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.

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Keith

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Chapter 1

Introduction

> *“ Let my dataset change your mindset. ”*
>
> [Hans Rosling, title of talk at TED@State, 03 Jun 2009 [Rosling, 2009].]

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

Visualisation

- The broader field of visualisation has three main sub-fields:
  - SciVis: Scientific Visualisation (flows, volumes, surfaces).
  - GeoVis: Geographic Visualisation (maps).
  - InfoVis: Information Visualisation (abstract structures).
- DataVis: Data Visualisation = InfoVis + GeoVis.

Information Visualisation

- Visualisation of *abstract* information structures.
- InfoVis ≠ SciVis or GeoVis:
  - In SciVis, the visual representation is usually given, suggested by geometry inherent in the data: say a 3d
  - In GeoVis, the visual representation is usually given, based upon a map.
  - In InfoVis, an appropriate visual representation must be (carefully) designed or “invented”.
- The visual representation is only half the story: interaction (appropriate navigational and manipulation facilities) must still be provided.

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

Conferences

- IEEE Symposium on Information Visualization (InfoVis). Since 1995. The main conference in the field, quite low acceptance rate (25% in 2013), very focussed, high quality papers, single-track. `ieeevis.org` Proceedings published with IEEE: `http://conferences.computer.org/infovis/`
- Eurographics/IEEE Symposium on Visualization (EuroVis). Formerly VisSym. Fairly high quality. `eurovis.org/` 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/IV2015/` Proceedings published with IEEE: `http://ieeexplore.ieee.org/servlet/opac?punumber=1000370`
- See Conference, Germany. `see-conference.org/`
- Some papers at CHI, AVI, UIST.
- Visual Analytics and Information Visualisation track at I-Know conference in Graz, Austria. `i-know.at`

InfoVis Companies

Suppliers of infovis toolkits and components:

- Inxight `inxight.com` (Inxight was bought by BusinessObjects in May 2007, BusinessObjects was bought by SAP in Oct 2007).
- Spotfire `spotfire.com` (Spotfire was bought by Tibco in May 2007).
- Tableau `tableausoftware.com`
- The Hive Group `hivegroup.com`
- Panopticon `panopticon.com`
- macrofocus `macrofocus.com`
- Maya Viz `mayaviz.com` (Maya Viz was bought by General Dynamics in Apr 2005).
- OmniViz `omniviz.com` (OmniViz was bought by BioWisdom in Feb 2007, BioWisdom was bought by Instem in Mar 2011).
- AVS `avs.com`
- NComVA `ncomva.com`
- Visual Insights `visualinsights.com` (Visual Insights was renamed Advizor Solutions in 2003).
- magnaview `magnaview.com`
- Oculus Info `oculusinfo.com`
- Tom Sawyer Software `tomsawyer.com`
- ILOG `ilog.com` (ILOG was bought by IBM in Jan 2009).

Video: Stephen Few

- Stephen Few; *Now You See It*; 58-minute video [Few, 2008] [14:12–27:00]

Month	*Salesperson A*	*Salesperson B*
2012-01	28366	23274
2012-02	27050	21732
2012-03	29463	23845
2012-04	32561	28732
2012-05	28050	24023
2012-06	30100	26089
2012-07	22343	19026
2012-08	21506	17903
2012-09	24664	19387
2012-10	28842	23490
2012-11	30621	25873
2012-12	36254	28490

Table 1.1: Sales for 2012 in € by salesperson. Table of fictional sales data. Compare the sales figures of the two salespeople.

Figure 1.1: Sales for 2012 in € by salesperson. Line chart of the same sales data. It is much easier to see the trends and compare the data, when it is presented visually.

1.2 Why Visualise?

Table vs Line Chart

Compare the table of numbers in Table 1.1 with the visual representation (a line chart) of the same data in Figure 1.1.

- It is much easier to see trends and patterns in the visual representation.
- It is easier to make comparisons in the visual representation.
- It is easier to read off exact data values in the tabular representation (although you could, for example, display exact values upon mouseover in an interactive version of the line chart).

