Information Visualisation

Tutorial Notes

Version of 5th July 2002

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These lecture notes are available online at

http://www.iicm.edu/ivis/

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Preface

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1 Introduction

Information visualisation 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 $\neq$ Data Vis.
- An appropriate visual representation is carefully designed or "invented".
- Appropriate navigational and manipulation facilities are provided.

1.1 References

Books

- Card, MacKinlay, Shneiderman; *Readings in Information Visualization : Using Vision to Think*; Morgan Kaufman, Jan. 1999. ISBN 1558605339 (de, uk)
- Bob Spence; *Information Visualization*; Addison-Wesley, Dec. 2000. ISBN 0201596261 (de, uk)
- Colin Ware; *Information Visualization: Perception for Design*; Morgan Kaufmann, Jan. 2000. ISBN 1558605118 (de, uk)
- Chaomei Chen; *Information Visualisation and Virtual Environments*; Springer, Nov. 1999. ISBN 1852331364 (de, uk) .
- Fayyad et al; *Information Visualization in Data Mining and Knowledge Discovery*; Morgan Kaufmann, Aug. 2001. ISBN 1558606890 (de, uk) .
- Jacques Bertin; *Semiology of Graphics : Diagrams, Networks, Maps*; Univ. of Wisconsin Press, 1983. ISBN 0299090604 (de, uk) [Out of print]
- Robert Harris; *Information Graphics: A Comprehensive Illustrated Reference*; Oxford University Press, Feb. 2000. ISBN 0195135326 (de, uk)
- Richard Saul Wurman; *Information Architects*; Graphis Press, 1996. ISBN 3857094583 (de, uk)
- Edward Tufte; *Visual Explanations*; Graphics Press, 1997. ISBN 0961392126 (de, uk)
- Edward Tufte; *The Visual Display of Quantitative Information*; Graphics Press, 1992. ISBN 096139210X (de, uk)
- Edward Tufte; *Envisioning Information*; Graphics Press, 1990. ISBN 0961392118 (de, uk)

Articles

- Herman et al; *Graph Visualisation and Navigation in Information Visualisation: A Survey*; IEEE Trans. V&CG, Vol. 6, No. 1, Jan.-Mar. 2000. http://www.cwi.nl/InfoVisu/Survey/FinalFromIEEE.pdf
- Ben Shneiderman; *The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations*; Proc. 1996 IEEE Symposium on Visual Languages (VL'96), Boulder, Colorado, Sept. 1996. [Chapter 15 of [Shneiderman, 1997]]
- Gershon, Eick, Card; *Information Visualization*; ACM Interactions, March/April 1998.
- Nahum Gershon and Steve Eick; *Visualization's New Tack: Making Sense of Information*; IEEE Spectrum, Nov. 1995.

Conferences

- IEEE Symposium on Information Visualization (InfoVis). Since 1995. The main conference in the field, very focussed. http://www.infovis.org/
- International Conference on Information Visualisation, London. Since 1997. Much broader in scope. http://www.graphicslink.demon.co.uk/IV02/
- Some papers at CHI, AVI, UIST.
- Knowledge and Information Visualisation 2003 (KIV 2003), Graz, Austria. http://www.know-center.at/en/conference/i-know03/workshop.htm

Journals

- Information Visualization, Palgrave. http://www.palgrave-journals.com/ivs/
- IEEE Computer Graphics and Applications. http://www.computer.org/cga/
- IEEE Transactions on Visualization and Computer Graphics. http://www.computer.org/tvcg/

Online Resources

- Gary Ng; *Information Visualization Resources*; May 2002. http://www.cs.man.ac.uk/~ngg/InfoViz/
- Martin Dodge; *Cyber-Geography Research* April 2002. http://www.cybergeography.org/
- Michael Reed and Dan Heller; *OLIVE: On-line Library of Information Visualization Environments*; University of Maryland, Nov. 1997. http://www.otal.umd.edu/Olive/
- Peter Young; *Three Dimensional Information Visualisation*; University of Durham, Nov. 1996. http://vrg.dur.ac.uk/misc/PeterYoung/pages/work/documents/lit-survey/IV-Survey/

InfoVis Companies

Suppliers of infovis toolkits and components:

- Inxight http://www.inxight.com
- Visual Insights http://www.visualinsights.com/
- Spotfire http://www.spotfire.com/

- Maya Viz http://www.mayaviz.com/
- OmniViz http://www.omniviz.com/
- Tom Sawyer Software http://www.tomsawyer.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 surrounding context (but not in as much detail).

- **3d perspective**: naturally focuses on objects in the foreground.
- **Fisheye views**: geometric distortion like a magnifying glass over the area of interest [Furnas, 1981, 1986].
- **Overview plus detail**: an overview map complements 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].

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.
- **Vector Spaces**: From information retrieval (IR), text document corpus, word frequencies, similarity measures between documents, document clustering, etc.
- **[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.

2 Visualising Linear Structures

Linearly structured information:

- alphabetical lists
- program source files
- tables
- chronological lists.

2.1 Perspective Wall

- Xerox PARC, 1990.
- 3d perspective technique for linear information.
- CHI'91 paper [Mackinlay et al., 1991] and video [Robertson et al., 1991b].
- US Patent 5339390 [Robertson et al., 1994b].

2.2 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 2.2.
- Articles [Eick et al., 1992; Ball and Eick, 1996] and InterCHI'93 video [Steffen and Eick, 1993].
- US Patent 5644692 [Eick, 1997].

2.3 Table Lens

- Xerox PARC, 1994.
- Focus + context technique for large tables.
- Rows and columns are squeezed down to pixel and subpixel sizes. See Figure 2.3.
- CHI'94 paper [Rao and Card, 1994] and CHI'95 video [Rao and Card, 1995].
- US Patent 5632009 [Rao and Card, 1997].

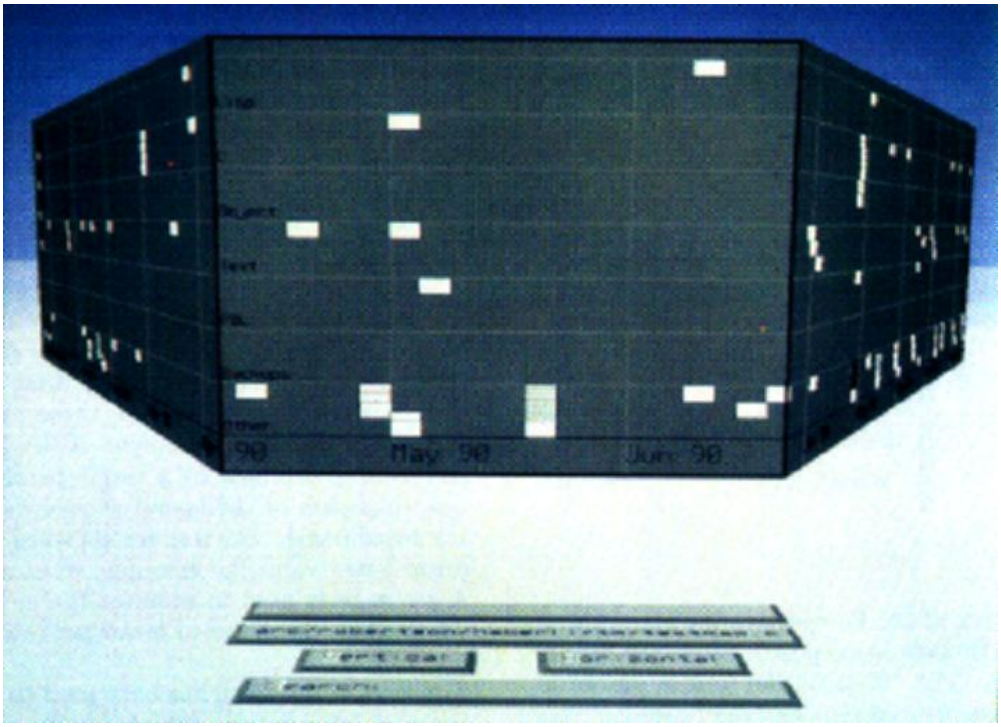

Figure 2.1: The perspective wall spreads linearly structured information across a wall from left to right. 3d perspective provides focus on the central segment of interest. Copyright ©by the Association for Computing Machinery, Inc.

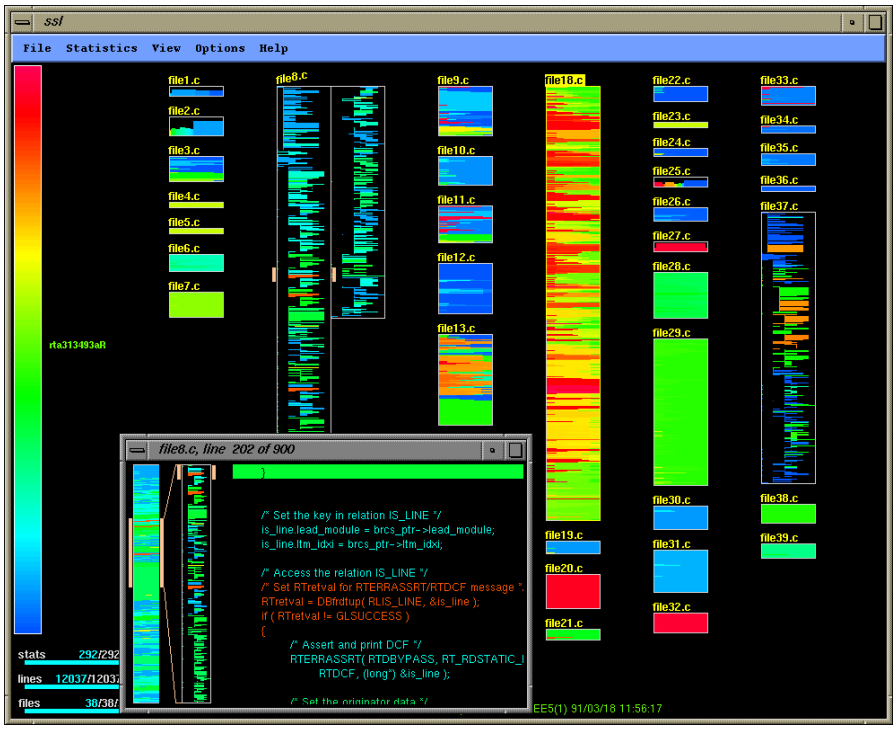

Figure 2.2: Seesoft visualising software consisting of 38 files comprising 12037 lines of code. The newest lines are shown in red, the oldest in blue, with a rainbow colour scale in between.

