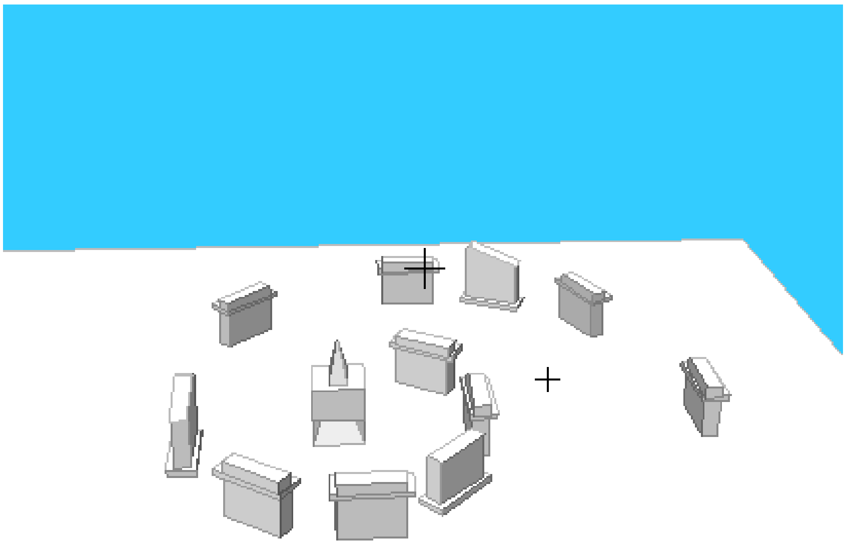

Figure 3.4: GopherVR spiral of search results. [Image used with kind permission of Tom Erickson]

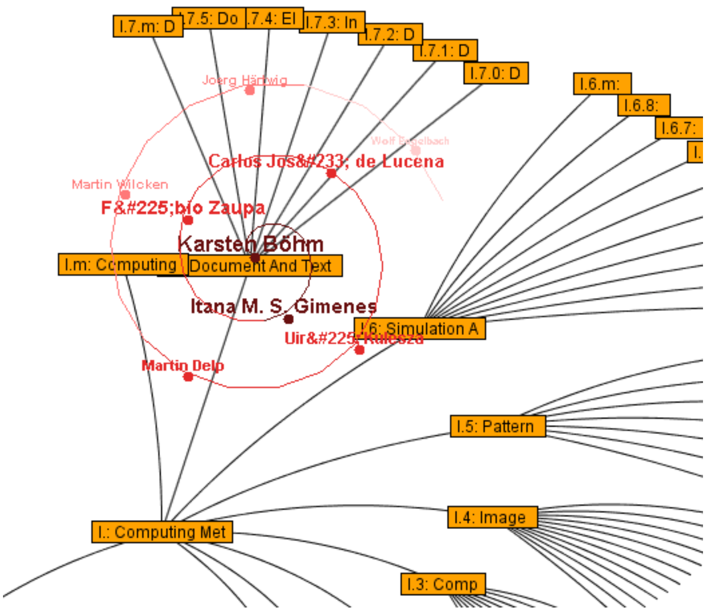

Figure 3.5: JUCS spiral of authors.

Chapter 4

Visualising Hierarchies

> *" The organization of ideas and objects into categories and subcategories is fundamental to human experience. We classify to understand. Tree structures lie at the roots of our consciousness. "*
>
> [Peter Morville, Ambient Findability, page 127, Sept. 2005.]

Hierarchies are extremely common:

- file systems
- library classification systems
- family trees

Many general graphs (networks) can also be transformed to a tree plus backlinks.

4.1 Outliners

4.1.1 Tree Views

- Tree view on left shows structure, list view on right shows items (files, documents) at a particular level.
- Windows Explorer.
- Java Swing JTree component (see Figure 4.1).
- Harmony Collection Browser [Andrews, 1996].

4.1.2 MagTree

- Andy Clark and Dave Smith, IBM, Jan 2001.
- File Magnitude Viewer (MagTree).
- Part of a tutorial on Java tree views [Smith and Clark, 2001].

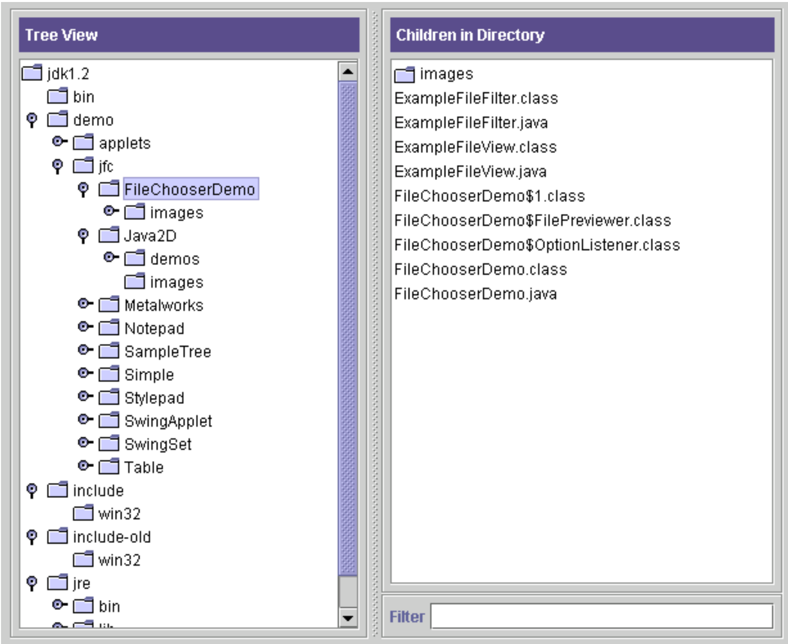

Figure 4.1: The Java Swing JTree tree view component. A view of directories on the left and their contents on the right.

- Extends traditional tree view with preview of size statistics.
- Coloured pie indicates proportion of bytes in each subdirectory.
- Sizes are either relative to the root or relative to the parent.

4.1.3 WebTOC

- David Nation, Department of Defense and HCIL, 1997.
- Generates tree view of web site.
- Extends traditional tree view by overlaying supplementary statistical information.
- Coloured bars indicate proportion of various media types, shadows indicate number of files.
- HFweb 1997 paper [Nation et al., 1997] and CHI'98 video [Nation, 1998].

4.2 Layered Node-Link Tree Browsers

4.2.1 Walker Layout

- Walker [1990], improved by Buchheim et al. [2002].
- Drawing trees of unbounded degree in linear time.
- The root is at the top, children on successive layers beneath.

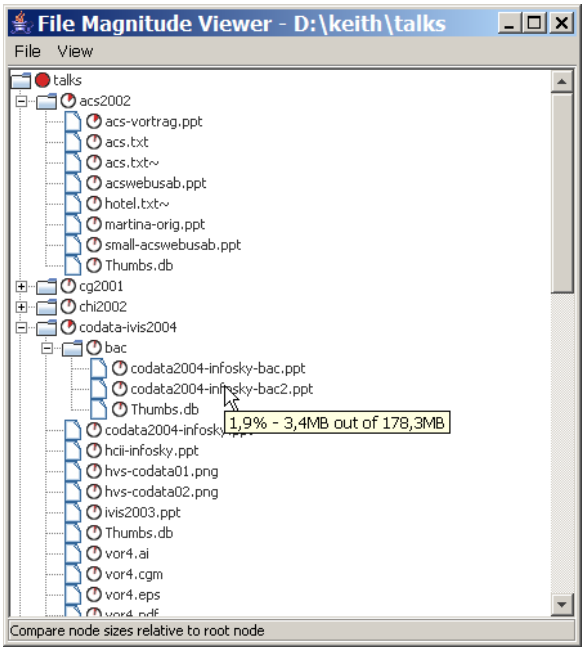

Figure 4.2: MagTree showing part of a file system hierarchy. Here, the sizes are all relative to the root.

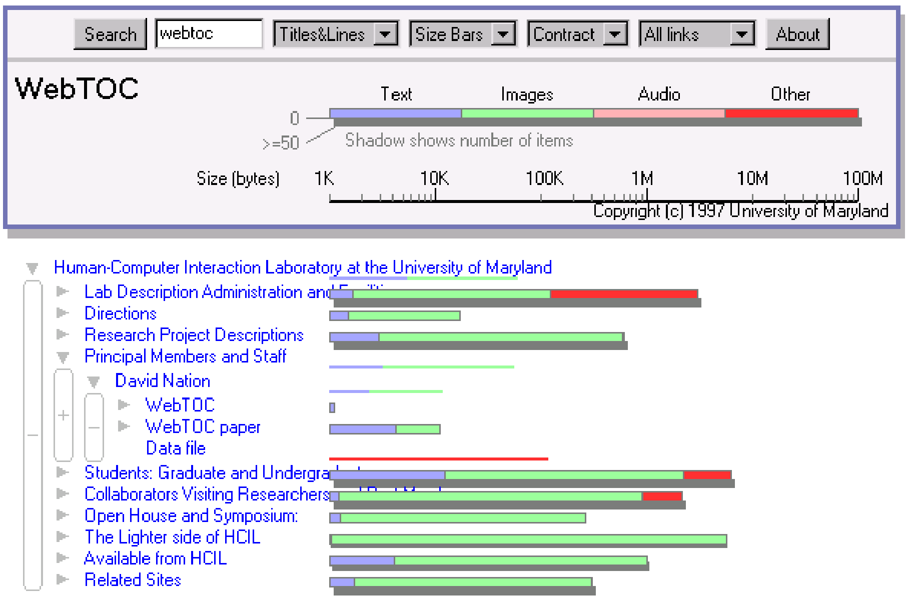

Figure 4.3: A WebTOC table of contents for the University of Maryland's HCI Lab web site.

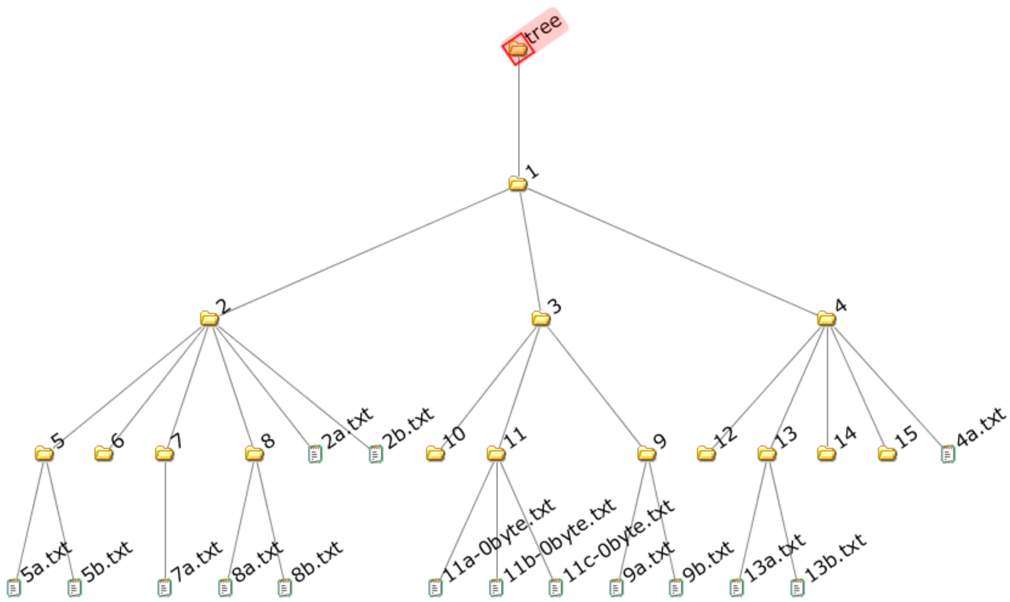

Figure 4.4: The Walker tree browser.

- The layout progresses bottom-up, allocating the same amount of space to each leaf node. See Figure 4.4.

4.2.2 File System Navigator (FSN)

- SGI, 1992.
- 3d landscape visualisation of file system.
- Files sit atop pedestals, subdirectories recede into the background. See Figure 4.5.
- Featured in Jurassic Park.
- Used in MineSet product to visualise decision trees.
- Software (binaries) available online [Tesler and Strasnick, 1992].
- Patented under [Strasnick and Tesler, 1996a,b].

4.2.3 Harmony Information Landscape

- IICM, 1994–1995.
- 3d landscape visualisation of Hyperwave collection structures. See Figure 4.6.
- Similar to FSN, documents sit atop pedestals, subcollections recede into the background.
- Paper at IEEE InfoVis'95 (reprinted in [Card et al., 1999]), [Andrews, 1996].

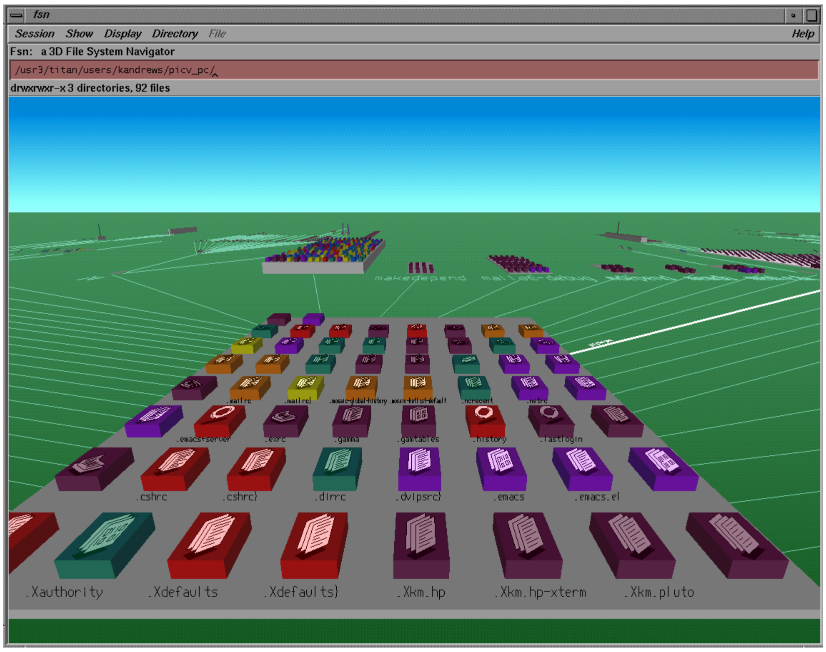

Figure 4.5: FSN landscape visualisation of a file system hierarchy. Files sit atop pedestals, subdirectories recede into the background.

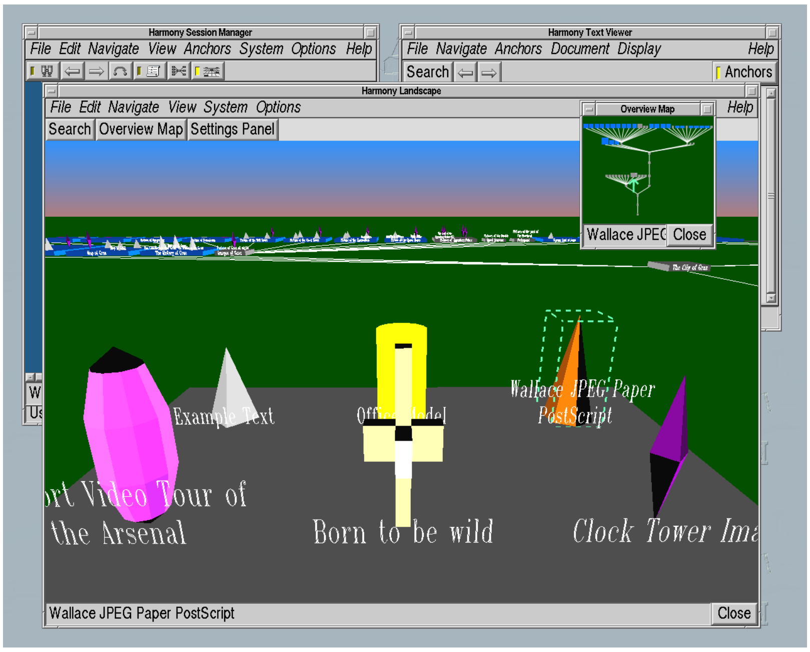

Figure 4.6: The Harmony Information Landscape visualises Hyperwave collection structures.