175496490872545628327267094621
635280462905702676727325929055
561548569586711934907152874596
596289748716229184490082538851
180265490932887579802909278921
872634890928895000283058985889
927756990049828005987761883115

Figure 1.2: Count the number of 3s. Attentive processing requires conscious effort and proceeds serially.

175496490872545628327267094621
635280462905702676727325929055
561548569586711934907152874596
596289748716229184490082538851
180265490932887579802909278921
872634890928895000283058985889
927756990049828005987761883115

Figure 1.3: Count the number of 3s. Colour is a pre-attentive attribute. By encoding the target 3s in red, they can be rapidly processed by the human visual system pre-attentively. Pre-attentive processing occurs without conscious effort and in parallel.

Attentive vs Pre-Attentive Processing

View Figure 1.2 and count the number of 3s. Then do the same with Figure 1.3.

- Text and numbers have to be processed attentively, which requires cognitive effort and proceeds in serial (slow).
- Certain visual attributes can be processed pre-attentively, which happens without conscious effort and in parallel (fast).

Anscombe's Quartet

- Table 1.2 shows Francis Anscombe's 1973 dataset [Anscombe, 1973; Wikipedia, 2013; Kosara, 2011] with four variables in x and y.

	v_1		v_2		v_3		v_4	
	x_1	y_1	x_2	y_2	x_3	y_3	x_4	y_4
	10.00	8.04	10.00	9.14	10.00	7.46	8.00	6.58
	8.00	6.95	8.00	8.14	8.00	6.77	8.00	5.76
	13.00	7.58	13.00	8.74	13.00	12.74	8.00	7.71
	9.00	8.81	9.00	8.77	9.00	7.11	8.00	8.84
	11.00	8.33	11.00	9.26	11.00	7.81	8.00	8.47
	14.00	9.96	14.00	8.10	14.00	8.84	8.00	7.04
	6.00	7.24	6.00	6.13	6.00	6.08	8.00	5.25
	4.00	4.26	4.00	3.10	4.00	5.39	19.00	12.50
	12.00	10.84	12.00	9.13	12.00	8.15	8.00	5.56
	7.00	4.82	7.00	7.26	7.00	6.42	8.00	7.91
	5.00	5.68	5.00	4.74	5.00	5.73	8.00	6.89
mean	**9.00**	**7.50**	**9.00**	**7.50**	**9.00**	**7.50**	**9.00**	**7.50**
sd	**3.3166**	**2.0316**	**3.3166**	**2.0317**	**3.3166**	**2.0304**	**3.3166**	**2.0306**

Table 1.2: The four variables known as Anscombe's Quartet look almost identical if only standard summary statistics such as mean and standard deviation (sd) are considered.

- Standard summary statistics such as mean and standard deviation are almost identical for all four variables.
- However, when plotted graphically, as shown in Figure 1.4, the four variables are revealed to be very different.

1.3 Visual Lies

Misuse of 3D Perspective

- Surely, no-one would ever misuse 3d perspective to a false impression?
- In his Macworld 2008 keynote speech, Steve Jobs showed a 3d pie chart of US smartphone market share data by brand. Figure 1.5 shows the original slide and Figure 1.6 is a reconstruction of Jobs' 3d pie chart. Table 1.3 shows the raw data in a table.
- The "Apple" slice of 19.5% is at the bottom of the pie chart and is tilted towards the viewer, making it appear much larger than the "Other" slice of 21.2% at the top.
- A fairer representation would be to use a standard 2d pie chart (see Figure 1.7), or even better a bar chart (see Figure 1.8) of the same data.
- As Jack Schofield of the Guardian points out [Schofield, 2008], the graphic is cleverly deceptive in at least two other ways as well:
  - Splitting market share by brand emphasises Apple. A more honest appraisal would be to split by operating system (OS), since certain OSes are used by several brands.
  - At the time, Symbian dominated the world smartphone market share, but was weak in the US, so showing only US data places Apple in the best light.