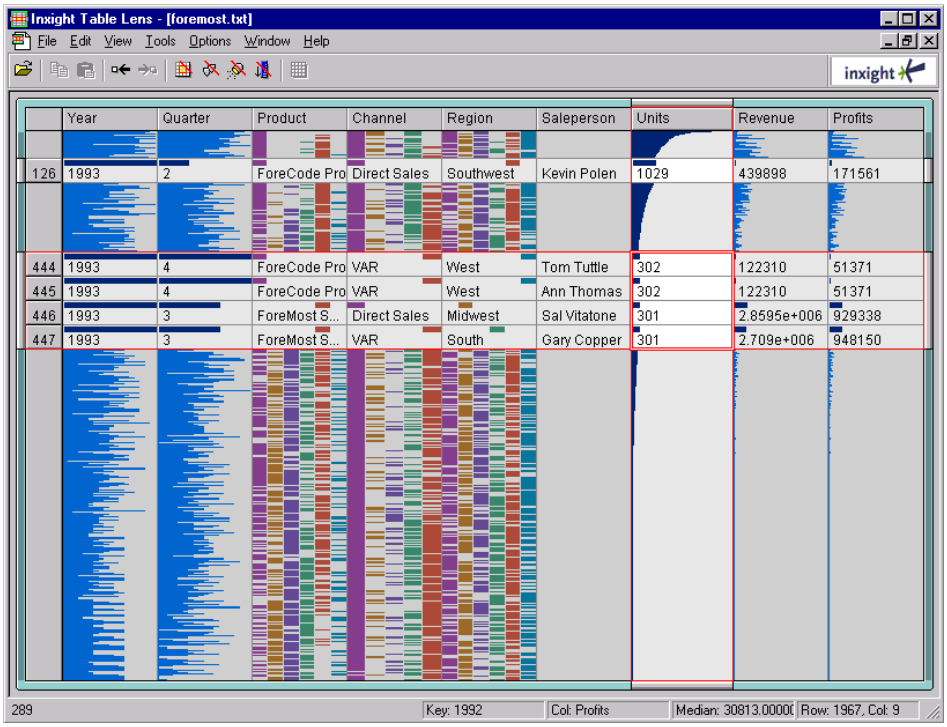

Figure 2.3: The table lens represents rows of a table as rows of pixels. The user can focus and stretch out rows or columns to see the data, whilst maintaining surrounding context.

2.4 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].

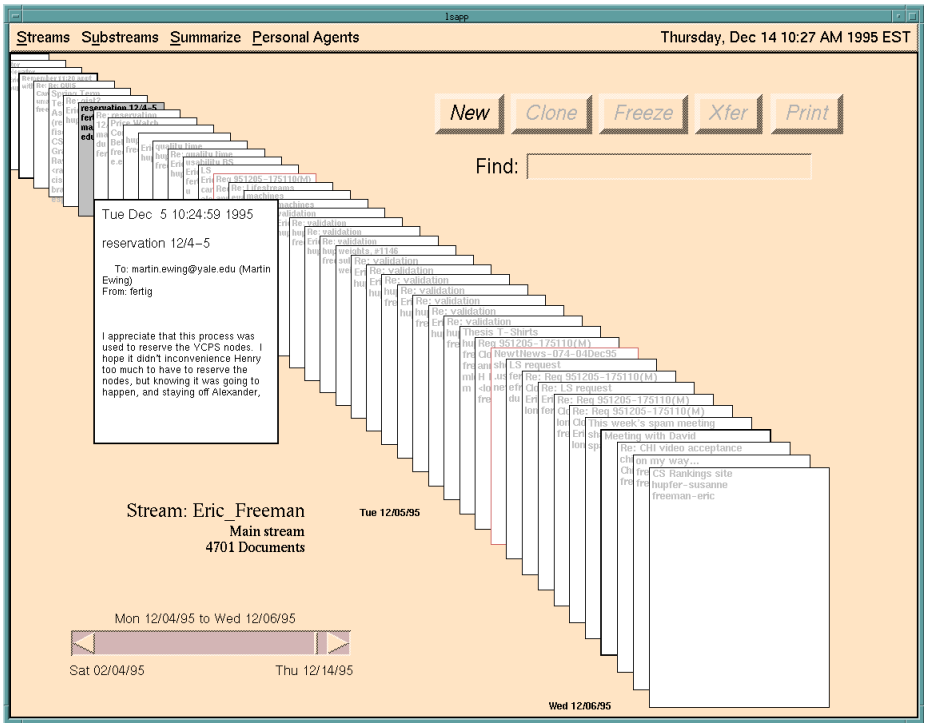

Figure 2.4: Lifestreams orders streams of item chronologically. It is possible to filter items into substreams. Copyright ©by the Association for Computing Machinery, Inc.

3 Visualising Hierarchies

Hierarchies are extremely common:

- file systems
- library classification systems
- family trees

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

3.1 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 3.1).
- Harmony Collection Browser [Andrews, 1996].

3.2 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].

3.3 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.
- Vertical space allocated proportional to size of each subdirectory.
- Software (source) available online [Dykstra, 1991].

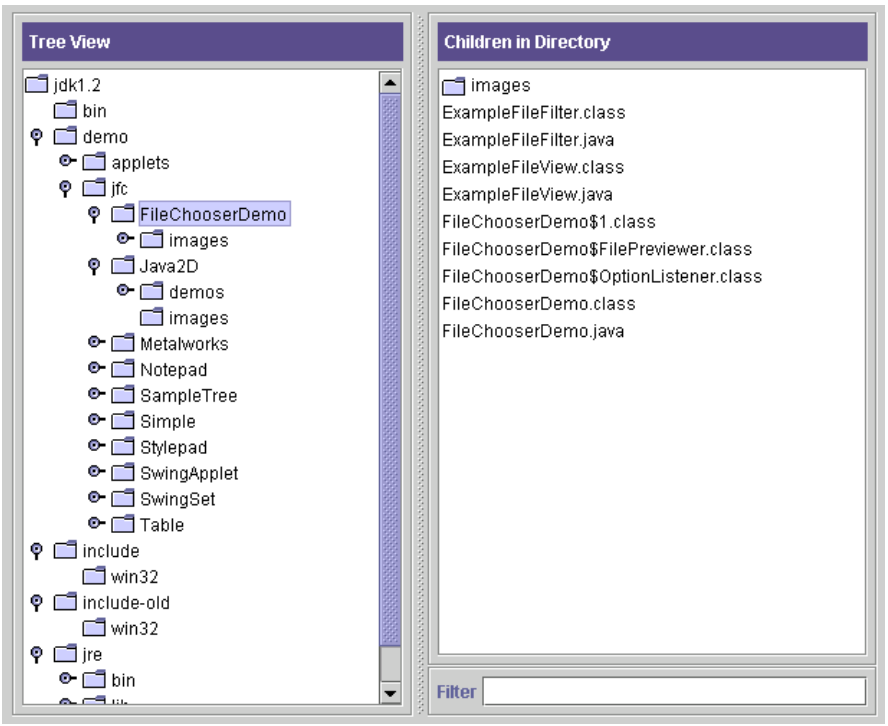

Figure 3.1: The Java Swing JTree tree view component. A view of directories on the left and their contents on the right.

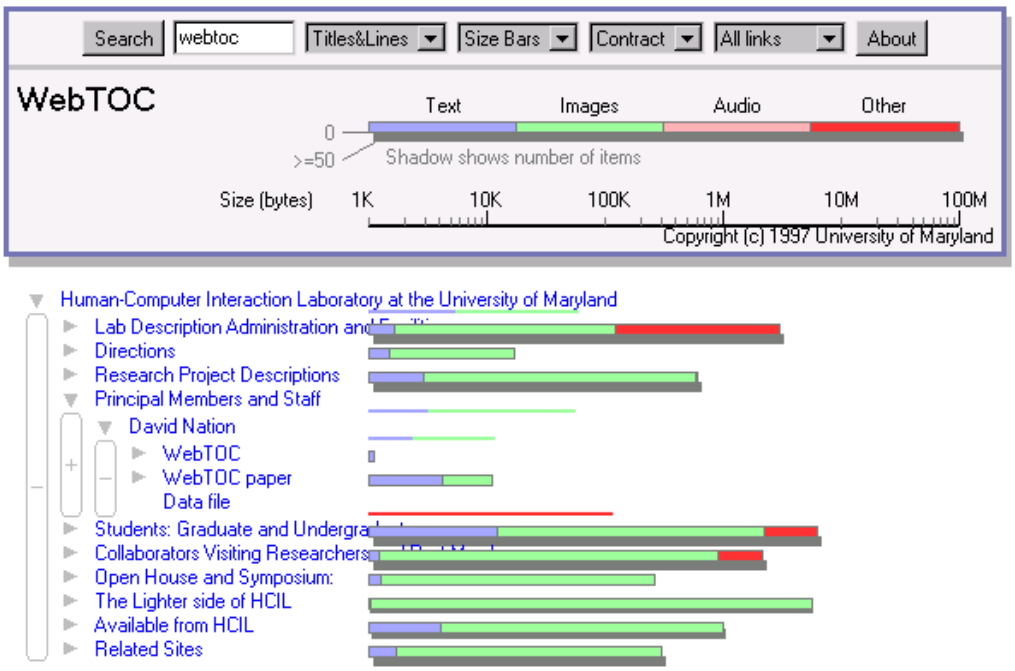

Figure 3.2: A WebTOC table of contents for the University of Maryland's HCI Lab web site.