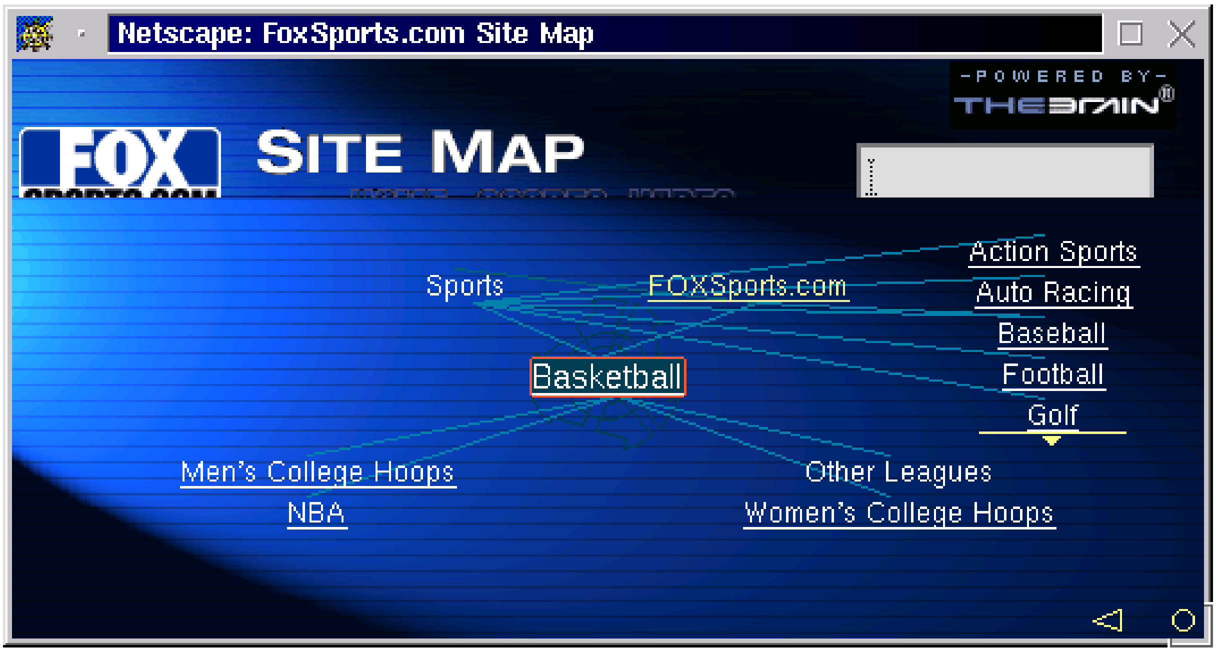

Figure 4.7: The Brain.

4.3 Radial Node-Link Tree Browsers

4.3.1 The Brain

- Harlan, 1996.
- Radial layout of web site structure. See Figure 4.7.
- Web site `http://thebrain.com/`
- Patented under [Harlan, 2000a,b].

4.3.2 Hyperbolic Browser

- Xerox PARC, 1994–1995.
- Focus+context technique, always displaying the entire hierarchy. See Figure 4.8.
- Layout on a hyperbolic plane, which is then mapped to the unit disc. Each child places its children in a wedge of space.
- Now sold as a software component by Inxight `http://www.inxight.com`, an offshoot of Xerox.
- Papers at UIST'94 and CHI'95 [Lamping and Rao, 1994; Lamping et al., 1995].
- Video at CHI'96 [Lamping and Rao, 1996].
- Patented under [Lamping and Rao, 1997].
- Won the CHI'97 Great Browse Off !

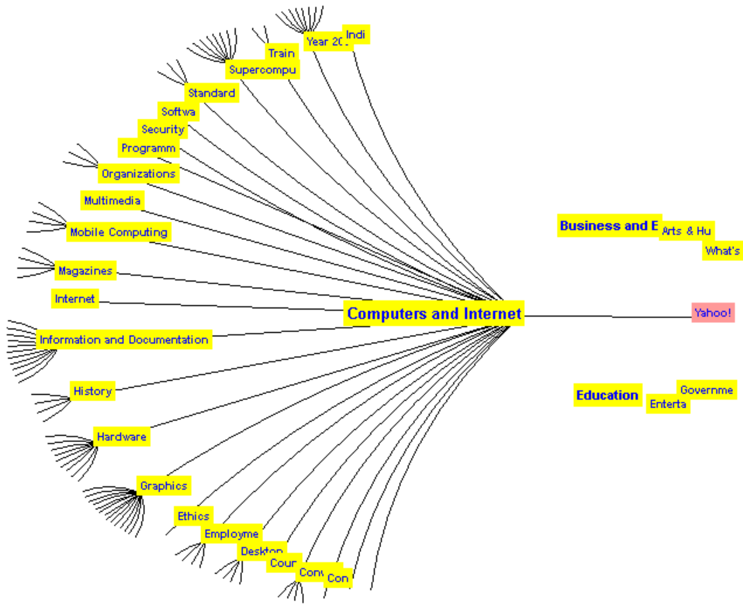

Figure 4.8: The hyperbolic browser always displays the entire hierarchy. However, subtrees around the edge of the disk become so small they are invisible. Here we see the top levels of the Yahoo hierarchy.

4.3.3 3D Hyperbolic Browser

- Tamara Munzner, University of Minnesota and Stanford University.
- 3D hyperbolic browser. See Figure 4.9.
- For web sites, spanning tree is generated and laid out, cross-links are displayed on request.
- Paper at VRML'95 [Munzner and Burchard, 1995] and InfoVis '97 [Munzner, 1997].

4.3.4 Walrus

- Young Hyun, CAIDA, 2002.
- 3D hyperbolic browser, homegrown implementation of Tamara Munzner's algorithms. See Figure 4.10.
- Paper in BMC Bioinformatics Journal 2004 [Hughes et al., 2004], web site [Hyun, 2005].

4.3.5 SInVis Magic Eye View

- Institute of Computer Graphics, University of Rostock, 1999–2001.
- The hierarchy is first laid out in 2d space according to the classic Reingold [Reingold and Tilford, 1981] or Walker [Buchheim et al., 2002] algorithm.
- It is then mapped geometrically onto the surface of a hemisphere. See Figure 4.11.

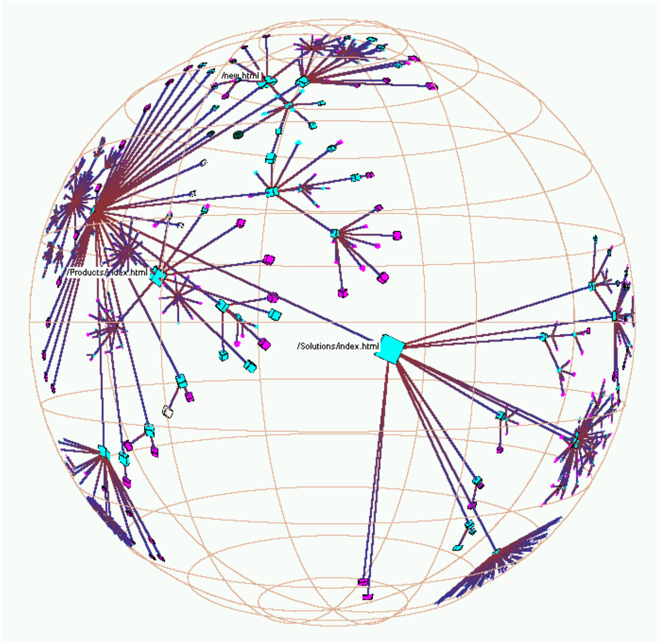

Figure 4.9: The H3 3d hyperbolic browser.

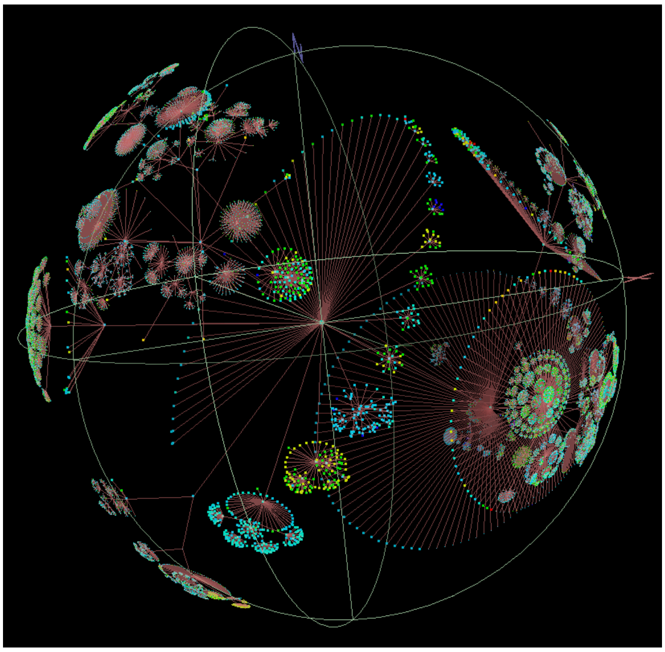

Figure 4.10: The Walrus 3d hyperbolic browser displaying a directory tree. [Image used with kind permission of Young Hyun, CAIDA.]

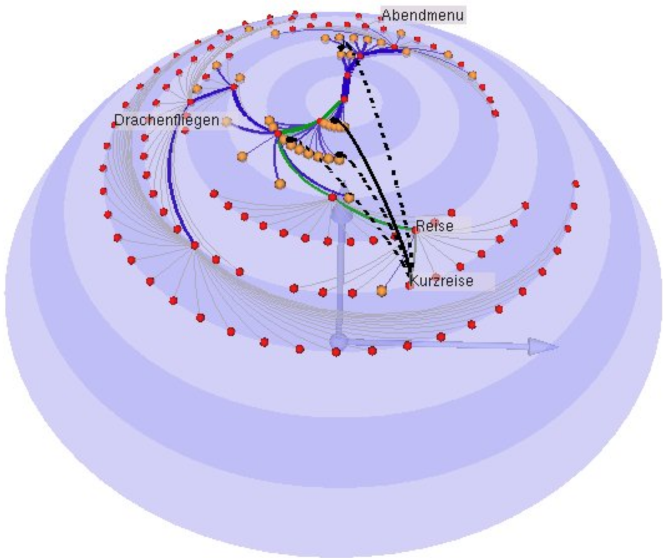

Figure 4.11: The SInVis Magic Eye View. [Image used with kind permission of Matthias Kreuseler, University of Rostock.]

- Smooth animated transitions are possible.
- The effect is similar to a hyperbolic browser, but hyperbolic geometry is not used.
- Masters Thesis (in German) in 1999 [Burger, 1999], papers at NPIV'99 [Kreuseler and Schumann, 1999] and IEEE InfoVis 2000 [Kreuseler et al., 2000].

4.3.6 Cone Tree

- Xerox PARC, 1990.
- 3d conical representation of tree. See Figure 4.12.
- A horizontal layout (cam tree) allows better labeling of nodes.
- CHI'91 paper [Robertson et al., 1991a] and video [Robertson et al., 1991b].
- Patented under [Robertson et al., 1994a].

4.3.7 Botanical Visualisation

- Eindhoven University of Technology, 2001.
- An abstract tree is converted into a geometric model of branches and leaves and then rendered.
- For beter aesthetics, continuing branches are emphasised, long branches are contracted, and leaves are shown as fruit.
- Paper at InfoVis 2001 [Kleiberg et al., 2001].

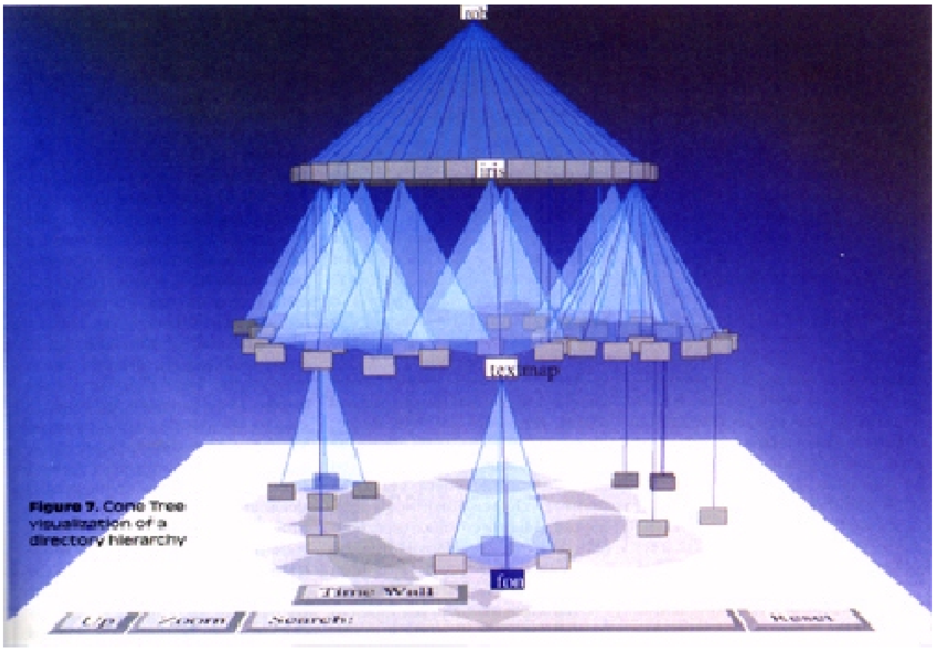

Figure 4.12: The cone tree is a 3d conical representation of a hierarchy. [Copyright © by the Association for Computing Machinery, Inc.]

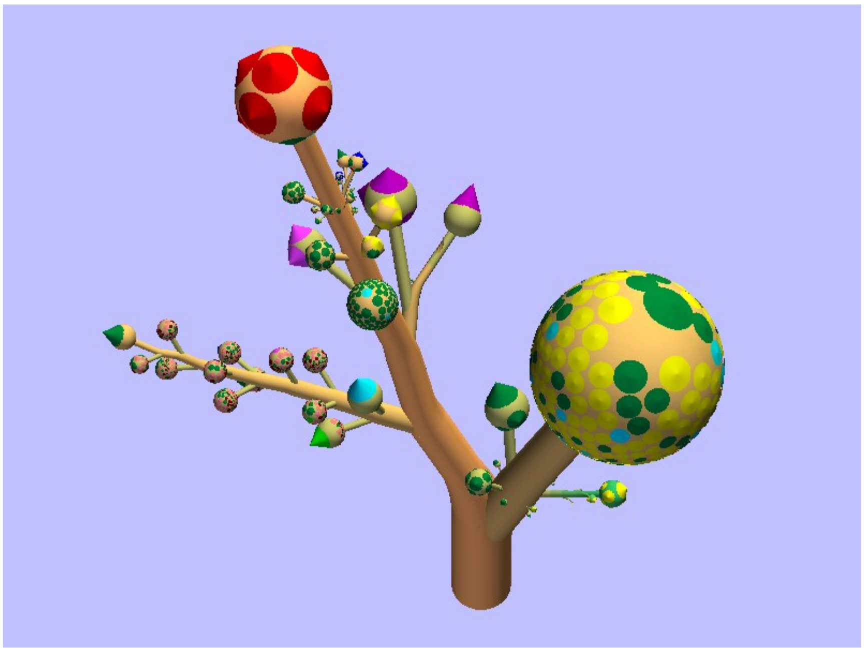

Figure 4.13: Botanical visualisation of a hierarchy. [Image used with kind permission of Jack van Wijk, Eindhoven University of Technology.]