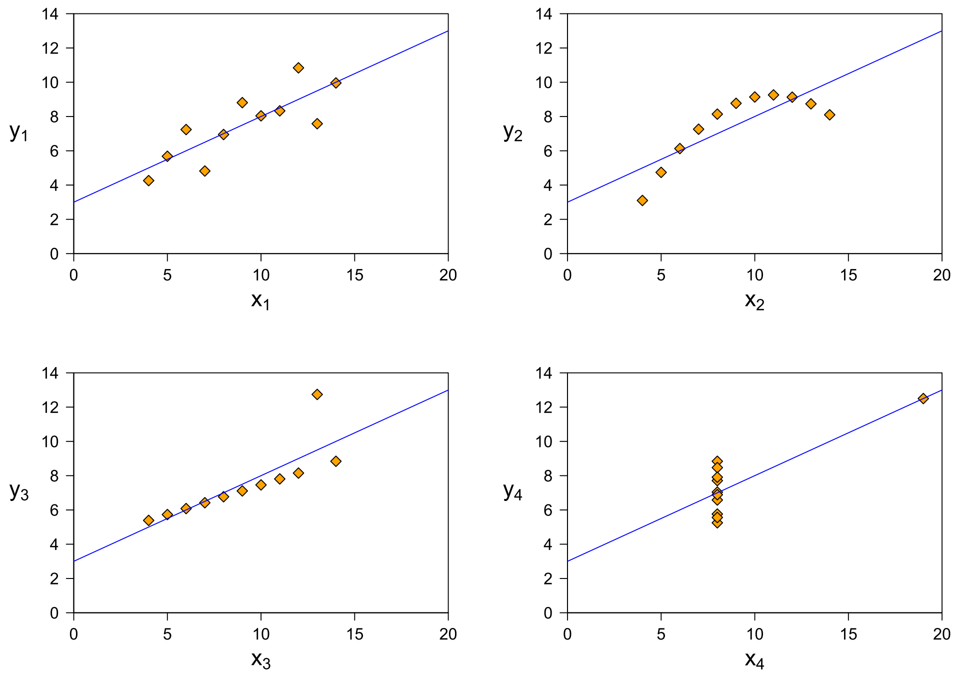

Figure 1.4: The four variables in Anscombe's Quartet have almost identical summary statistics (mean, standard deviation, etc.). However, when plotted graphically, they are revealed to be rather different in nature.