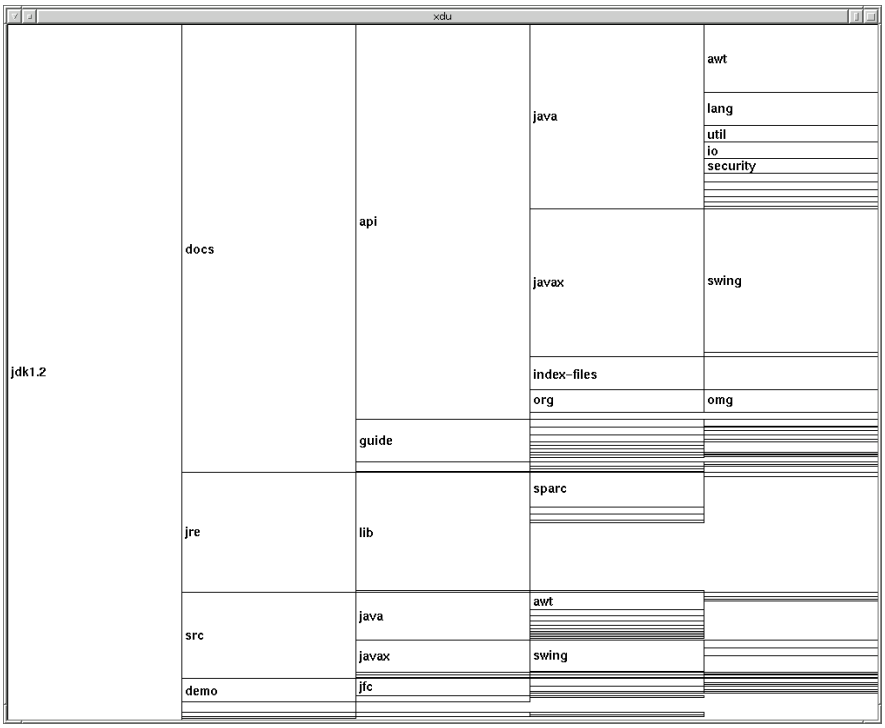

Figure 3.3: An xdu visualisation of the Java JDK 1.2 distribution.

3.4 Tree Maps

- HCIL, University of Maryland, 1991–1993.
- Screen-filling visualisation by alternating vertical and horizontal slicing of screen space, as shown in Figure 3.4.
- Size of each rectangle is proportional to its *weight*, typically the total number or size of items within it.
- Visualization'91 paper [Johnson and Shneiderman, 1991] and CHI'94 video [Turo, 1994].
- Software at `http://www.cs.umd.edu/hcil/treemap3/`.

3.5 Market Map

- Martin Wattenberg, SmartMoney, 1999.
- Extension of tree map, avoiding excessively narrow strips. See Figure 3.5.
- Uses heuristics to slice up each rectangle into more evenly proportioned sub-rectangles.
- CHI 99 late breaking paper [Wattenberg, 1999], InfoVis 2001 paper [Shneiderman and Wattenberg, 2001].

3.6 Hyperbolic Browser

- Xerox PARC, 1994–1995.
- Space-filling focus+context technique, see several levels of the hierarchy at once. See Figure 3.6.

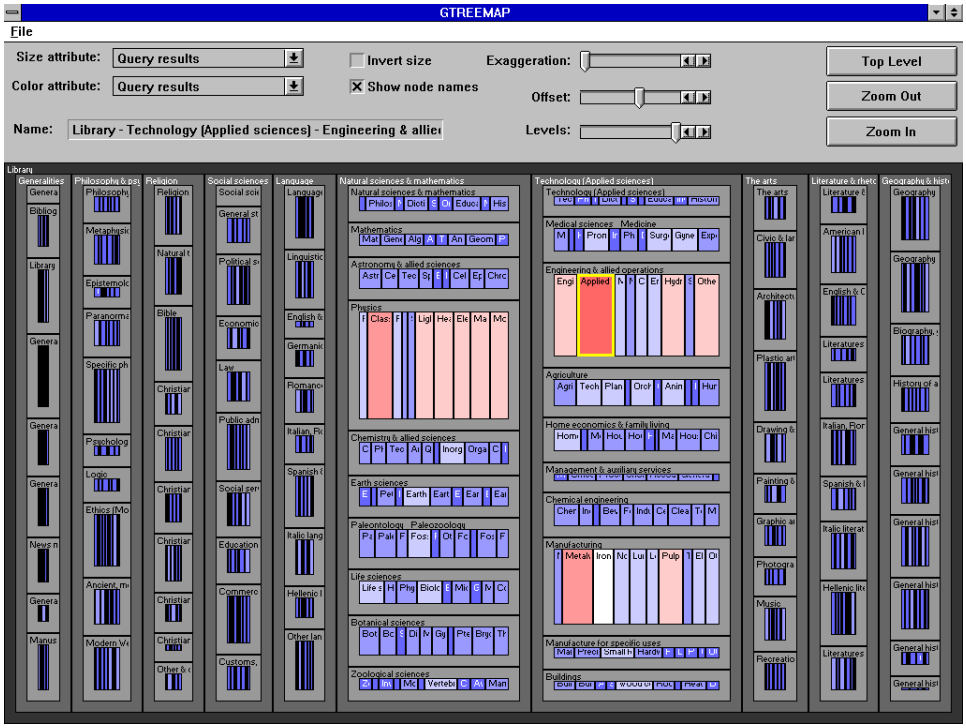

Figure 3.4: A tree map of the Dewey Decimal classification hierarchy widely used in libraries. Copyright ©University of Maryland 1984-1994, all rights reserved.

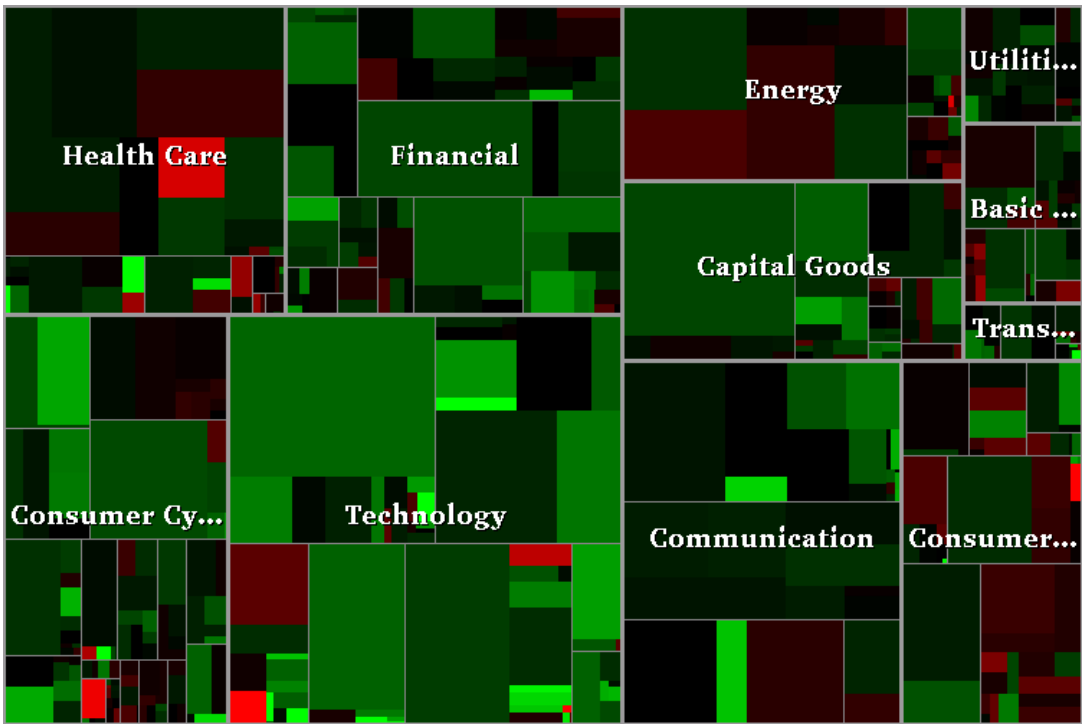

Figure 3.5: A market map of US stocks generated on 17th September 1999.

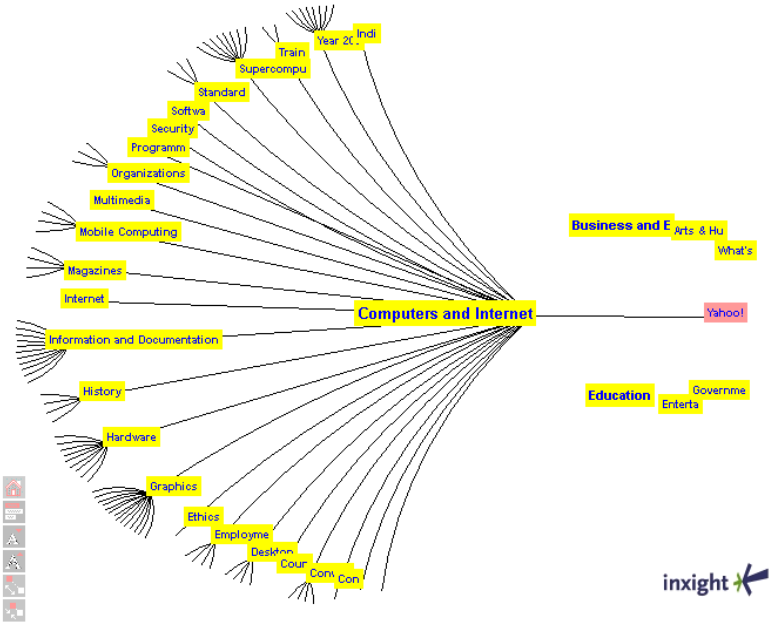

Figure 3.6: The hyperbolic browser always displays the entire hierarchy. However, subtrees around the edge of the disk become so small they are invisible. Here we see the top levels of the Yahoo hierarchy.

- Layout on hyperbolic plane, which is then mapped to the unit disc. Each child places its children in a wedge of space.
- Now sold as software component by Inxight `http://www.inxight.com`, a Xerox offshoot (30-day trial).
- 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 !

3.7 Cheops

- Centre du recherche Informatique de Montréal, 1996.
- Compact 2d representation of a hierarchy by overlaying (squashing together) children to save on screen space. See Figure 3.7.
- Paper at Visualization'96 [Beaudoin et al., 1996].
- Software (Java classes) at `http://www.crim.ca/hci/cheops/`

3.8 Information Slices

- IICM, 1998–1999.