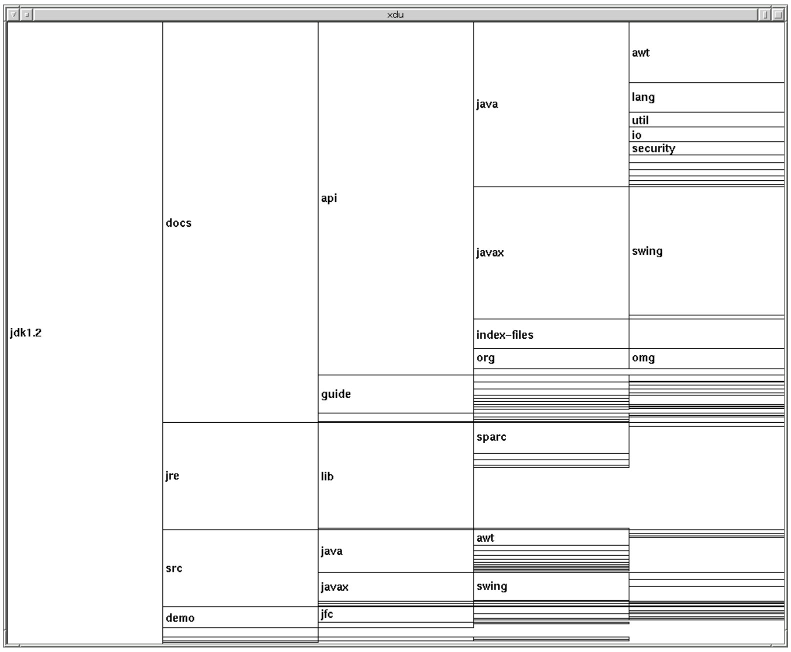

Figure 4.14: An xdu visualisation of the Java JDK 1.2 distribution.

4.4 Layered Space-Filling Tree Browsers

4.4.1 Xdu

- Phil Dykstra, Army Research Laboratory, 1991.
- Utility for the X window system which displays a graphical disk usage for Unix file systems.
- Rectangles are stacked from left to right as the directory tree is descended.
- The vertical space allocated is proportional to size of each subdirectory.
- Software (source) available online [Dykstra, 1991].

4.5 Radial Space-Filling Tree Browsers

4.5.1 Information Slices

- IICM, 1998–1999.
- The hierarchy is fanned out across one or more semi-circular discs. See Figure 4.15.
- The number of levels displayed on each disc can be changed interactively, 4 or 5 works well.
- The area of each segment is proportional to the total size of its contents.
- Clicking on a directory in the left disc fans out its contents in the right disc, allowing rapid exploration of large hierarchies.

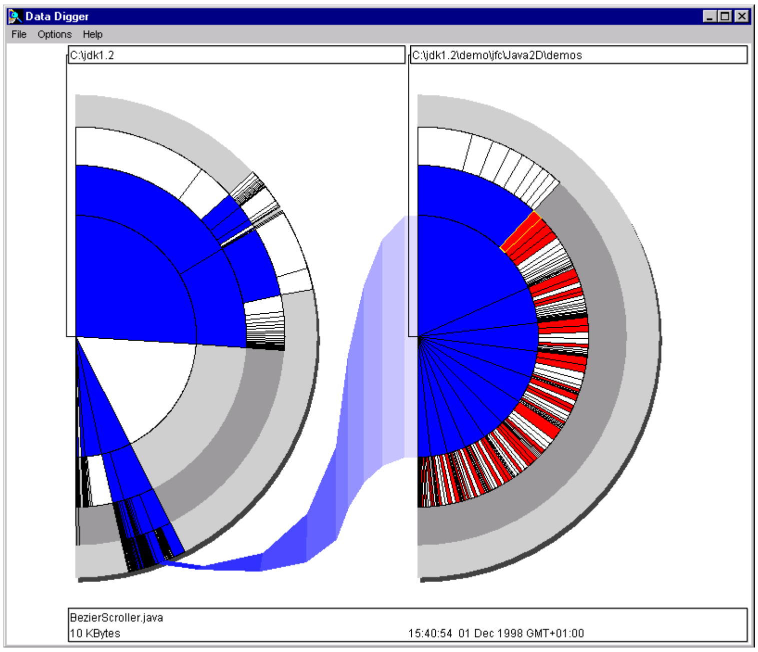

Figure 4.15: An Information Slices visualisation of the JDK 1.2 tree. For deeper hierarchies discs are stacked up in the left margin.

- For very deep hierarchies, clicking on a directory in the right disc causes the left disc to be miniaturised and slide off to the left (to join a stack of miniature discs), and a fresh disc is opened to the right.
- Late Breaking Hot Topic Paper at IEEE InfoVis'98 [Andrews and Heidegger, 1998] and IEEE CG&A July/Aug. 1998 [Andrews, 1998].

4.5.2 SunBurst

- John Stasko et al, GVU, Georgia Tech, 1999-2000.
- Much more advanced version of InfoSlices. See Figure 4.16.
- Uses full disc and implements fan-out of subtrees.
- Papers at IEEE InfoVis 2000 [Stasko and Zhang, 2000a] and International Journal of Human-Computer Studies [Stasko et al., 2000].
- Video at InfoVis 2000 [Stasko and Zhang, 2000b].

4.6 Inclusive Space-Filling Tree Browsers

4.6.1 Tree Maps

- HCIL, University of Maryland, 1991–1993.
- Screen-filling visualisation by alternate vertical and horizontal slicing of available space ("Slice and Dice"), as shown in Figure 4.17.

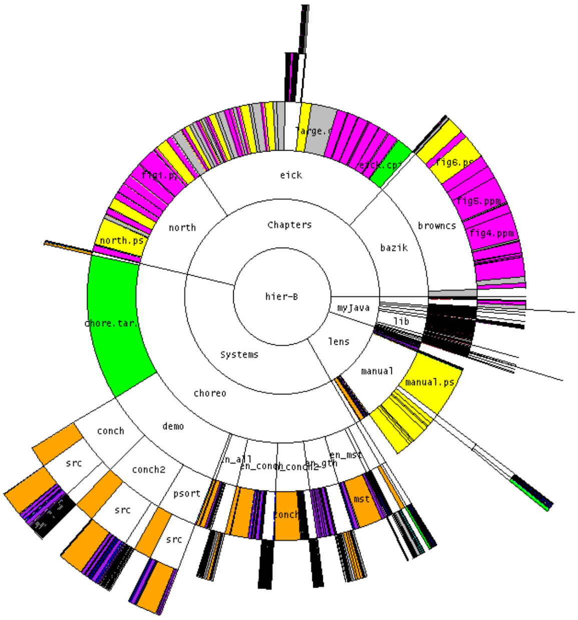

Figure 4.16: The SunBurst directory visualiser. [Image used with kind permission of John Stasko, Georgia Tech.]

- The size of each rectangle is proportional to its *weight*, typically the total number or size of items within it.
- Child rectangles can be ordered (say alphabetically) within their parent rectangle, but rectangles can degenerate to very narrow strips.
- Visualization'91 paper [Johnson and Shneiderman, 1991] and CHI'94 video [Turo, 1994].
- Software at `http://www.cs.umd.edu/hcil/treemap3/`.

4.6.2 Market Map

- Martin Wattenberg, SmartMoney, 1999.
- Extension of tree map, avoiding the excessively narrow strips produced by Slice and Dice. See Figure 4.18.
- Uses heuristics to slice up each rectangle into more evenly proportioned sub-rectangles ("Squarified").
- Squarified tree maps look better and sub-rectangles are more easily compared in size, but at the cost of no ordering of child rectangles within the parent rectangle.
- CHI 99 late breaking paper [Wattenberg, 1999], InfoVis 2001 paper [Shneiderman and Wattenberg, 2001].

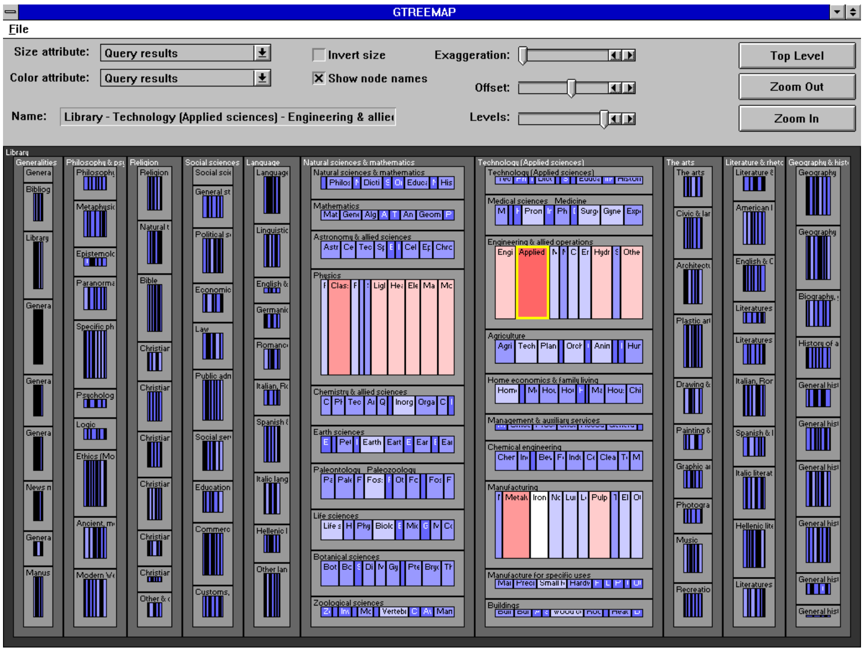

Figure 4.17: A tree map of the Dewey Decimal classification hierarchy widely used in libraries. Copyright ©University of Maryland 1984-1994, all rights reserved.

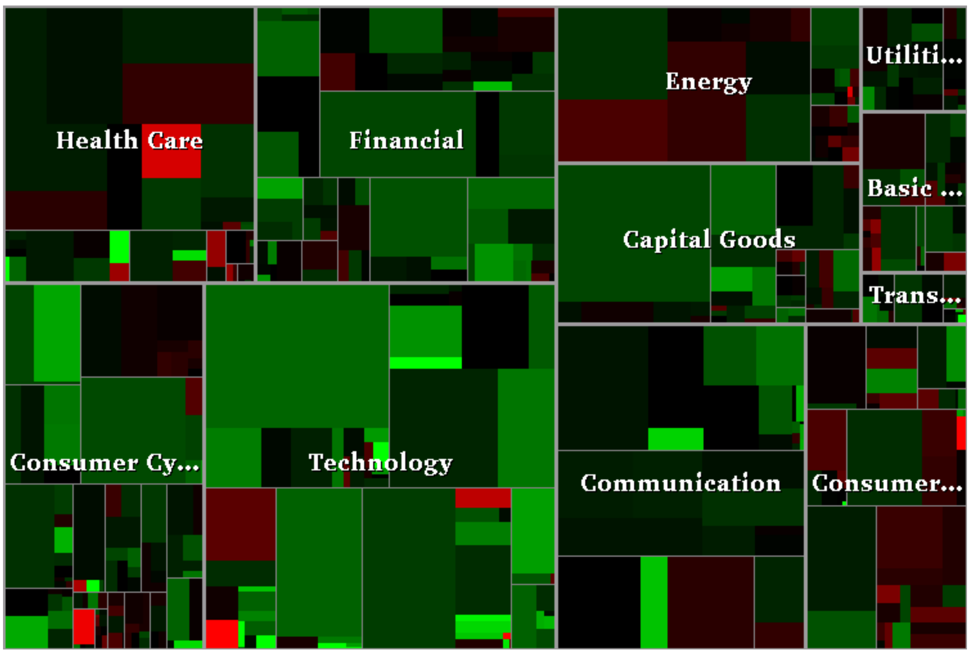

Figure 4.18: A market map of US stocks generated on 17th September 1999.

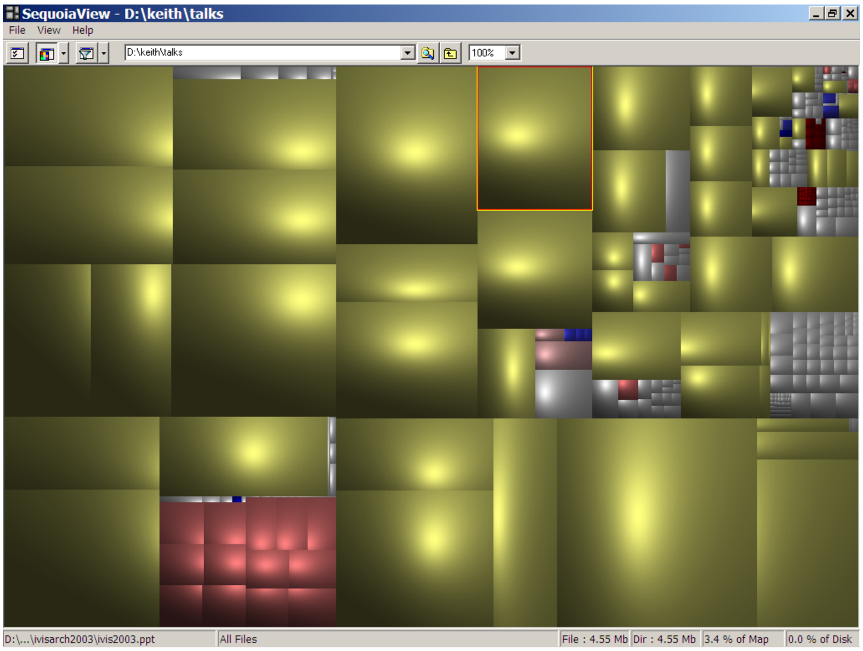

Figure 4.19: SequoiaView produces disk usage maps using squarified cushion treemaps.

4.6.3 Cushion Treemaps

- Cushion treemaps: Three-dimensional shading is used to indicate the borders between treemap regions. See Figure 4.19.
- This means that borders between regions can be eliminated and more pixels used to visualise information.
- Software package called SequoiaView produces disk usage maps using squarified cushion treemaps [SequoiaView, 2005].
- More recently, clones of SequoiaView have appeared for various platforms: KDirStat for Unix/X11 [Hundhammer, 2010], WinDirStat for Windows [Seifert and Schneider, 2010], and Disc Inventory X for Mac [Derlien, 2010].
- InfoVis'99 paper [van Wijk and van de Wetering, 1999], VisSym 2000 paper [Bruls et al., 2000].

4.6.4 Information Pyramids

- IICM, 1997–2001.
- A plateau represents the root of the tree. Other, smaller plateaux arranged on top of it represent its subtrees. See Figure 4.20.
- The size of each block is, by default, proportional to the total size of its contents.
- Separate icons are used to represent non-subtree members of a node such as files or documents.
- The overall impression is that of pyramids growing upwards as the hierarchy is descended.
- The current version combines a pyramids display with a Java tree viewer. See Figure 4.21.