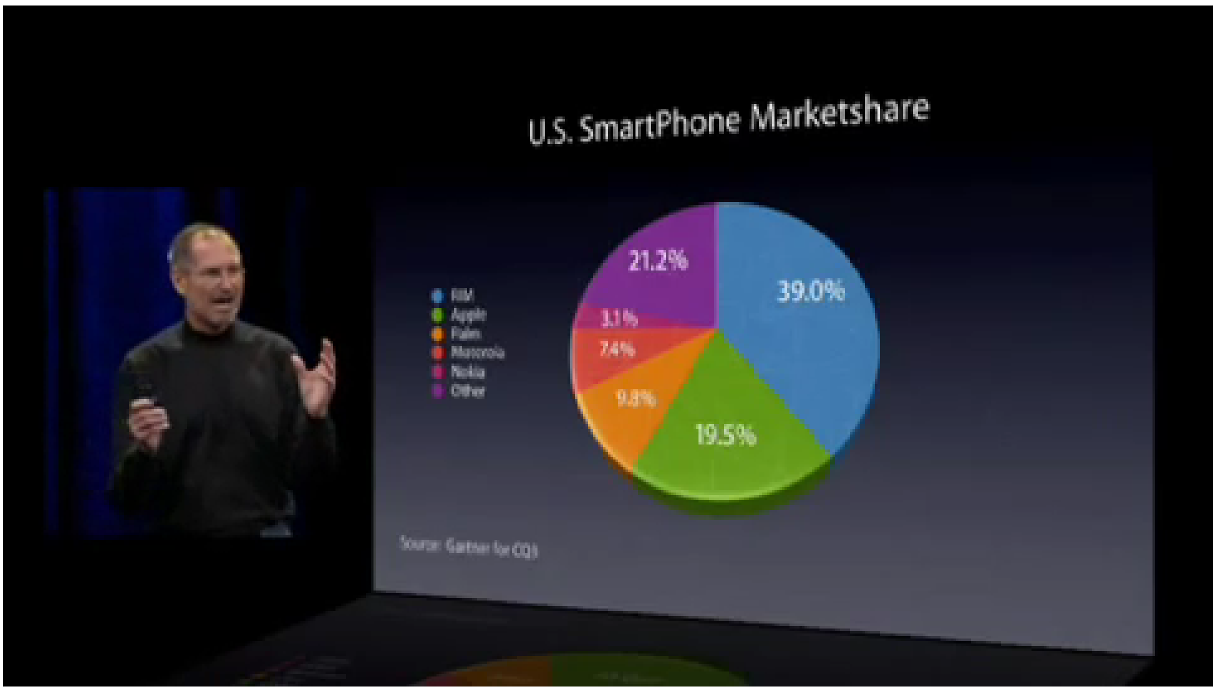

Figure 1.5: Steve Jobs' 3d pie chart. [The image is a still from the video of Steve Jobs' keynote speech at Macworld 2008 [Jobs, 2008, 00:03:00]. It is used under the provisions of fair use.]

Manufacturer	Market Share (%)
RIM	39.0
Apple	19.5
Palm	9.8
Motorola	7.4
Nokia	3.1
Other	21.2

Table 1.3: Steve Jobs' pie chart data showing U.S. smartphone market share for Q3 2007 as given by Gartner.

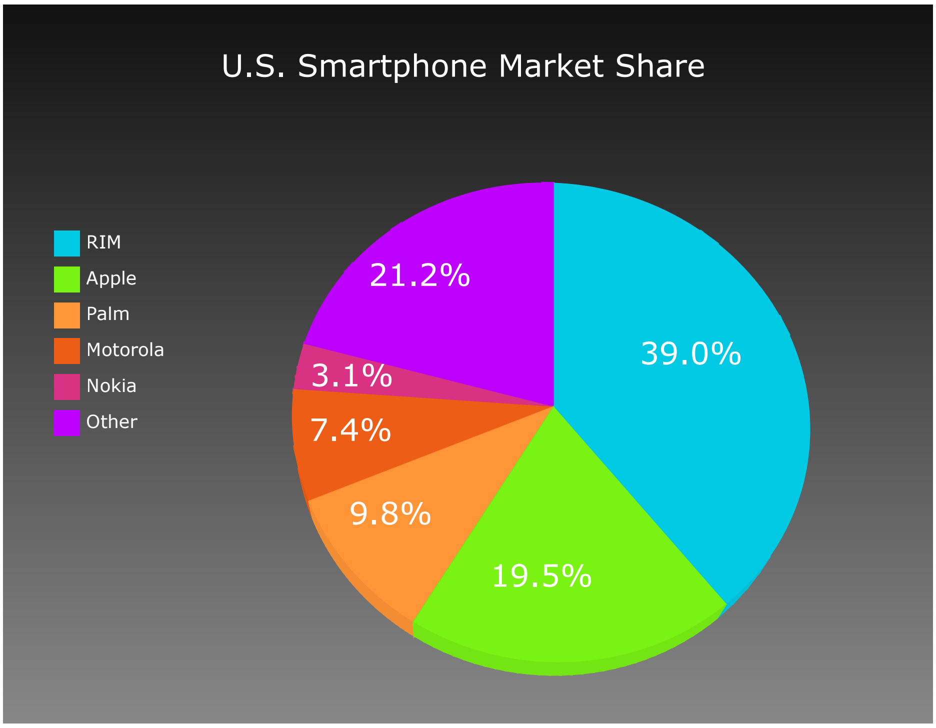

Figure 1.6: A reconstruction of Steve Jobs' 3d pie chart. The chart was created with the LiquidDiagrams package.