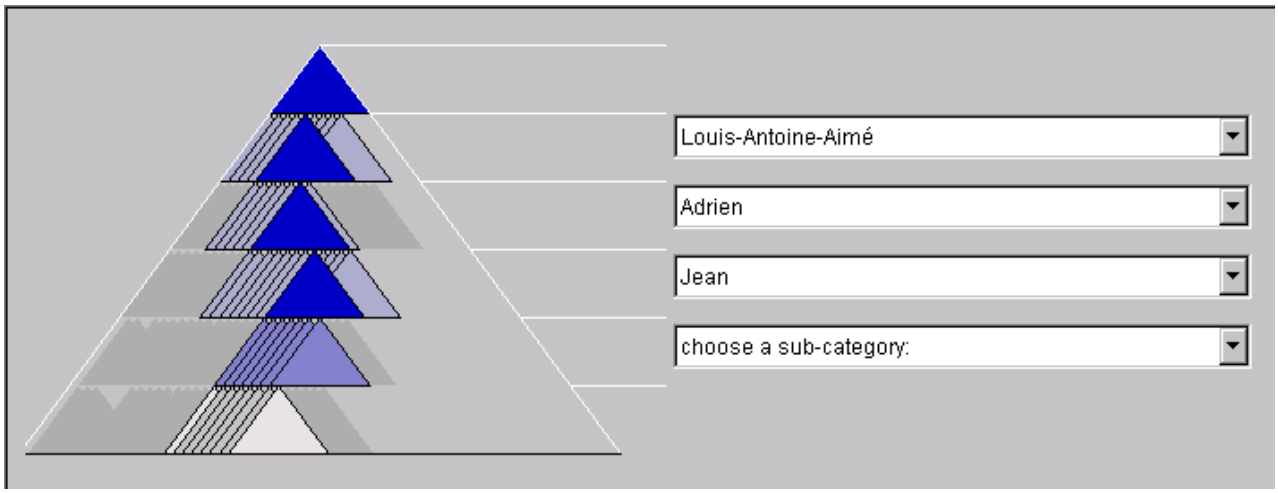

Figure 3.7: Cheops uses stacked triangles to compactly display a hierarchy.

- The hierarchy is fanned out across one or more semi-circular discs. See Figure 3.8.
- 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.
- 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].

3.9 Sunburst

- Jogn Stasko et al, Georgia Tech, 1999-2000.
- Much more advanced version of InfoSlices.
- Uses full disc and implements fan-out of subtrees.
- Paper at IEEE InfoVis 2000 [Stasko and Zhang, 2000] and International Journal of Human-Computer Studies [Stasko et al., 2000].

3.10 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 3.9.
- 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].

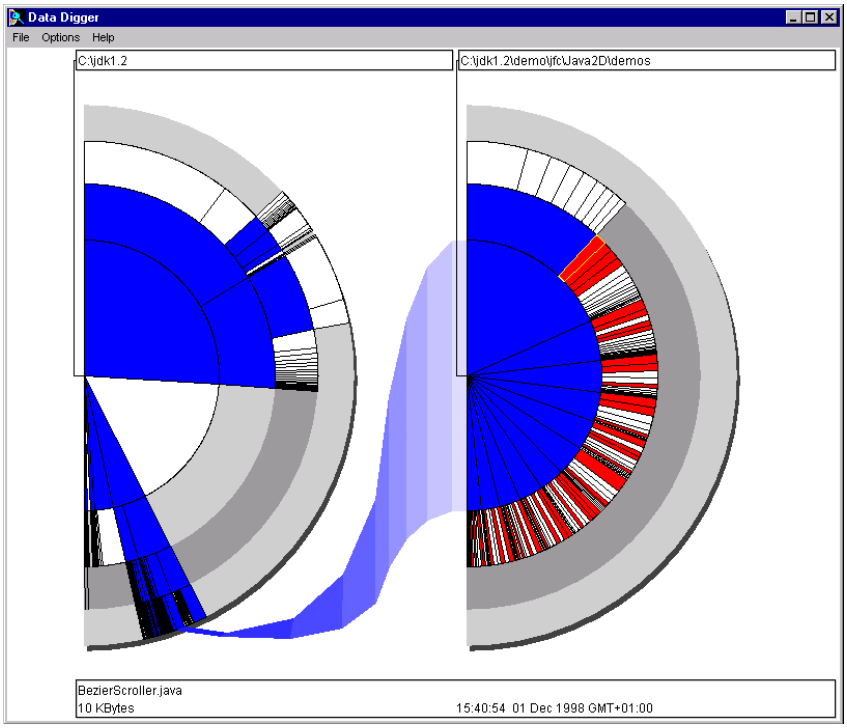

Figure 3.8: An Information Slices visualisation of the JDK 1.2 tree. For deeper hierarchies discs are stacked up in the left margin.

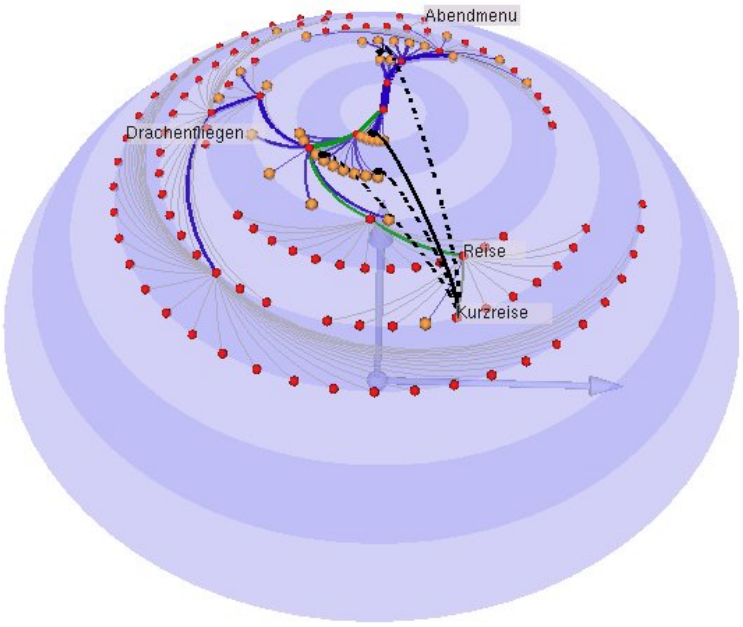

Figure 3.9: The SInVis Magic Eye View.

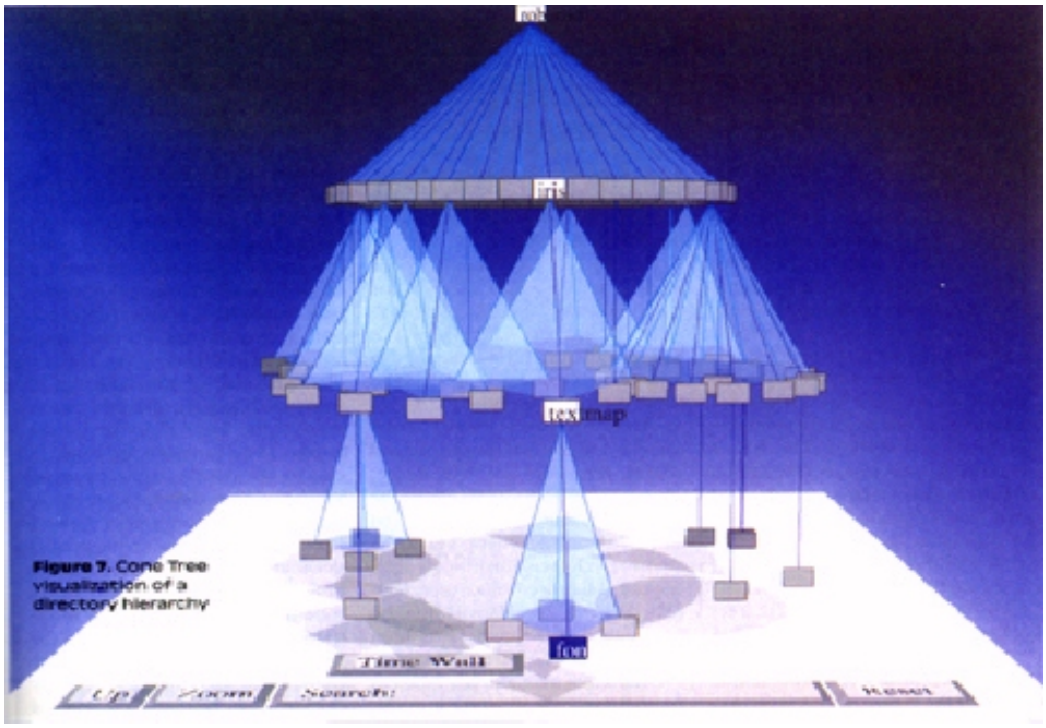

Figure 3.10: The cone tree is a 3d conical representation of a hierarchy. Copyright ©by the Association for Computing Machinery, Inc.

3.11 Cone Tree

- Xerox PARC, 1990.
- 3d conical representation of tree. See Figure 3.10.
- 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].

3.12 File System Navigator (FSN)

- SGI, 1992.
- 3d landscape visualisation of file system.
- Files sit atop pedestals, subdirectories recede into the background. See Figure 3.11.
- 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].

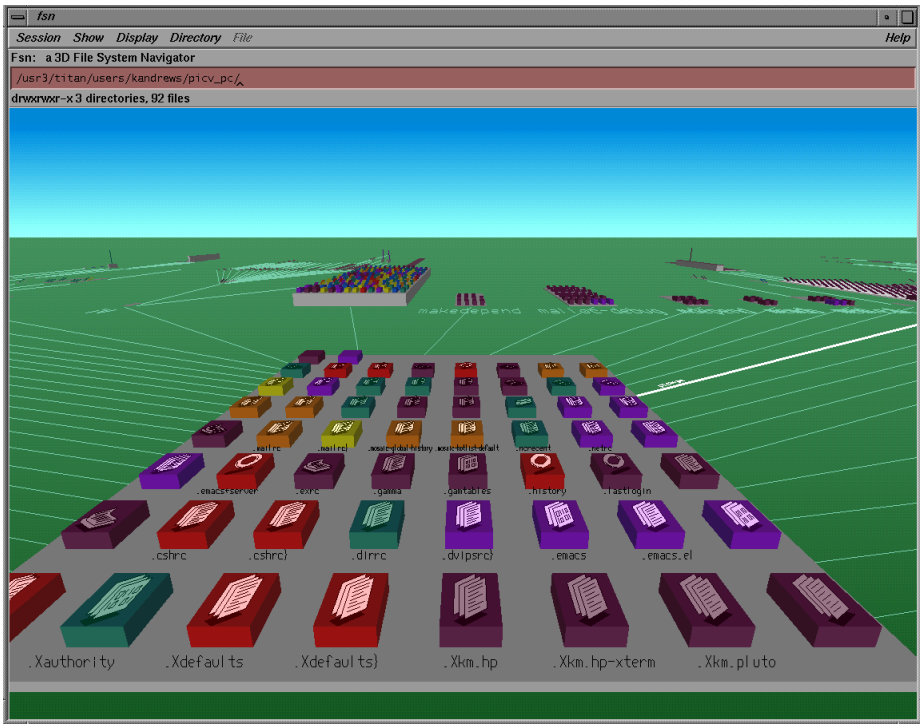

Figure 3.11: FSN landscape visualisation of a file system hierarchy. Files sit atop pedestals, subdirectories recede into the background.