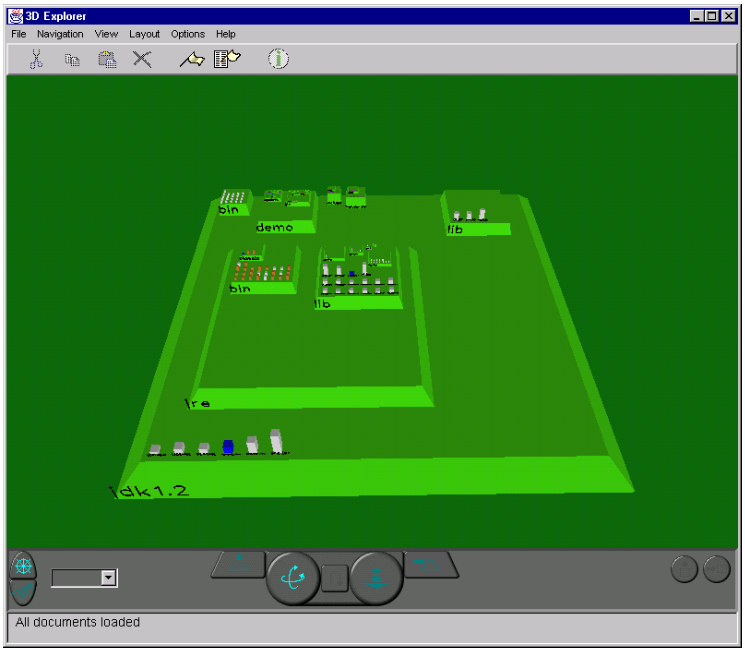

Figure 4.20: An Information Pyramids visualisation of the JDK 1.2 tree. The view from above gives a graphical disk usage. The dashboard provides user navigation. This version uses OpenGL for 3d output.

- Late Breaking Hot Topics Proc., IEEE Visualization'97 [Andrews et al., 1997] and IEEE CG&A July/Aug. 1998 [Andrews, 1998], IV'02 [Andrews, 2002].

4.6.5 InfoSky Cobweb Browser

- The InfoSky cobweb browser uses space-filling, recursive Voronoi subdivision to allocate available space to child polygons. See Figures 4.22 and 4.23.
- Paper in journal [Andrews et al., 2002] and at InfoVis 2004 [Granitzer et al., 2004].
- Video and demo application at [Graz, 2006].

4.6.6 Voronoi Treemap

- Like the InfoSky Cobweb, uses space-filling, recursive voronoi subdivision to allocate available space to child polygons. See Figure 4.24.
- Papers at SoftVis 2005 [Balzer et al., 2005] and InfoVis 2005 [Balzer and Deussen, 2005a].
- Video at [Balzer and Deussen, 2005b].

4.7 Overlapping Space-Filling Tree Browsers

4.7.1 Cheops

- Centre du recherche Informatique de Montréal, 1996.

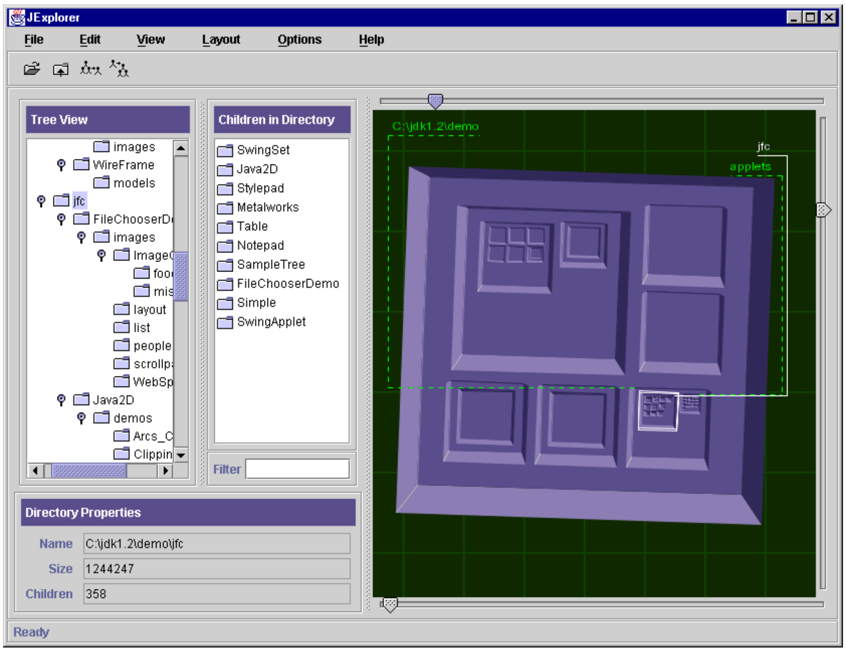

Figure 4.21: The JExplorer combines a Java tree viewer with a synchronised Information Pyramids display.

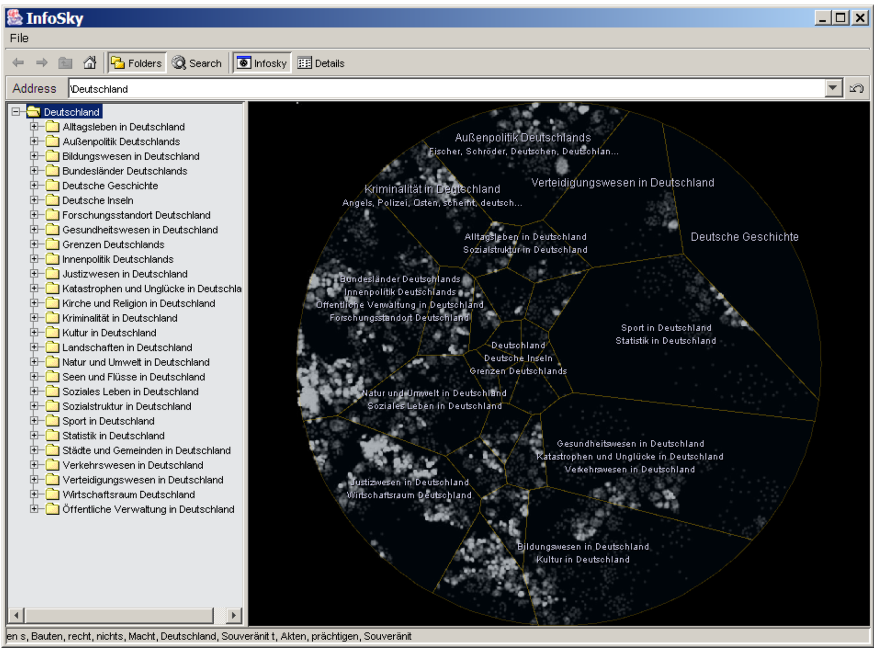

Figure 4.22: The InfoSky Cobweb hierarchy browser.

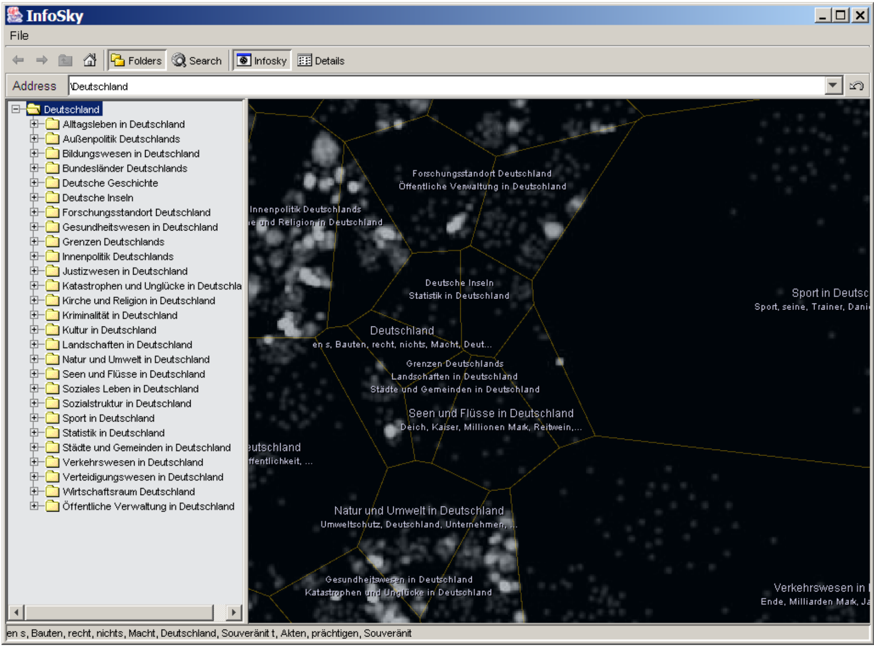

Figure 4.23: The InfoSky Cobweb hierarchy browser, zoomed in for a closer look.

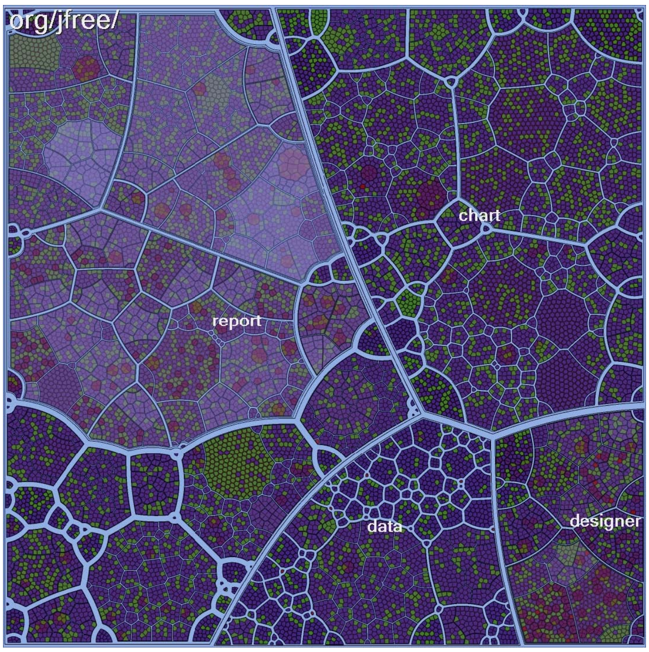

Figure 4.24: The Voronoi Treemap also uses recursive voronoi subdivision. [Image extracted from [Balzer et al., 2005], Copyright © by the Association for Computing Machinery, Inc.]

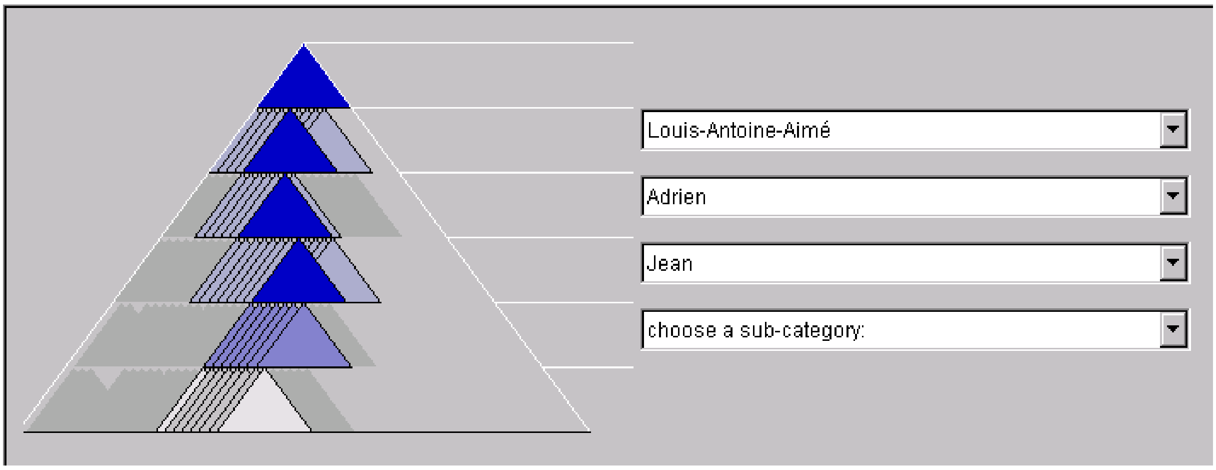

Figure 4.25: Cheops uses stacked triangles to compactly display a hierarchy.

- Compact 2d representation of a hierarchy by overlaying (squashing together) children to save on screen space. See Figure 4.25.
- Paper at Visualization'96 [Beaudoin et al., 1996].
- Software (Java classes) at `http://www.crim.ca/hci/cheops/`

4.7.2 BeamTree

- Directories are in blue, files in other colours.
- The root beam is in the background, other beams are laid on top.
- See Figures 4.26 and 4.27.
- InfoVis 2002 paper [van Ham and van Wijk, 2002].

4.8 Single-Level Tree Browsers

4.8.1 GopherVR

- University of Minnesota, 1995.
- 3d landscape visualisation of *individual* levels of a Gopher hierarchy. Members of a collection are arranged in a stonehenge-like circle.
- Spiral visualisation of Gopher search result sets, spiraling out from centre with decreasing relevance.
- Possibility to hand-place items, for example grouping related items.
- Papers [McCahill and Erickson, 1995; Iacovou and McCahill, 1995].

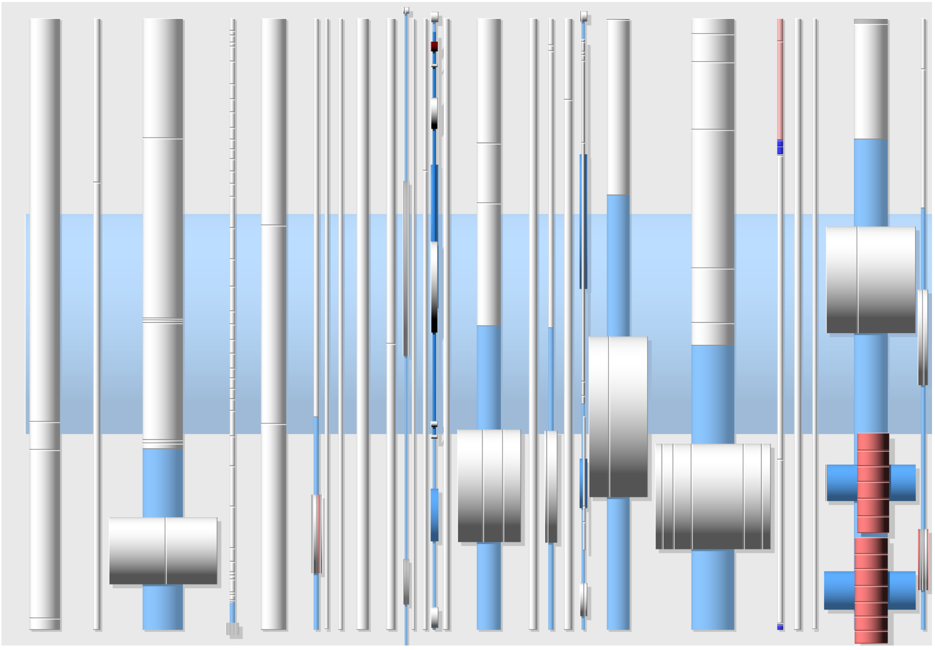

Figure 4.26: BeamTrees are a variation on treemaps using overlapping beams. Directories are coloured blue, files are other colours. The root directory is at the back, other directories are overlaid upon it.