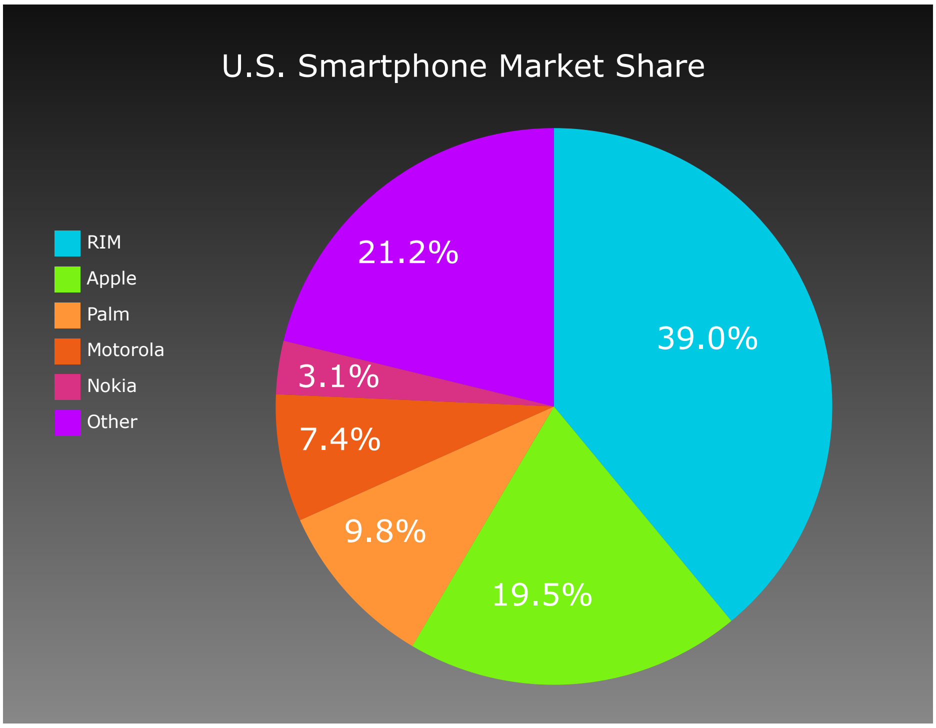

Figure 1.7: A standard, 2d pie chart of the data. The chart was created with the LiquidDiagrams package.

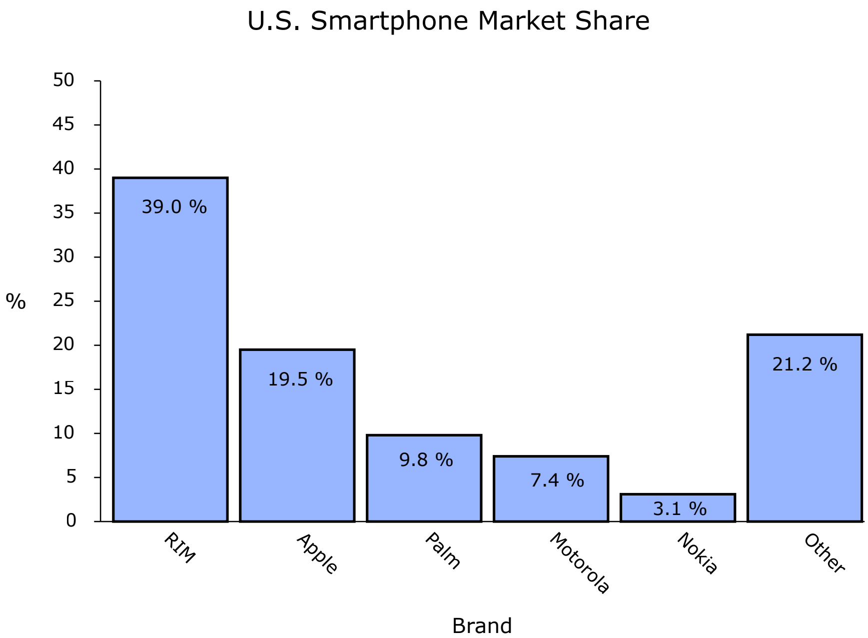

Figure 1.8: A bar chart of the data. The chart was created with the LiquidDiagrams package.