3.13 Harmony Information Landscape

- IICM, 1994–1995.
- 3d landscape visualisation of Hyperwave collection structures. See Figure 3.12.
- 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].

3.14 3D Hyperbolic Browser

- Tamara Munzner, University of Minnesota and Stanford University.
- 3D hyperbolic browser. See Figure 3.13.
- 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].

3.15 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.

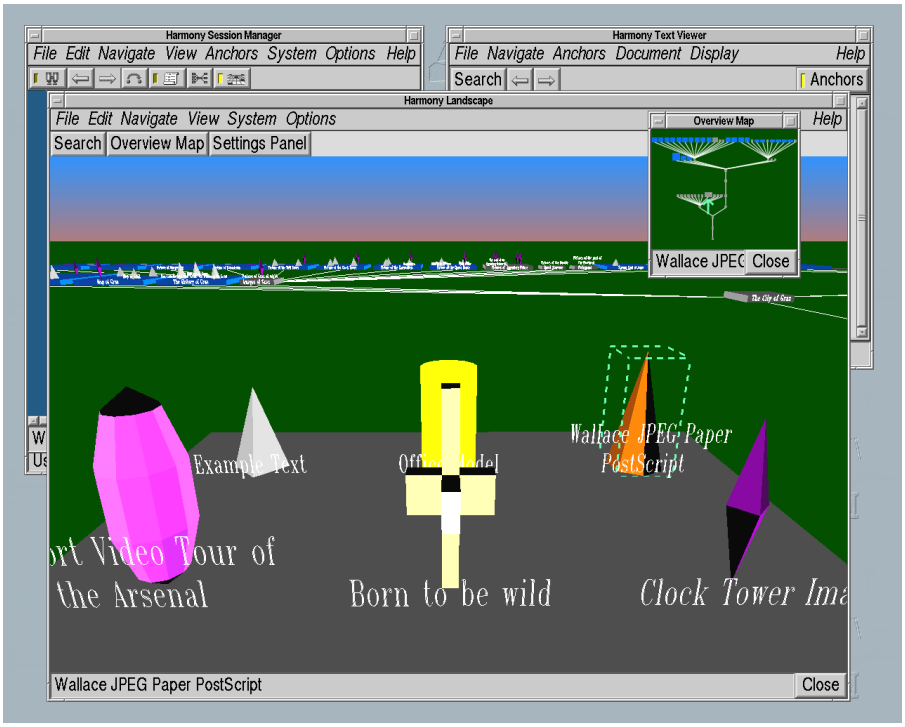

Figure 3.12: The Harmony Information Landscape visualises Hyperwave collection structures.

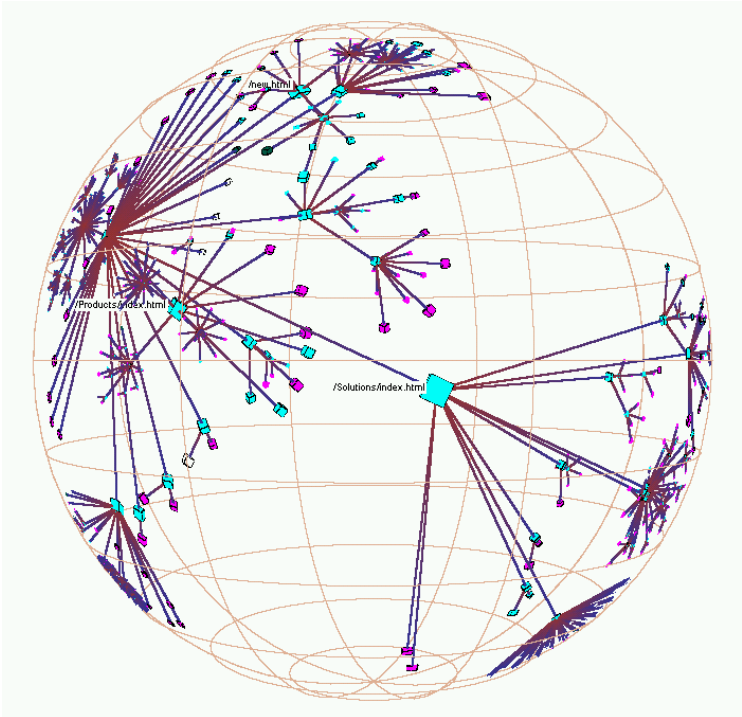

Figure 3.13: The H3 3d hyperbolic browser.

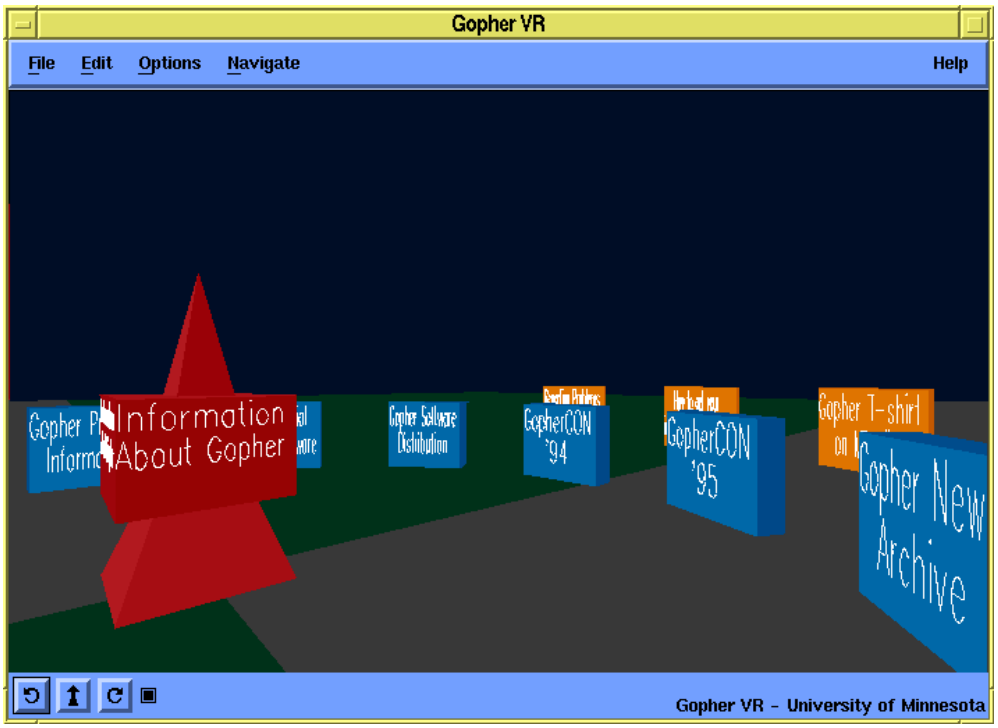

Figure 3.14: GopherVR visualises one level of a Gopher hierarchy at a time. The central pyramid bears the name of the current level, clicking on it returns the user to the next higher level.

- Possibility to hand-place items, for example grouping related items.
- Papers [McCahill and Erickson, 1995; Iacovou and McCahill, 1995].

3.16 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 3.15.
- 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 3.16.
- 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].

3.17 Botanical Visualisation

- Eindhoven University of Technology, 2001.
- An abstract tree is converted into a geometric model of branches and leaves and then rendered.

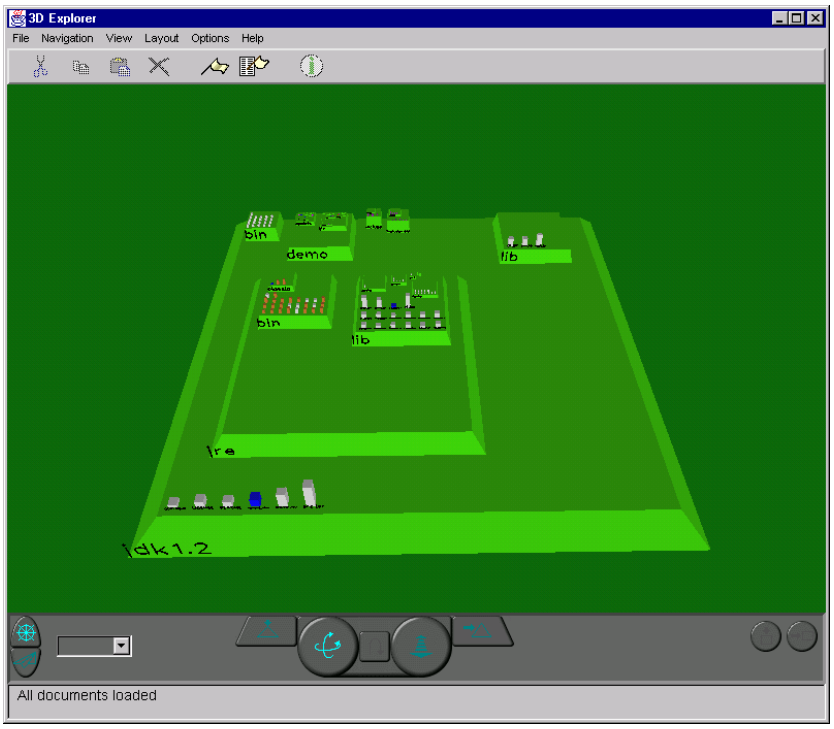

Figure 3.15: An Information Pyramids visualisation of the JDK 1.2 tree. The view from above gives a graphical disk usage. The dashboard provides user navigation. This version uses OpenGL for 3d output.