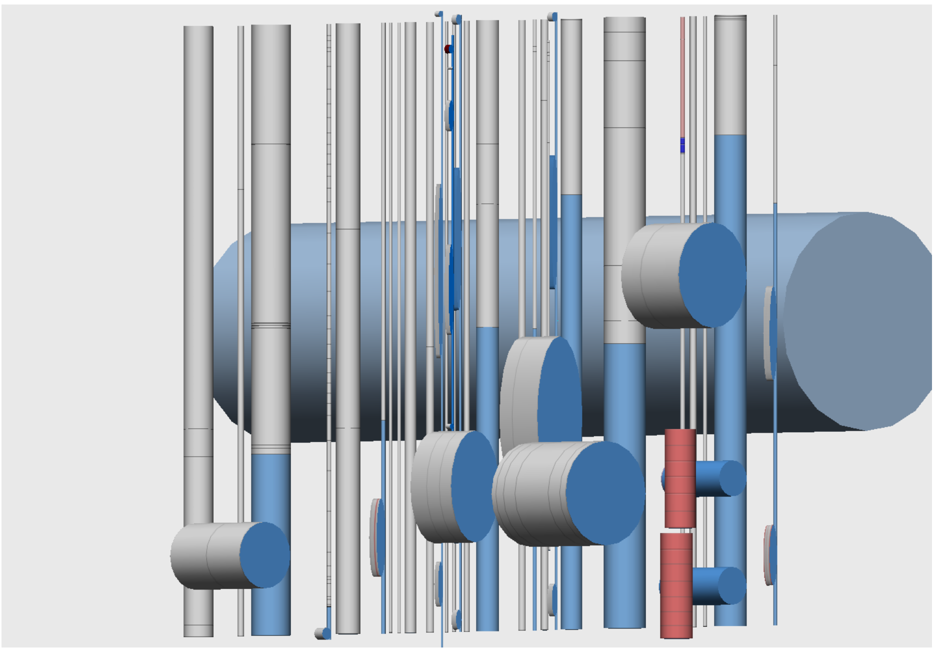

Figure 4.27: The directory structure is only really recognisable when a 3D rendering is used.

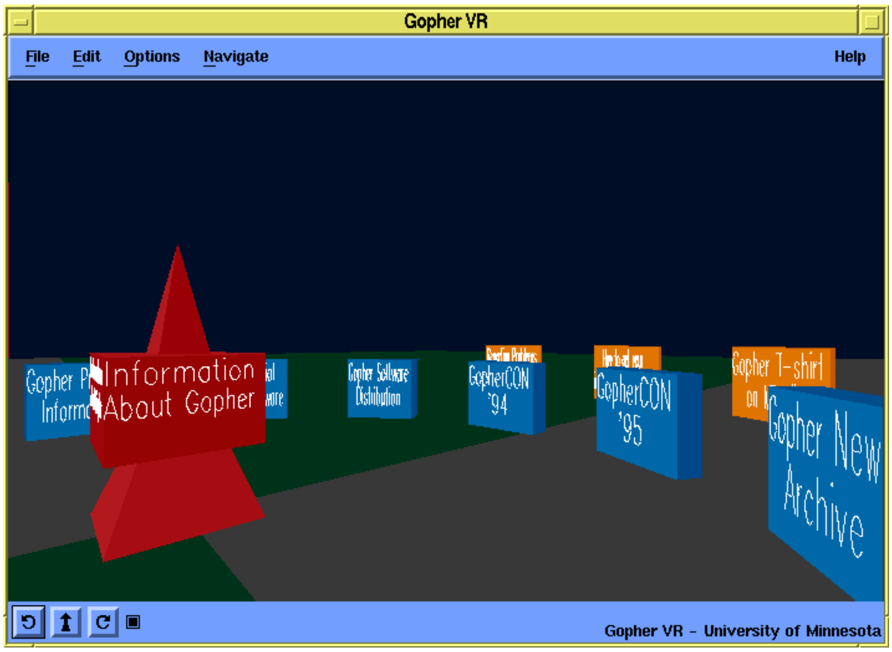

Figure 4.28: GopherVR visualises one level of a Gopher hierarchy at a time. The central pyramid bears the name of the current level, clicking on it returns the user to the next higher level.

Chapter 5

Visualising Networks and Graphs

5.1 Adjacency Matrix

An *adjacency matrix* explicitly tabulates links between nodes.

- Also sometimes called a *connectivity matrix* and a *design structure matrix* (DSM).
- For a graph with N nodes, an $N \times N$ matrix is used to indicate where edges occur.
- Figure 5.1 shows an example for a graph with five nodes and six edges.

5.2 Predetermined Position

The nodes of a graph are laid out in predetermined positions (ring, grid, geographically) and the edges are routed and coded in various ways.

5.2.1 Linear

Thread Arcs

- Thread Arcs were developed to visualise threads of conversation between email or newsgroup messages [Kerr, 2003].
- ThreadVis is an implementation of Thread Arcs for the Thunderbird news and email client [Hubmann-Haidvogel, 2008]. See Figure 5.2. `http://threadvis.mozdev.org/`

5.2.2 Ring-Based

NetMap

- NetMap, Peter Duffett and Rudi Vernik, CSIRO, Australia, 1997. [Duffett and Vernik, 1997]

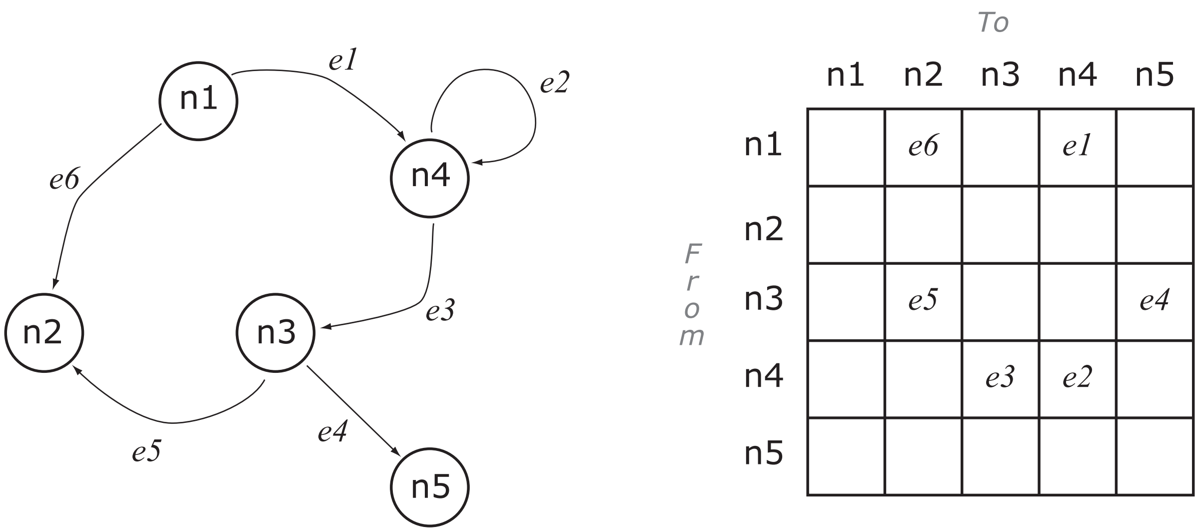

Figure 5.1: A graph with five nodes and six directed edges. The drawing on the left is hand-drawn. The representation on the right shows the same graph in the form of an adjacency matrix.

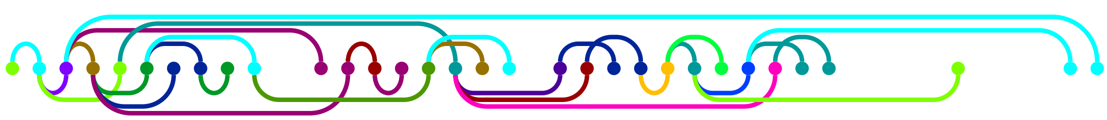

Figure 5.2: ThreadVis implements the Thread Arcs visualisation as an add-on for Thunderbird. Here is a thread from the `alt.gesellschaft.recht` newsgroup containing 32 messages.

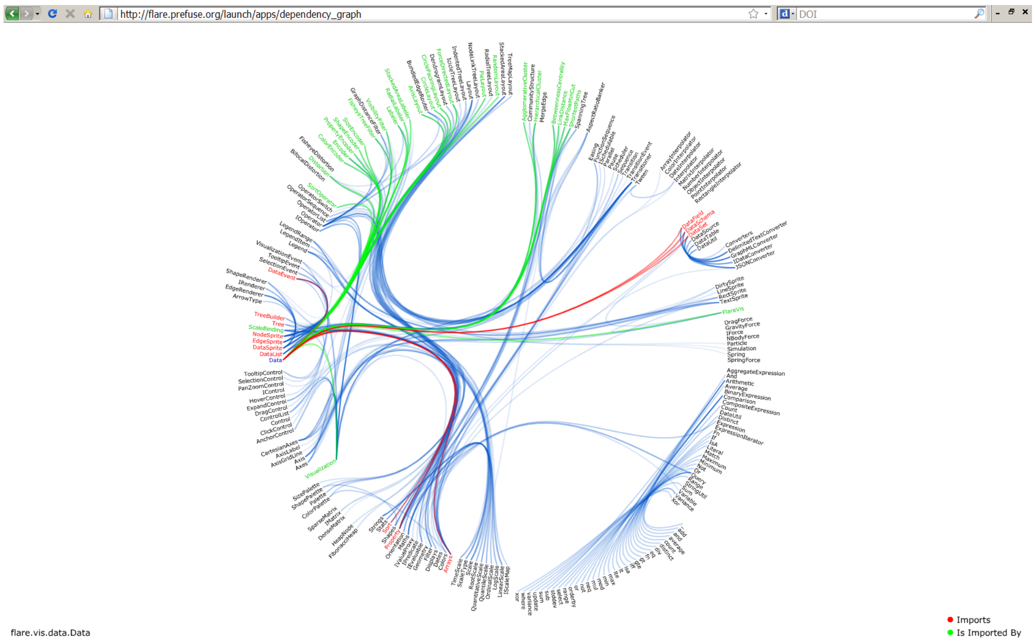

Figure 5.3: The Flare Dependency Graph is a ring-based layout showing the dependencies between classes in the Flare library. Here the class Data has been selected.

Flare Dependency Graph

- The Flare Dependency Graph is a ring-based layout showing dependencies among classes within the Flare library [Heer, 2010].
- Each class is placed around the edge of the ring. The exact radius indicates the depth of the class in the package structure tree.
- A link indicates that a class imports another.
- Edges are “bundled” together for greater clarity.
- See Figure 5.3.

5.2.3 Grid-Based

Intermedia Global Map

- Intermedia was a network hypermedia system developed for Aplle computers in the 1980s. [Haan et al., 1992; Yankelovich et al., 1988].
- Hypermedia nodes (documents) are placed on a regular grid and links are drawn between them.
- See Figure 5.4.

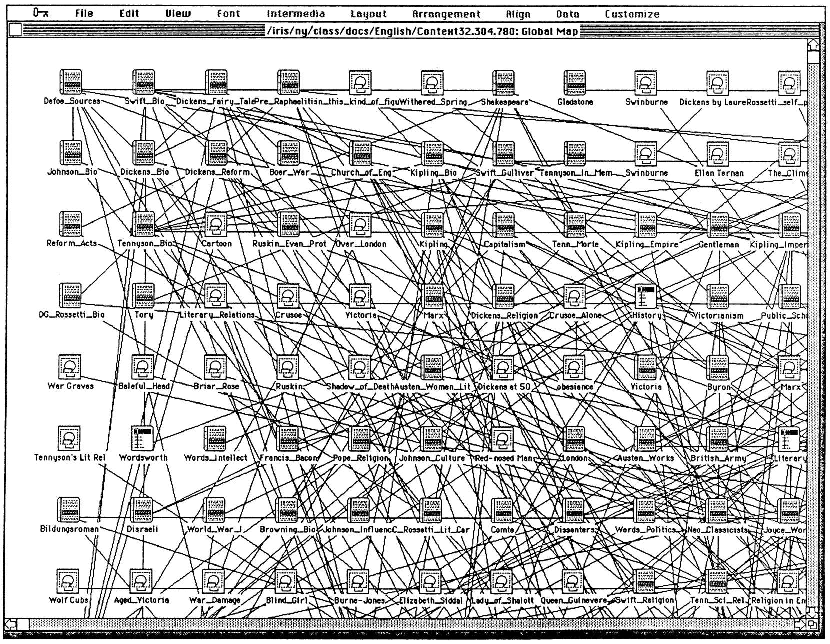

Figure 5.4: The Intermedia Global Map. Hypermedia nodes (documents) are placed on a regular grid and links are drawn between them. [Image extracted from Conklin [1987]. Copyright ©1987 IEEE. Used with permission.]

5.2.4 Geography-Based

Flow Maps

- Historical flow maps created by Charles Minard.
- Layout algorithm described by Doantam Phan et al in InfoVis 2005 paper [Phan et al., 2005].
- See Figure 5.5 shows migration to California using US Census data from 2000.

5.3 Layered Graph Drawing

Three main steps:

1. Layering
2. Crossing reduction
3. X-coordinate assignment

Ideal for directed graphs: directionality is reflected in the layering (flow from top to bottom, or left to right).

5.3.1 Harmony Local Map

- IICM, 1993-1994.

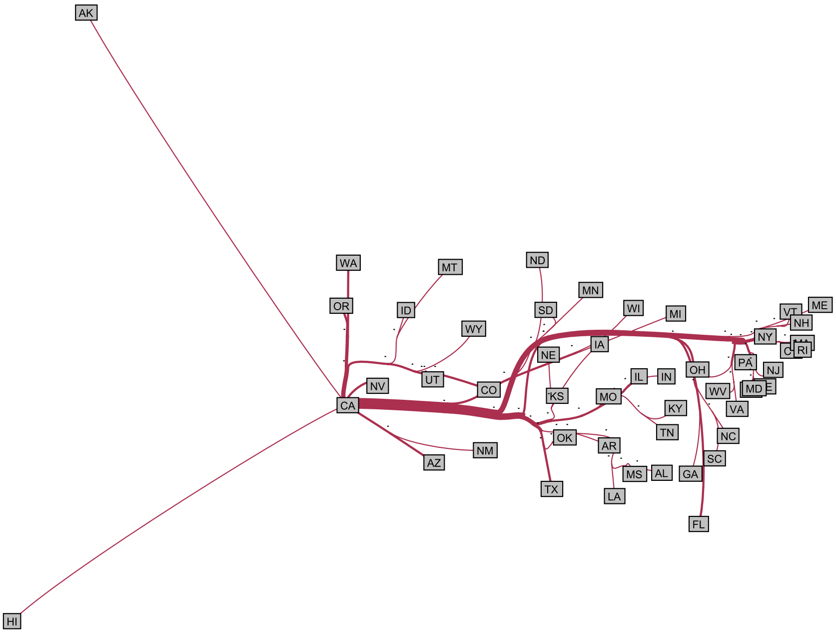

Figure 5.5: A flow map showing migration to California from other US states, using data from the US Census 2000. The map was produced by Keith Andrews using the software available from Phan et al. [2006].

- Graph layout for nodes and links of a hypermedia network.
- Modified version of Eades and Sugiyama's [Eades and Sugiyama, 1990] graph layout algorithm [di Battista et al., 1999].
- Description in Chapter 8 of [Andrews, 1996].

Harmony Local Map 3D

- IICM, 1995.
- Links in vertical plane superimposed atop information landscape. See Figure 5.7.
- Description in Chapter 8 of [Andrews, 1996].

5.4 Force-Based Layouts

5.4.1 SemNet

- Fairchild, Poltrock, Furnas, MCC, 1988.
- The first 3d information visualisation.
- 3d spatial layout of a semantic network. See Figure 5.8.
- Article [Fairchild et al., 1988].