Video: Noah Iliinsky

- Noah Iliinsky; *Data Visualizations Done Wrong*; 5-minute video [Iliinsky, 2012] [05:11]

1.4 General Concepts 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:

- **Overview-plus-detail**: two separate, synchronised windows, an overview and a detail view.
- **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; Furnas, 1986].
- **Focus-plus-blur**: focus items are (optically) in focus, context items are blurred.

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, J. D. Mackinlay and S. K. Card, 1991a].

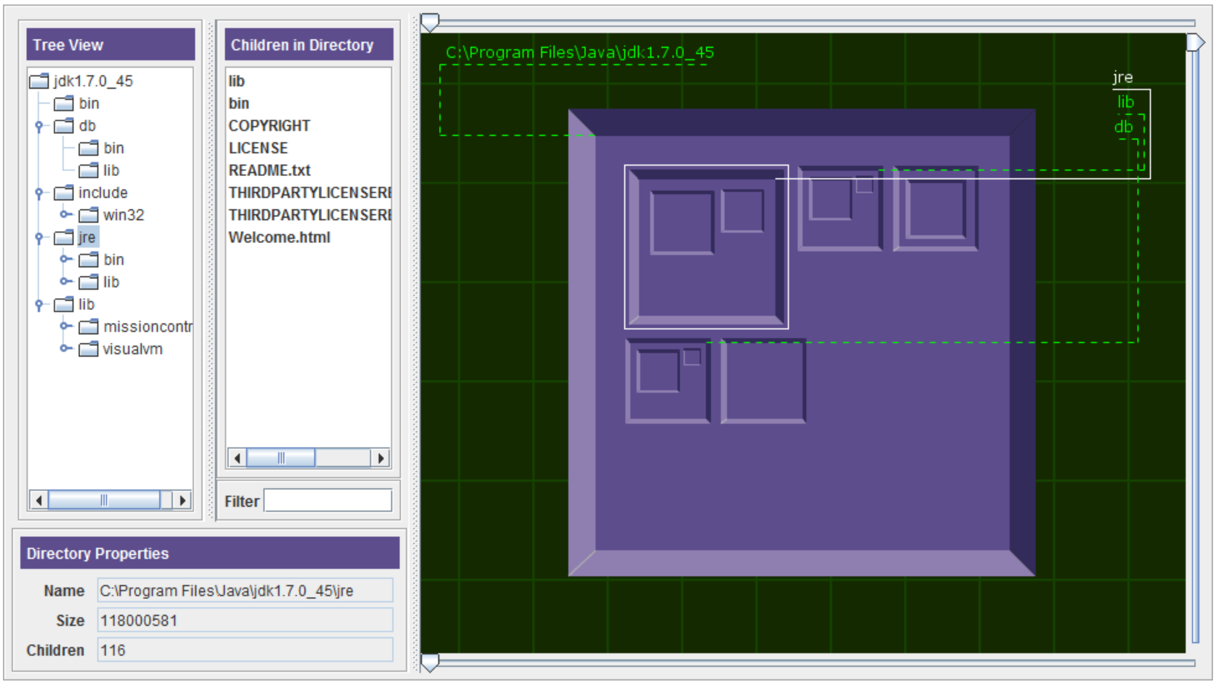

Figure 1.9: Excentric labels are drawn outside of the main visualisation and connected to the corresponding elements by lines. In the JExplorer tree browser, excentric labels are used to label the selected folder, its parent, and (some) siblings. [Screenshot made by Keith Andrews.]

Guaranteed Visibility

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

Edge Bundling

In node-link visualisations, there are sometimes so many edges that visual clutter results:

- Edge bundling [Holten, 2006; Holten and Van Wijk, 2009] ties edges with similar paths together visually to reduce clutter.
- It is like applying cable ties to a bunch of computer network cables which follow the same path.