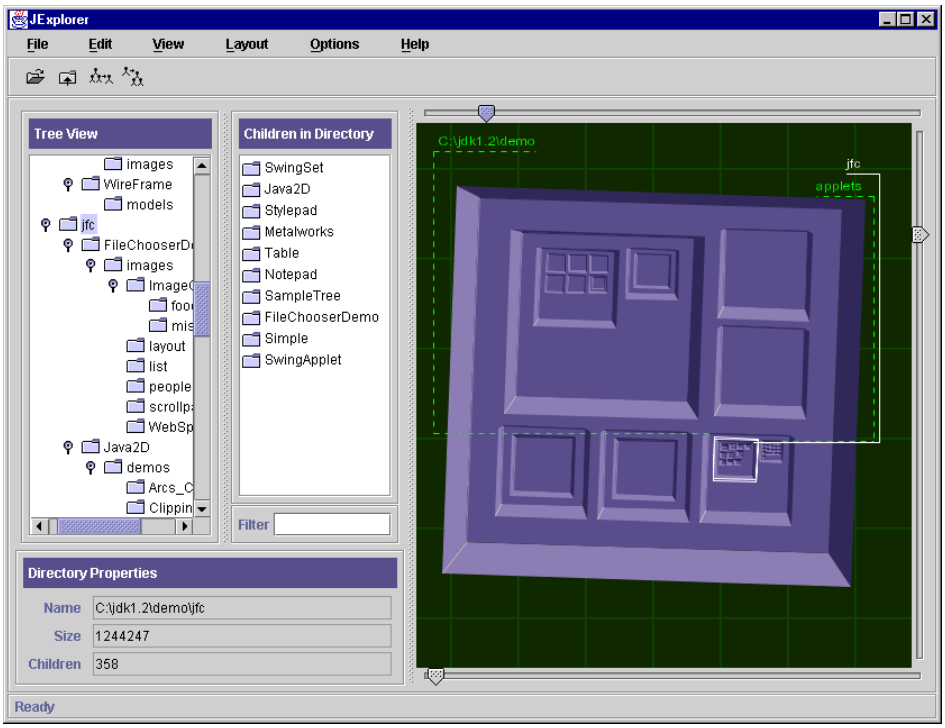

Figure 3.16: The JExplorer combines a Java tree viewer with a synchronised Information Pyramids display.

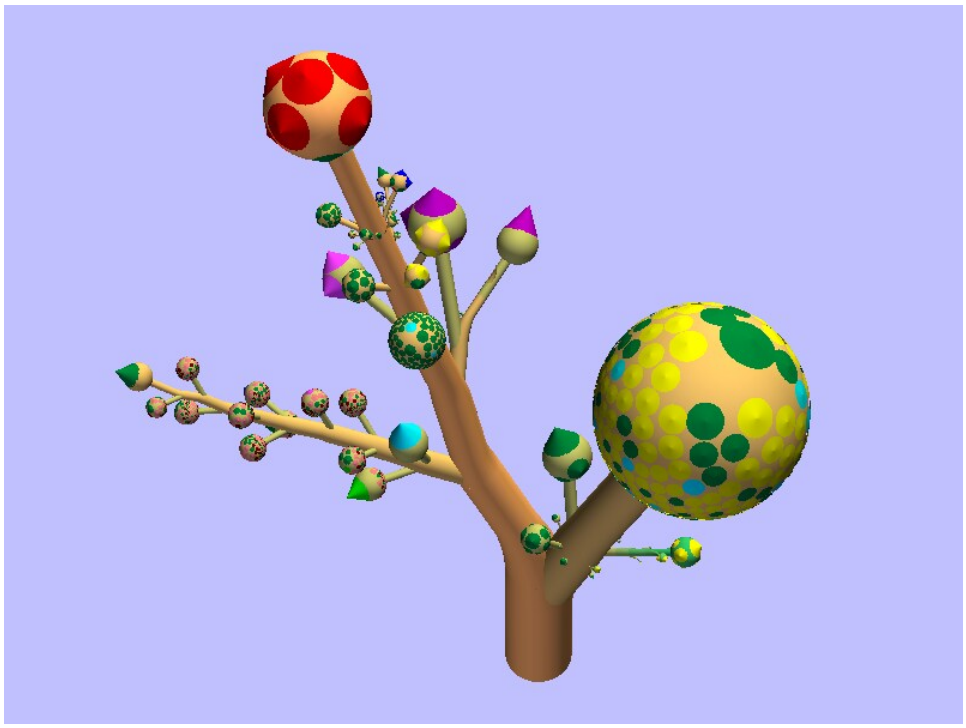

Figure 3.17: Botanical visualisation of a hierarchy.

- 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].

4 Visualising Networks

4.1 SemNet

- Fairchild, Poltrock, Furnas, MCC, 1988.
- The first 3d information visualisation.
- 3d spatial layout of a semantic network. See Figure 4.1.
- Article [Fairchild et al., 1988].
- Patented under [Wexelblat and Fairchild, 1991].

4.2 Harmony Local Map

- IICM, 1993-1994.
- 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].

4.3 Harmony Local Map 3D

- IICM, 1995.
- Links in vertical plane superimposed atop information landscape. See Figure 4.3.
- Description in Chapter 8 of [Andrews, 1996].

4.4 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].

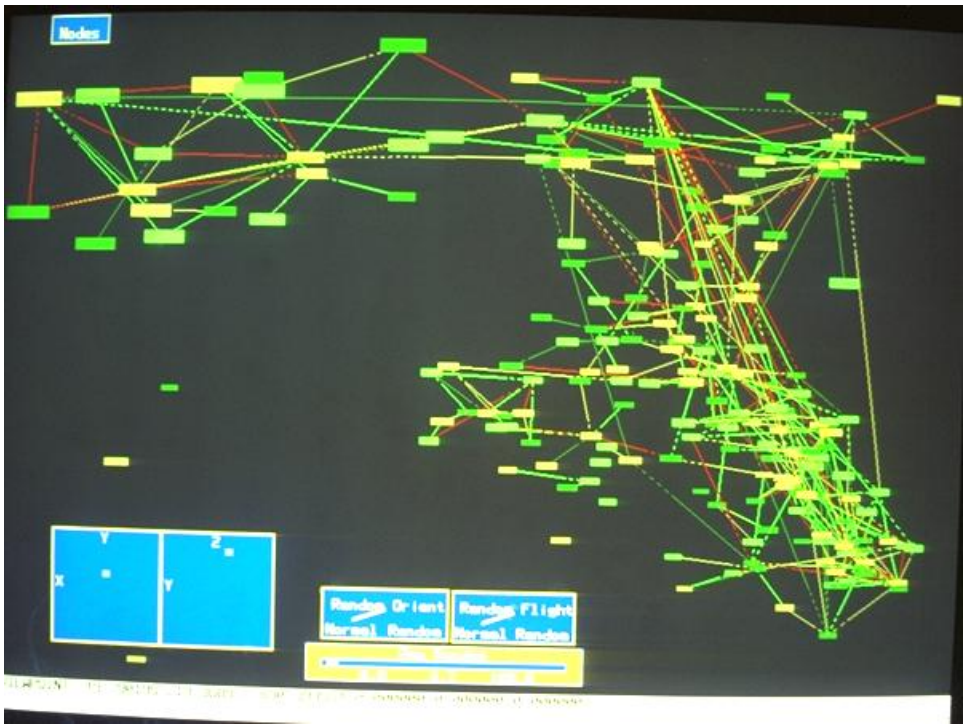

Figure 4.1: SemNet visualised a semantic network in 3d.

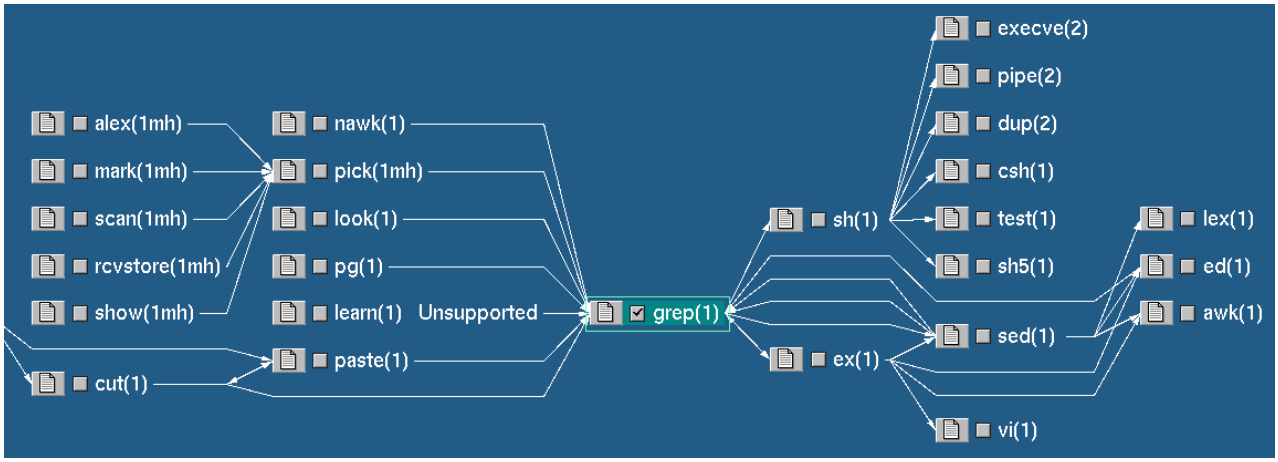

Figure 4.2: The Harmony Local Map uses graph drawing algorithms to lay out a map of the link environment of hypermedia documents. In this example, Unix manual pages one and two links away from the grep manual page are visualised.