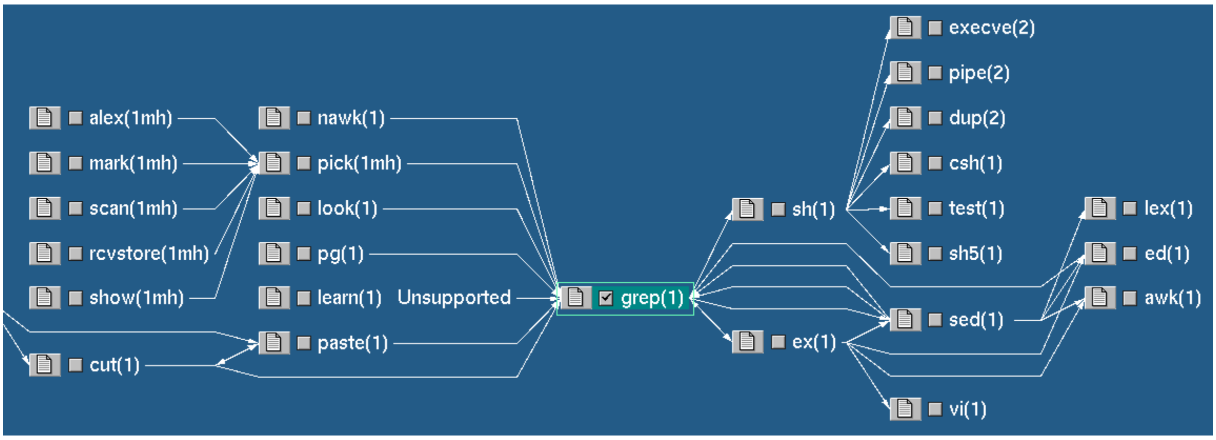

Figure 5.6: The Harmony Local Map uses graph drawing algorithms to lay out a map of the link environment of hypermedia documents. In this example, Unix manual pages one and two links away from the grep manual page are visualised.

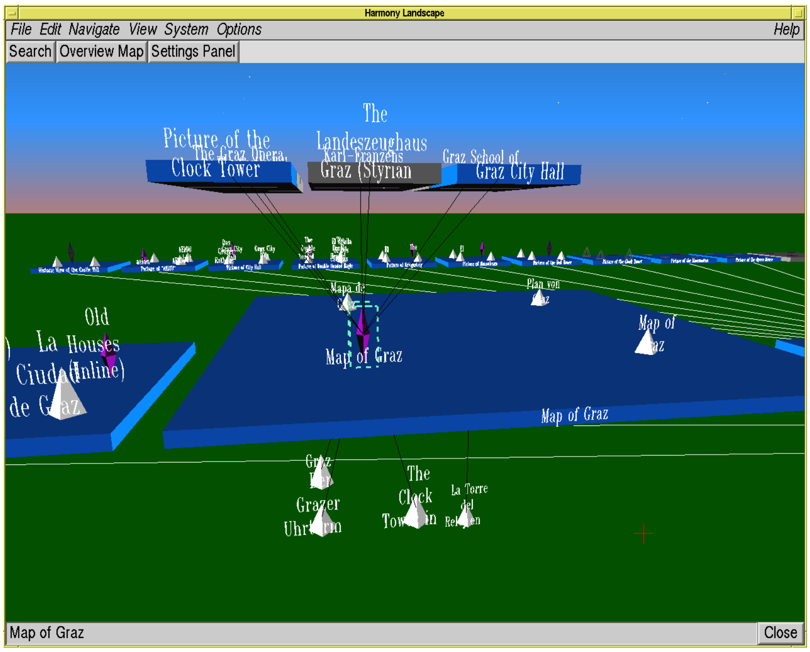

Figure 5.7: The Harmony Local Map 3D display hierarchical structure on the horizontal plane and superimposes hyperlink connections in the vertical plane.

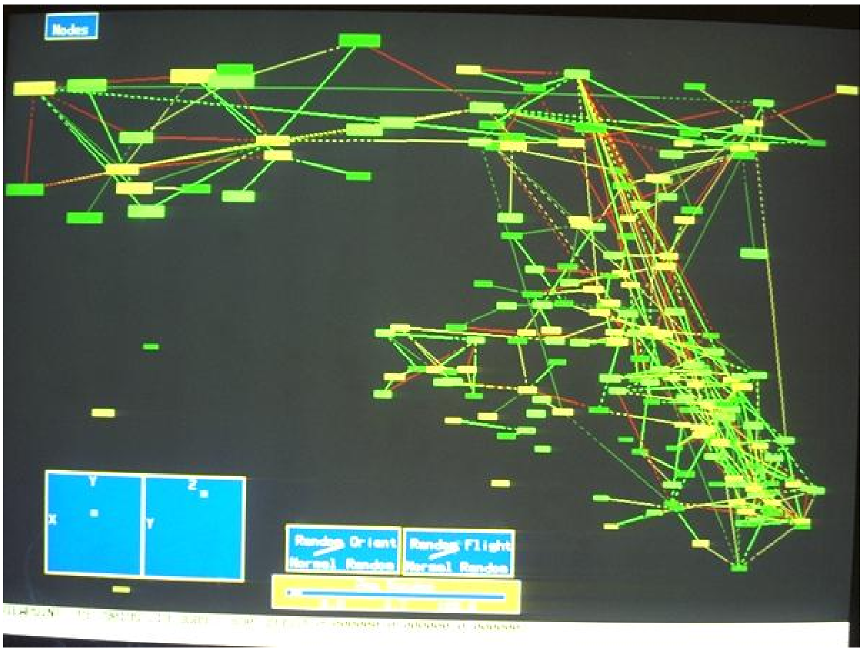

Figure 5.8: SemNet visualised a semantic network in 3d. [Image used with kind permission of Kim Fairchild.]

- Video at CHI '87 [Fairchild, 1987].
- Patented under [Wexelblat and Fairchild, 1991].

5.4.2 HyperSpace (Narcissus)

- University of Birmingham, 1995.
- Self-organising structure based forces and springs.
- The number of links between documents provides the attractive force.
- Narcissus [Hendley et al., 1995], later renamed HyperSpace [Wood et al., 1995].

Chapter 6

Visualising Multidimensional Metadata

“ Getting information from a table is like extracting sunlight from a cucumber. ”

[Arthur and Henry Farquhar, Economic and Industrial Delusions, Putnam, New York, 1891.]

6.1 Interactive Tables

6.1.1 Table Lens

- Xerox PARC, 1994.
- Focus + context technique for large tables.
- Rows and columns are squeezed down to pixel and subpixel sizes. See Figure 6.1.
- CHI’94 paper [Rao and Card, 1994] and CHI’95 video [Rao and Card, 1995].
- US Patent 5632009 [Rao and Card, 1997].

6.2 Interactive Scatterplots

6.2.1 FilmFinder

- HCIL, University of Maryland, 1991-1993.
- Sliders and controls directly manipulate an on-screen scatterplot.
- The scatterplot is called a “starfield display”.
- CHI’92 paper [Ahlberg et al., 1992] and video [Shneiderman et al., 1992], CHI’94 paper [Ahlberg and Shneiderman, 1994a] and video [Ahlberg and Shneiderman, 1994b].
- Commercialised as part of IVEE’s Spotfire toolkit [Spotfire, 2000].

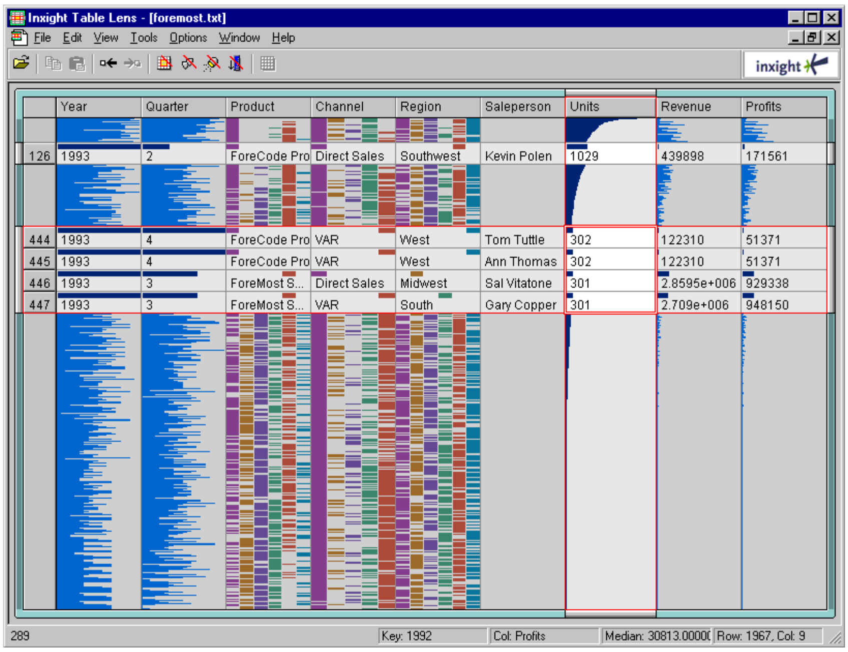

Figure 6.1: The table lens represents rows of a table as rows of pixels. The user can focus and stretch out rows or columns to see the data, whilst maintaining surrounding context.

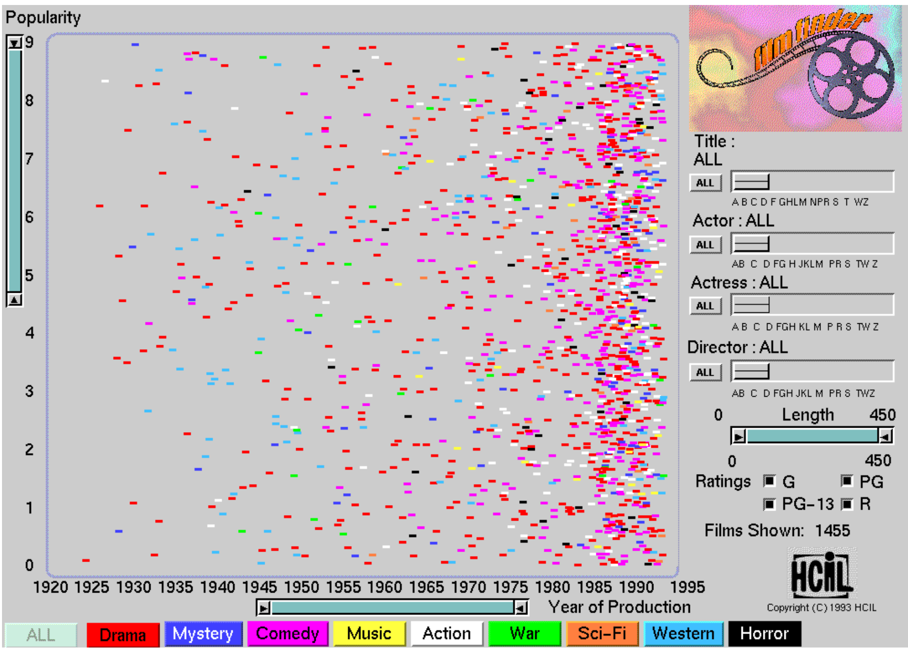

Figure 6.2: The FilmFinder, a starfield display combined with dynamic queries for rapid filtering. [Copyright ©University of Maryland 1984-1994.]

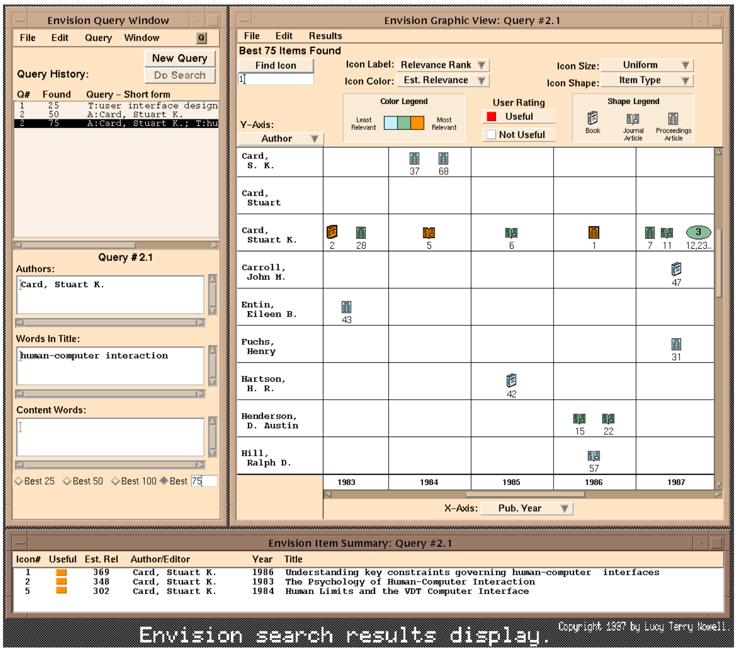

Figure 6.3: Envision visualises a set of search results, by mapping document attributes along two axes. Where too many documents would occupy a cell, an ellipse is used as a container object. Another problem is where to place documents matching multiple categories. [Copyright © by the Association for Computing Machinery, Inc.]

6.2.2 Envision

- Virginia Tech, 1993–1997.
- Direct manipulation of search result sets by mapping document attributes along two axes.
- SIGIR'96 paper [Nowell et al., 1996] and CHI'97 online abstracts [Nowell et al., 1997].

6.2.3 Search Result Explorer

- IICM, 1999.
- Similar to Envision, Java implementation for the xFIND search engine.
- Paper at UIDIS 2001 [Andrews et al., 2001].

6.3 Interactive Histograms

6.3.1 Attribute Explorer

- Imperial College, 1993.
- Direct manipulation of coupled views of histograms.
- CHI'94 video [Tweedie et al., 1994].

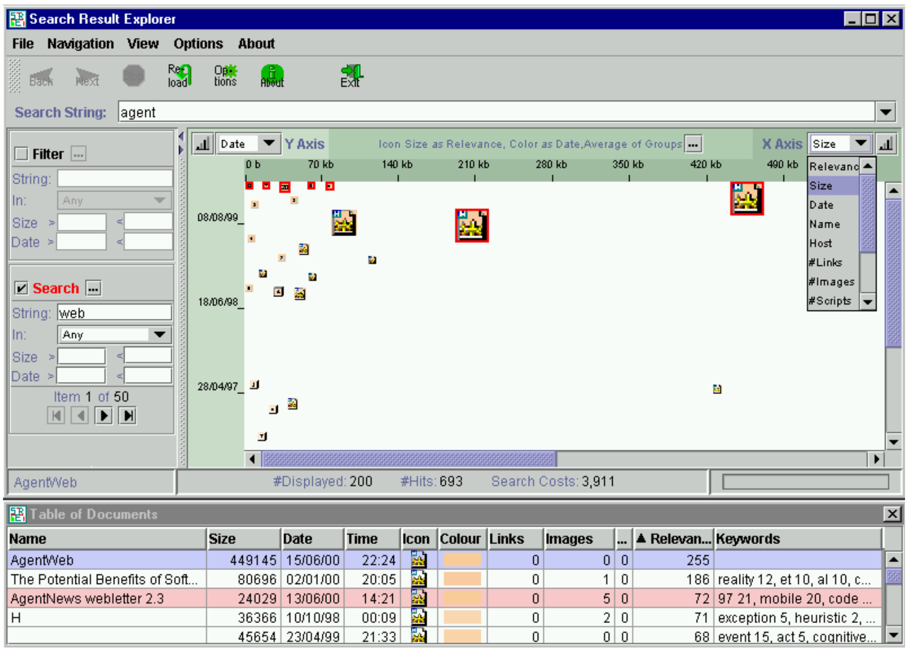

Figure 6.4: Search Result Explorer.

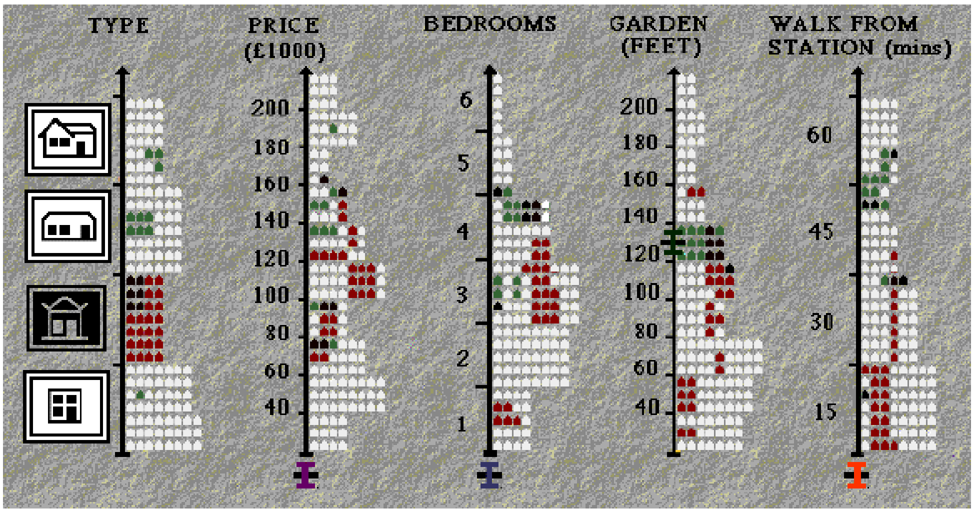

Figure 6.5: The Attribute Explorer. Each attribute is assigned to a scale with histograms showing the population spread running up one side. Initially these display each item in the total population. The user can interact with the scales: using sliders for continuous attributes (e.g. price) and buttons for discrete attributes (e.g. type of house). The effect of one attribute on the others can be explored by selecting values of interest on one scale and viewing where those items appear on the other attribute scales. [Copyright © by the Association for Computing Machinery, Inc.]

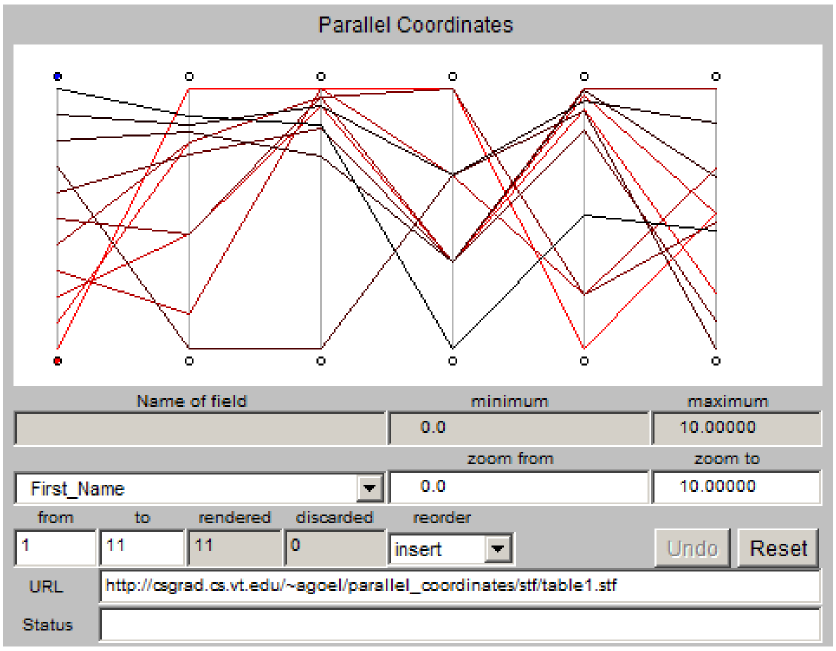

Figure 6.6: Parallel Coordinates. The six vertical lines represent (from left to right) the name and marks of students in five exams. The eleven polylines represent the data from eleven students. Polylines which mirror one another closely from vertical lines 2 to 6 indicate students achieving very similar marks.

6.4 Parallel Coordinates

6.4.1 Original Parallel Coordinates

- Al Inselberg, 1985.
- Equidistant parallel vertical lines represent the axes of a multidimensional space.
- One vertical line for each dimension.
- Each object is plotted as a polyline defined by values along each dimension.
- Objects which are very similar will have polylines which follow each other.
- Figure 6.6 shows plot of 11 data points (students) on six dimensions (FirstName, Quiz1, Quiz2, Homework1, Homework2, Final).
- Paper in The Visual Computer, Vol. 1, 1985 [Inselberg, 1985] and many since.

6.5 Circular Histograms

Daisy Chart

- Daisy Analysis, UK, 2003 [Daisy, 2003].
- Attributes and (ranges of) their values are arranged around a the perimter of a circle. A polygon of connecting lines represents an individual item. See Figure 6.7.

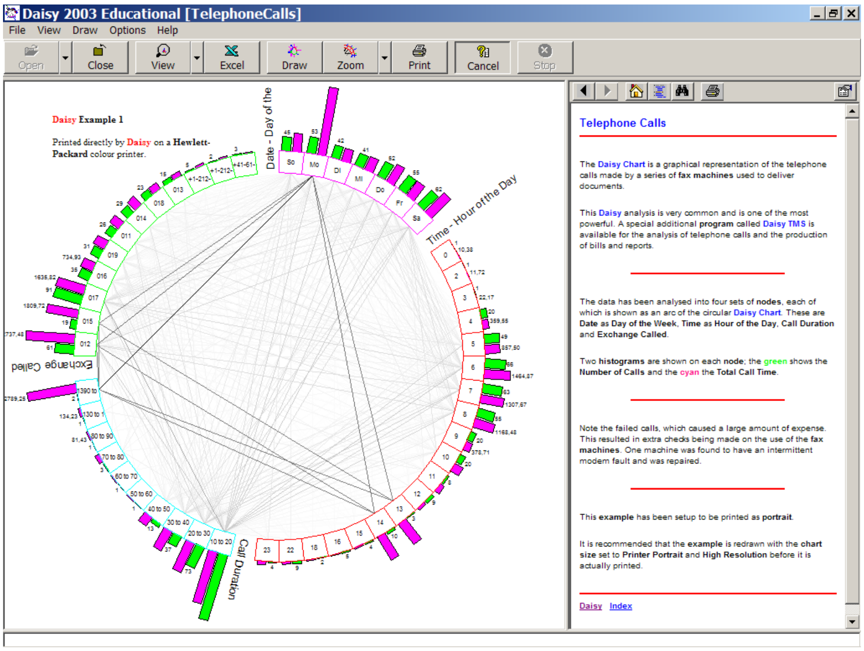

Figure 6.7: The Daisy Chart maps attributes and ranges of their values to positions on the circumference of a circle. Items are represented by polygons connecting attribute values.

•

Chapter 7

Visualising Text and Object Collections (Feature Spaces)

References

++ Borg and Groenen; *Modern Multidimensional Scaling*; Second Edition, Springer, 2005. ISBN 0387251502 (com, uk) [Borg and Groenen, 2005]

- Cox and Cox; *Multidimensional Scaling*; Second Edition, Chapman & Hall, 2000. ISBN 1584880945 (com, uk) [Cox and Cox, 2000]

7.1 Distance-Based Projection

Distance Calculation

Calculate the similarity (or dissimilarity) between every pair of objects in nD.

Techniques include:

- Vector space model and distance metric (such as scalar product).
- Normalised compression distance based on Kolmogorov complexity (NCD) [Telles et al., 2007].
- Distances are often normalised to values between 0 and 1.
- Results in a symmetric matrix of distance values.

Multidimensional Projection

- Each object is represented by a vector in nD space.
- Objects are mapped directly to positions in 1D, 2D, or 3D space.
- Preserving (as far as possible) the distance relationships from the high-dimensional space in the target space.
- Typically by minimising a stress function.

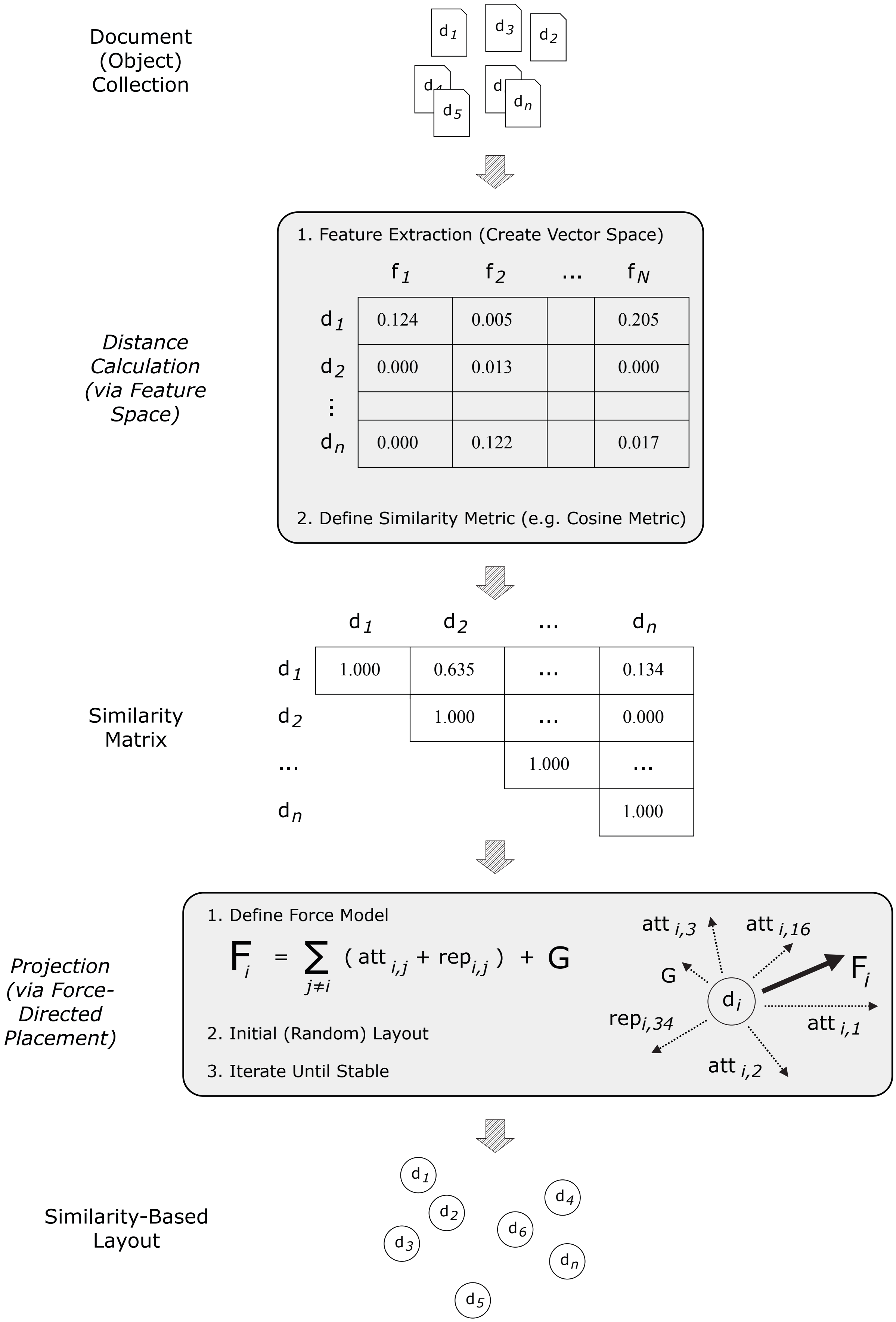

Figure 7.1: The visualisation pipeline for distance-based projection. Here, the vector space model has been chosen as the distance calculation algorithm and force-directed placement has been chosen as the projection algorithm.

7.1.1 Linear Projection

- Input is nD vector space.
- Can be directly calculated (no need for iterative process).
- Each embedding axis is a linear combination of the original axes.
- Creates meaningful axes which can be interpreted (given a "name").
- Straightforward mapping of new objects.
- Low computational complexity.

Linear Projection Techniques

- Principal Component Analysis (PCA):
  - Covariance matrix is decomposed into m eigenvectors, the first p with largest eigenvalues are chosen.
  - The first principal component accounts for as much of the variability in the data as possible.
  - Each succeeding component accounts for as much of the remaining variability as possible.
  - For a mapping to 2D, choose the first 2 principle components.

7.1.2 Non-Linear Projection

- Input is set (triangular matrix) of pairwise similarities (or dissimilarities).
- Similarity matrix can, of course, be calculated from an nD vector space.
- Usually needs an iterative process (cannot be directly calculated).
- Optimise a cost (stress) function.
- Change in objects means need to run a few more iterations (incremental layout).
- Can handle non-linear structures.
- New axes cannot be interpreted (given a "name").

Non-Linear Projection Techniques

- Multi-Dimensional Scaling (MDS)
  - Majorisation: iterative nonlinear optimisation based on steepest descent towards a (local) minimum.
- Force-directed placement (FDP): Iterative solution of a force model.
- Fastmap [Faloutsos and Lin, 1995].
- Nearest Neighbor Projection (NNP) [Tejada et al., 2003].
- Least Squares Projection (LSP) [Paulovich et al., 2008].

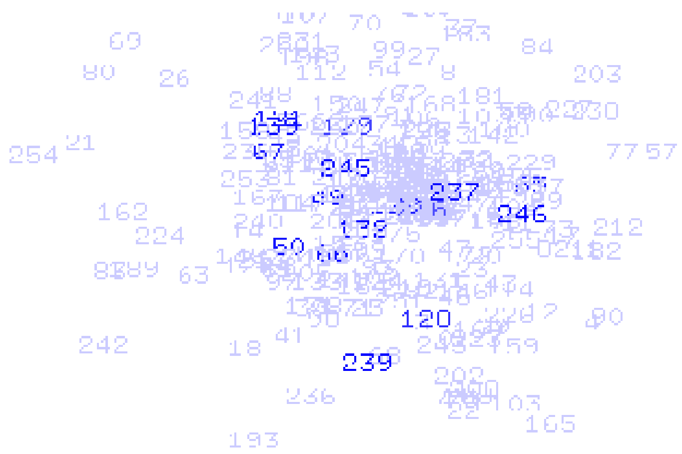

Figure 7.2: Part of the Bead visualisation of 301 entries from the HCI Bibliography. The objects represent articles from the field of HCI. Documents containing similar keywords are placed near each other in the 3d point cloud. A search has been done on the keywords "information retrieval" and the results are highlighted. [Copyright © by the Association for Computing Machinery, Inc.]

7.2 Force-Directed Placement (FDP)

- Invented in 1984 by Peter Eades [Eades, 1984]: spring model, forces move the system to a minimal energy state. Brute force, $\mathcal{O}(n^3)$.
- Improved and named *force-directed placement* in 1991 by Fruchtermann and Reingold [Fruchtermann and Reingold, 1991]. Forces are computed only to nearby objects (within a certain radius). Attempts to achieve uniform edge length.
- Series of improvements by Chalmers: 1992 $\mathcal{O}(n^2\sqrt{n})$ [Chalmers and Chitson, 1992], 1996 $\mathcal{O}(n^2)$ [Chalmers, 1996b], 2003 $\mathcal{O}(n^{\frac{5}{4}})$ [Morrison et al., 2003].
- Jourdan and Melancon, MultiscaleMDS, in 2004 $\mathcal{O}(n \log n)$ [Jourdan and Melancon, 2004].
- Brandes and Pich; PivotMDS, in 2006 $\mathcal{O}(n)$ through sampling and approximation [Brandes and Pich, 2006].
- Ingram, Munzner, and Olano; Glimmer, in 2009 theoretically $\mathcal{O}(n^2)$ but massively parallel [Ingram et al., 2009].