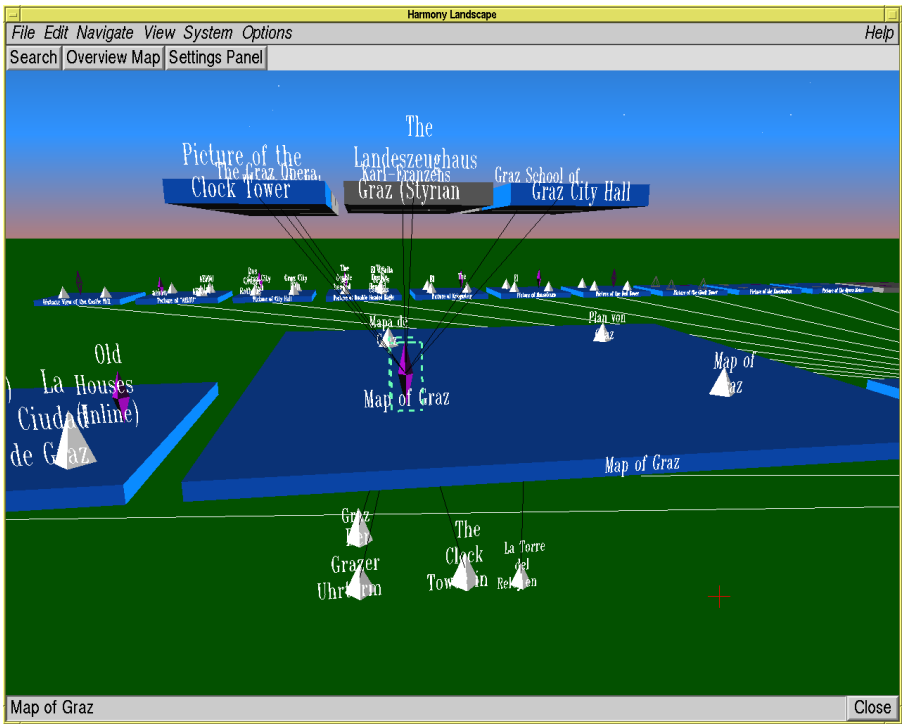

Figure 4.3: The Harmony Local Map 3D display hierarchical structure on the horizontal plane and superimposes hyperlink connections in the vertical plane.

4.5 The Brain

- Harlan, 1996.
- Link network in two dimensions. See Figure 4.4.
- Web site `http://thebrain.com/`
- Patented under [Harlan, 2000a,b].

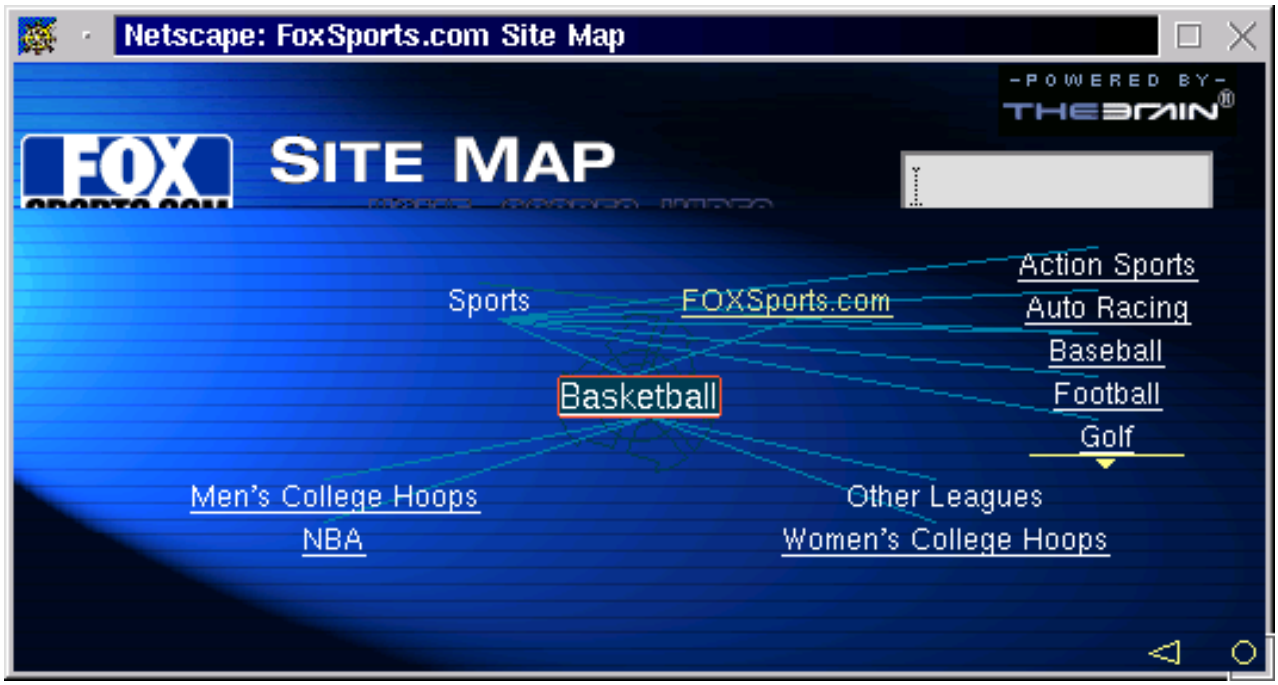

Figure 4.4: The Brain.

5 Visualising Multidimensional Information

5.1 Dynamic Queries and Starfield Display

- HCIL, University of Maryland, 1991-1993.
- Sliders and controls directly manipulate an on-screen scatterplot.
- 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].

5.2 Attribute Explorer

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

5.3 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].

5.4 Search Result Explorer

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

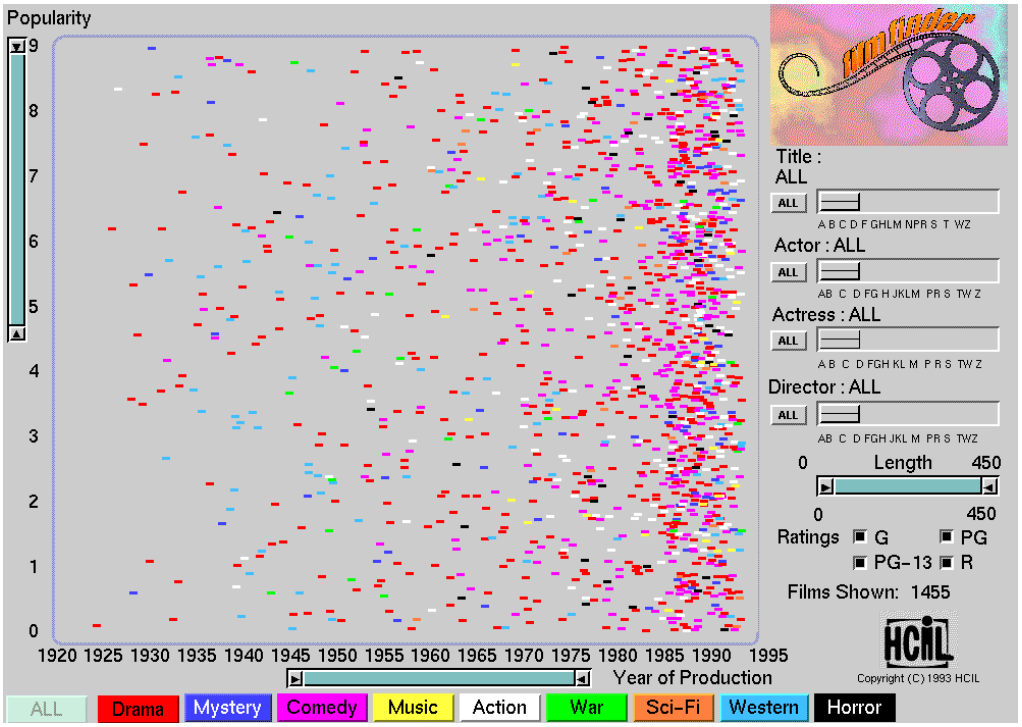

Figure 5.1: The FilmFinder, a starfield display combined with dynamic queries for rapid filtering.

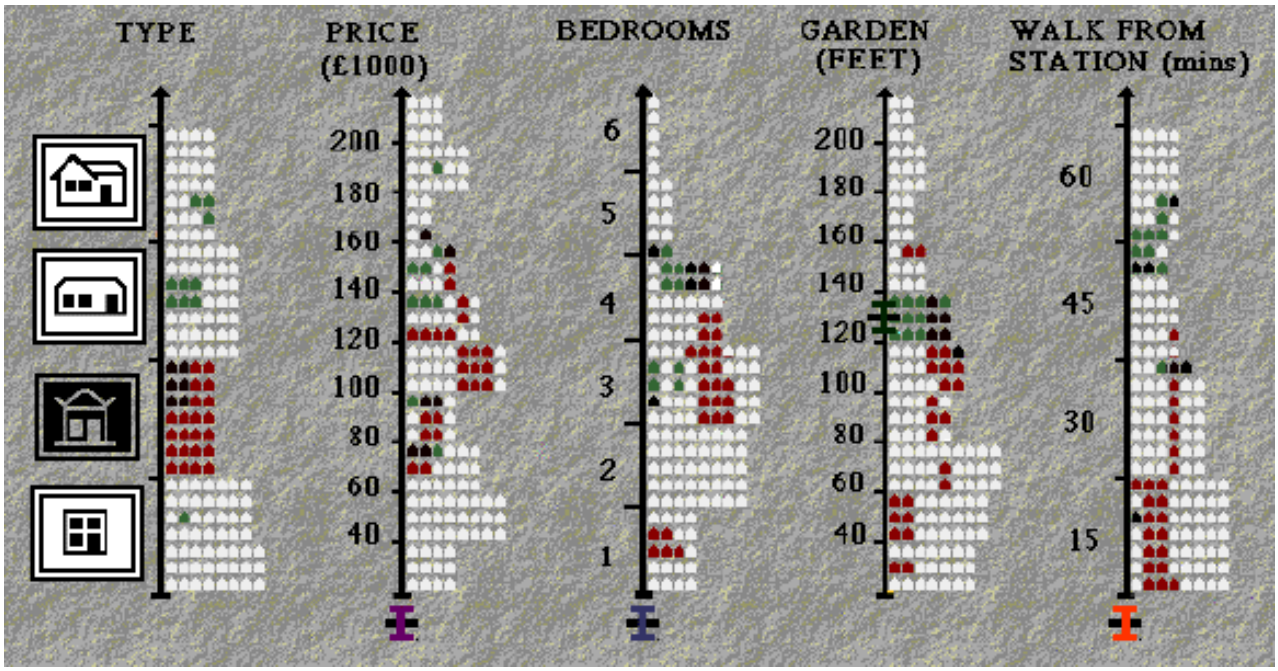

Figure 5.2: The Attribute Explorer. Each attribute is assigned to a scale with histograms showing the population spread running up one side. Initially these display each item in the total population. The user can interact with the scales: using sliders for continuous attributes (e.g. price) and buttons 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.

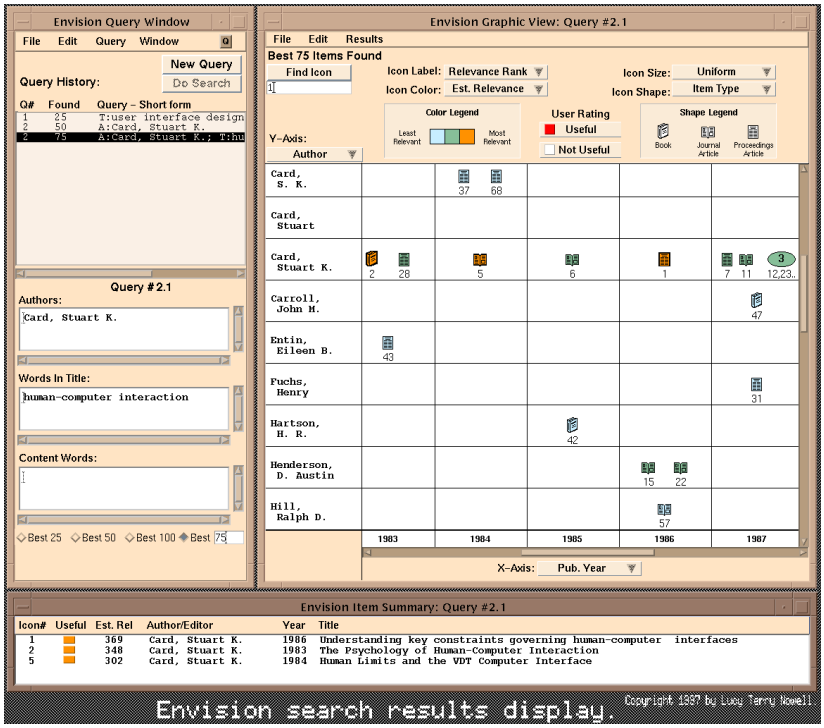

Figure 5.3: Envision visualises a set of search results, by mapping document attributes along two axes. Where too many documents would occupy a cell, an ellipse is used as a container object. Another problem is where to place documents matching multiple categories.

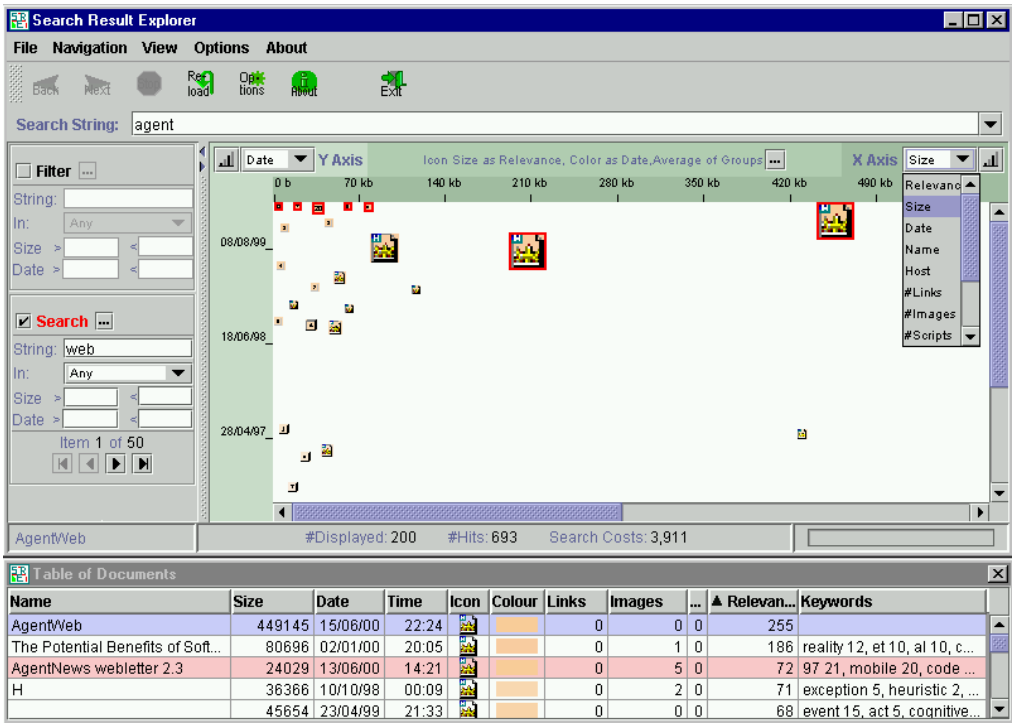

Figure 5.4: Search Result Explorer.

6 IR Based Visualisations

6.1 Bead

- Matthew Chalmers (EuroPARC, Ubilab), 1992–1997.
- Force-based models for laying out relationships between documents.
- Papers [Chalmers, 1993, 1996b,a]

6.2 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].

6.3 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/`

6.4 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].

6.5 SPIRE

- Pacific Northwest National Labs, 1995–2002.
- Build vector space model from text (or other document) corpus.
- Multidimensional scaling to map to 2d Galaxy View.

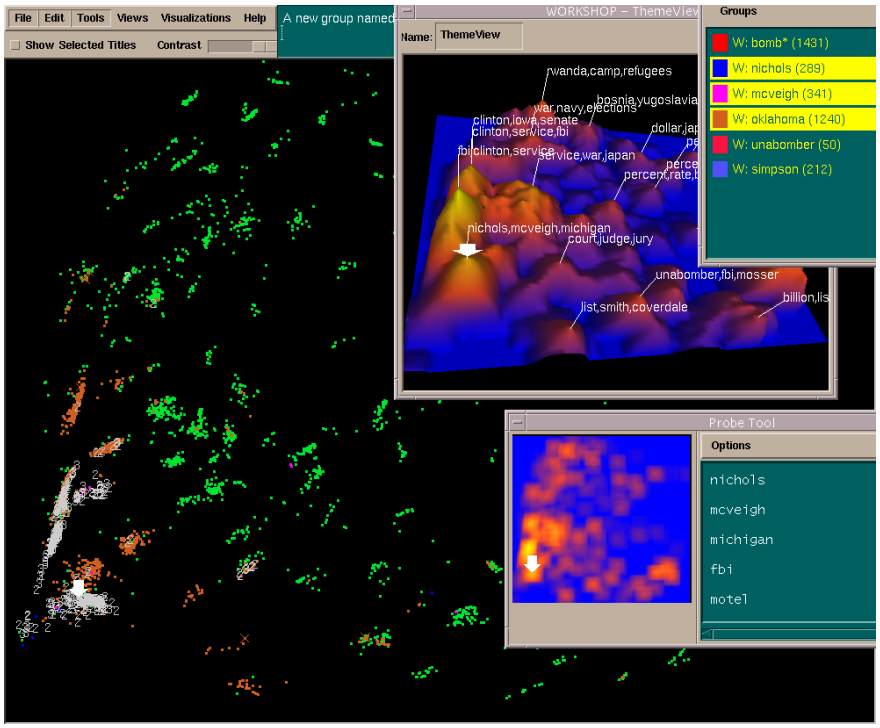

Figure 6.1: SPIRE showing the Galaxy View (below), Themescape (upper right) and Probe Tool.

- From Galaxy View aggregate of keywords in height dimension to form Themescape. See Figure 6.1.
- Paper in ISKO [Hetzler et al., 1998], technical details paper in JASIS [Wise, 1999], good overview at I-Know '01 [Thomas et al., 2001].

6.6 VisIslands

- IICM, 2001.
- Build vector space model from search result sets.
- Force-directed placement to map to 2d island scape.
- Paper at UIDIS 2001 [Andrews et al., 2001].

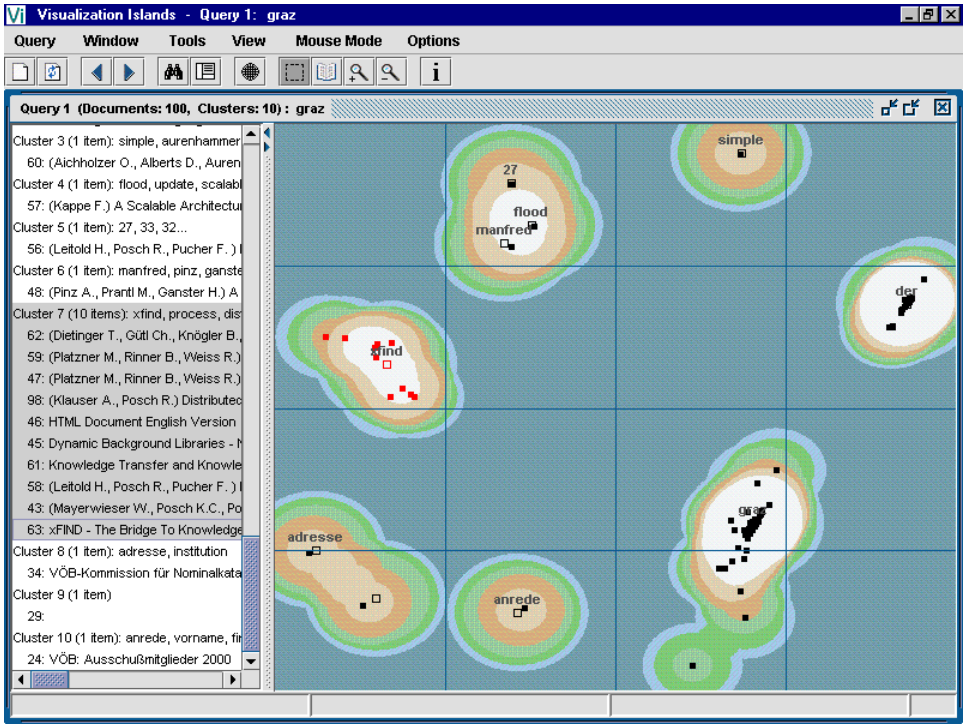

Figure 6.2: VisIslands forms visual clusters of search result sets.

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