7.3 Example Systems

7.3.1 Bead

- Matthew Chalmers (EuroPARC, Ubilab), 1992 [Chalmers and Chitson, 1992; Chalmers, 1993, 1996a].
- Vector space model and force-directed placement.
- Produces a 3d point cloud.

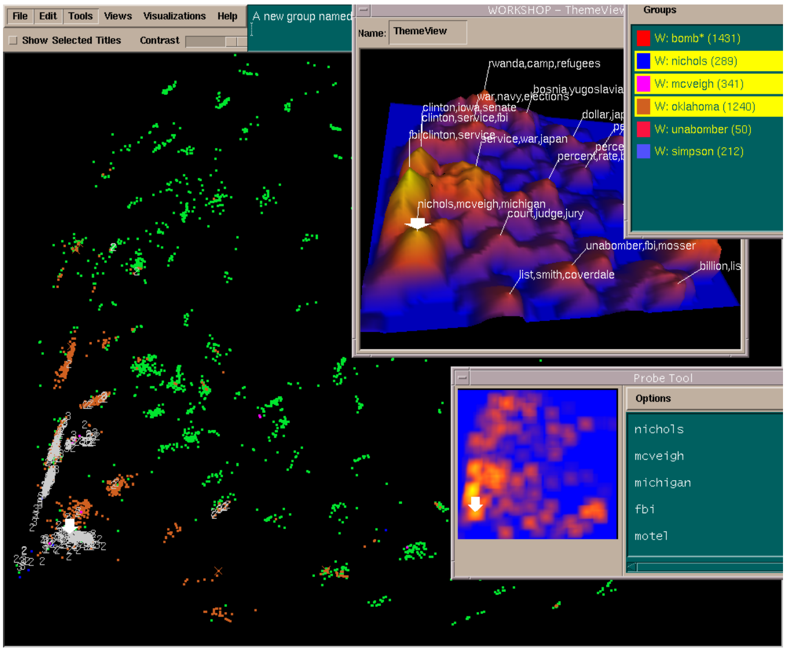

Figure 7.3: SPIRE showing the Galaxy View (below), Themescape (upper right) and Probe Tool. [Image used with kind permission of Pacific Northwest National Laboratory.]

7.3.2 SPIRE

- Pacific Northwest National Labs, 1995 [Wise et al., 1995; Wise, 1999].
- Build vector space model from text (or other document) corpus.
- Anchored Least Stress (ALS): first project small subset of objects using PCA (first two principle components), then interpolate remaining objects.
- Results in 2d Galaxy View.
- From Galaxy View aggregate of keywords in height dimension to form Themescape. See Figure 7.3.
- Paper in ISKO [Hetzler et al., 1998], technical details paper in JASIS [Wise et al., 1995], good overview at I-Know ’01 [Thomas et al., 2001].

7.3.3 VxInsight

- Sandia National Labs, 1998 [Davidson et al., 1998].
- VxOrd: force-directed placement.
- Accepts list of pre-computed similarities.
- Nodes are moved to minimise an energy function.

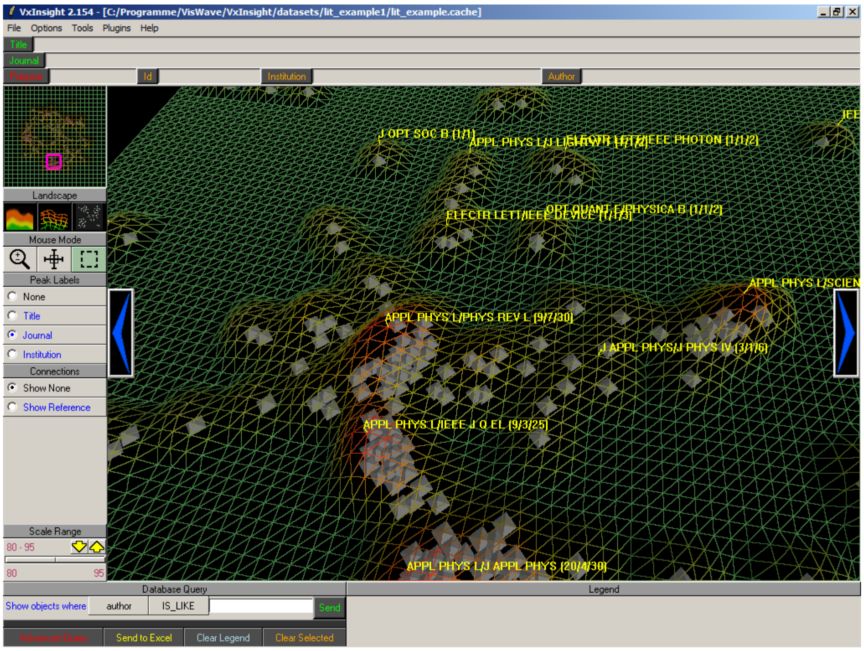

Figure 7.4: VxInsight showing some of 1,231 bibliographic records extracted from the physical sciences portion of the Science Citation Index Expanded. The layout uses similarities based on direct and cocitation links between articles. [Thanks to Brian Wylie, Sandia National Laboratories, for providing a demo version of VxInsight.]

7.3.4 VisIslands

- IICM, 2001 [Andrews et al., 2001].
- First (as far as we know) interactive FDP (a few seconds).
- Build vector space from objects in search result set.
- Initially cluster objects using fast algorithm.
- Position cluster centroids using FDP.
- Place other cluster members around centroid, then run a few iterations of FDP.

7.3.5 InfoSky

- IICM + Know-Center + Hyperwave, 2002 [Andrews et al., 2002].
- InfoSky assumes objects are pre-placed within a hierarchy.
- Force-directed placement is not done globally, but recursively at each level of the hierarchy (only for the nodes at that level).
- First system to use recursive Voronoi subdivision of a hierarchy.

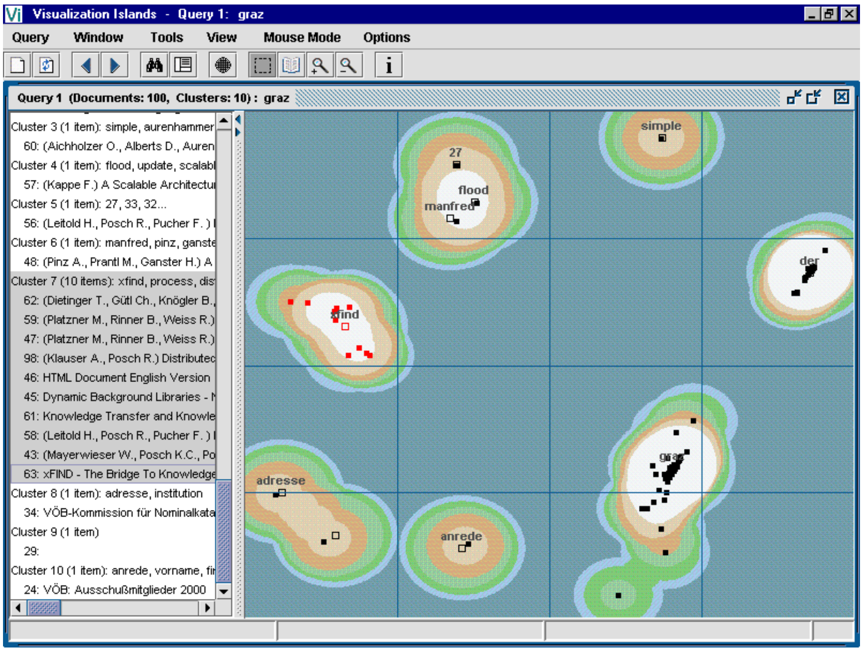

Figure 7.5: VisIslands forms visual clusters of search result sets.

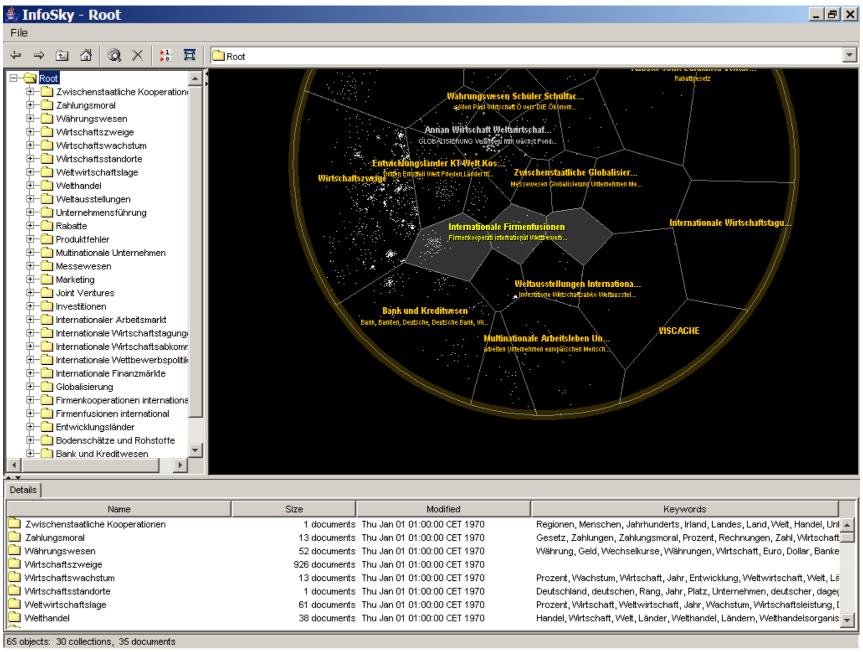

Figure 7.6: InfoSky showing a collection of newspaper articles from the German newspaper Sudeutscher Zeitung. The articles have previously been manually placed within a topical hierarchy by the newspaper editors.

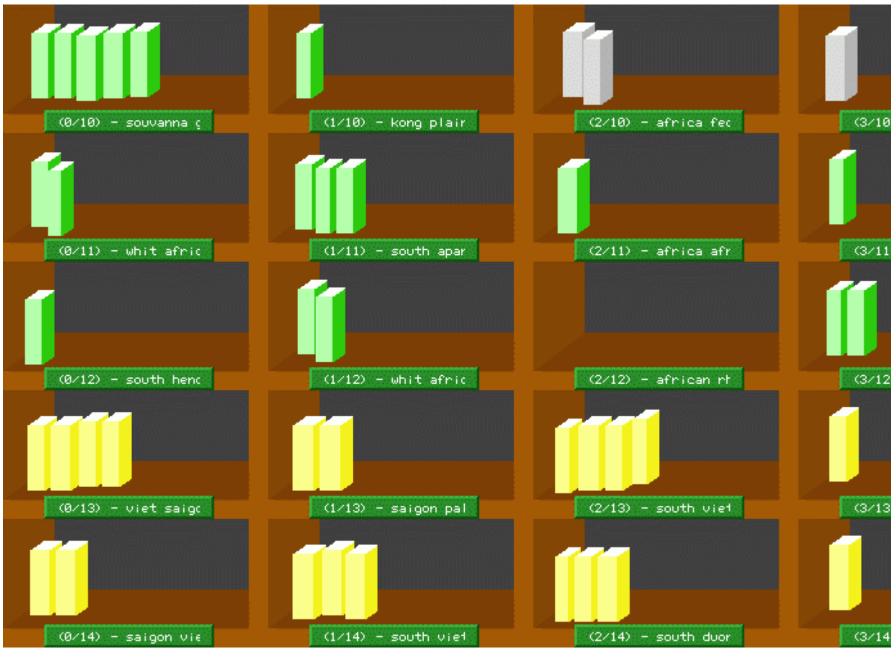

Figure 7.7: The SOMLib system with the libViewer interface. Documents are assigned to sections of a bookshelf (or post boxes) according to their content. [Image used with kind permission of Andreas Rauber.]

7.4 Self-Organizing Maps (SOM)

- Self-organizing map (SOM) invented by Kohonen [2000].
- Based on neural networks.
- The map consists of a regular grid of cells ("neurons").
- The cells may be rectangular (like a shelf of post boxes), hexagonal (like a wine rack), or other regular shapes.
- A feature vector (descriptor) describes each cell.
- Each object is represented by a feature vector.
- Cell descriptors are usually initialised using a training set.
- An object is assigned to its closest cell. The feature vectors of that cell and neighbouring cells are then updated to reflect the new object.

7.4.1 SOMLib

- Based on a variant of the SOM algorithm [Rauber and Merkl, 1999].

7.4.2 WEBSOM

- Self-organizing map (SOM) algorithm [Kohonen, 2000].

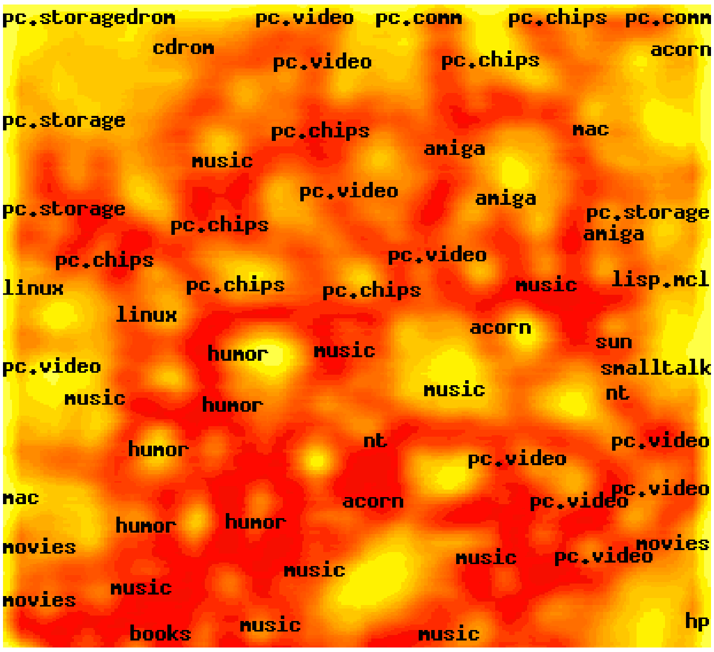

Figure 7.8: WEBSOM.

- Papers in IEEE Transactions on Neural Networks [Kohonen et al., 2000] and Information Sciences [Lagus et al., 2004]

Chapter 8

Visualising Query Spaces

8.1 InfoCrystal

- Anselm Spoerri, MIT, 1993.
- n boolean query terms at corners of regular polygon, icons representing documents are pulled towards the corners they satisfy.
- Paper at Visualization'93 [Spoerri, 1993].

8.2 LyberWorld

- Matthias Hemmje, GMD-IPSI, 1993.
- Cone tree with documents and terms at alternate levels.
- Paper at SIGIR'94 [Hemmje et al., 1994], Video at CHI'95 [Hemmje, 1995].
- Home page `http://www.darmstadt.gmd.de/~hemmje/Activities/Lyberworld/`

8.3 TileBars

- Marti Hearst, Berkeley 1993-94, Xerox PARC, 1994–95.
- Analyse structure of longer text documents.
- Graphical representation of where search terms occur.
- Paper at CHI'95 [Hearst, 1995], Video at CHI'96 [Hearst and Pedersen, 1996].

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