Excentric Labels

Sometimes, there is not enough room inside a visualisation to properly label individual elements:

- To avaoid clutter, *excentric labels* [Fekete and Plaisant, 1999; Welz, 1999, pages 57 and 81] are drawn outside of the main visualisation and connected to the corresponding elements by lines.

See Figure 1.9.

1.5 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.

Video: Hans Rosling

- Hans Rosling; *Stats That Reshape Your World View*; 20-minute video [Rosling, 2006] [00:00–18:54]

Video: David McCandless

- David McCandless; *The Beauty of Data Visualization*; 18-minute video [McCandless, 2010] [00:00–07:28, 17:09-17:54]

Chapter 2

Visual Perception

> “ *We see more with our mind than our eyes.* ”
>
> [Connie Malamed, Visual Language for Designers, 2009 [Malamed, 2009, page 25]]

References

++ Colin Ware; *Information Visualization: Perception for Design*; 3rd Edition, Morgan Kaufmann, Jun 2012. ISBN 0123814642 (com, uk) [Ware, 2012]

++ Christopher Healey and James Enns; *Attention and Visual Memory in Visualization and Computer Graphics*; IEEE Transactions on Visualization and Computer Graphics (TVCG), Jul 2012. doi:10.1109/TVCG.2011.127 [C. G. Healey and Enns, 2012]

+ Stephen Few; *Tapping into the Power of Visual Perception* Chapter 5 of *Information Dashboard Design*; 2nd Edition, Analytics Press, 15 Aug 2013. ISBN 1938377001 (com, uk) [Few, 2013, Chapter 5]

+ Connie Malamed; *Visual Language for Designers: Principles for Creating Graphics That People Understand*; Rockport Publishers, Jun 2009. ISBN 1592537413 (com, uk) [Malamed, 2009]

+ Christopher Chabris and Daniel Simons; *The Invisible Gorilla: And Other Ways Our Intuition Deceives Us*; Harper Collins, Mar 2011. ISBN 000731731X (com, uk) [Chabris and Simons, 2011]

◦ Richard Gregory; *Eye and Brain*; 5th Edition, Princeton University Press, 1997. ISBN 0691048371 (com, uk) [Gregory, 1997]

◦ Brian Wandell; *Foundations of Vision*; Sinauer Associates, 1995. ISBN 0878938532 (com, uk) [Wandell, 1995]

◦ Bruce, Green, and Georgeson; *Visual Perception*; 4th Edition, Psychology Press, 2003. ISBN 1841692379 (com, uk) [Bruce, Green and Georgeson, 2003]

Online Resources

++ Christopher Healey; *Perception in Visualization*; `http://www.csc.ncsu.edu/faculty/healey/PP/` [C. Healey, 2009]

++ Stephen Few; *Tapping the Power of Visual Perception*; Blog article, 04 Sept 2004. `http://www.perceptualedge.com/articles/ie/visual_perception.pdf` [Few, 2004]

++ Stephen Few; *Data Visualization for Human Perception*; Chapter 35 of The Encyclopedia of Human-Computer Interaction, 2nd Ed, 2014. https://interaction-design.org/encyclopedia/data_visualization_for_human_perception.html [Few, 2014]

◦ Steven Bradley; *What Designers Should Know About Visual Perception and Memory*; Blog article, 07 Mar 2011 http://www.vanseodesign.com/web-design/visual-perception-memory/ [Bradley, 2011]

◦ Connie Malamed; *Understanding Graphics*; understandinggraphics.com [Malamed, 2013]

Bandwidth of the Senses

- based on work by Tor Nørretranders.
- McCandless TED 2010 video [00:08:55–00:09:44].

2.1 Human Vision

The eyes sample the environment 3–4 times per second, building up a picture of what is there in our mind:

- Fixation: a brief stationary period when visual information is sampled.
- Saccade: a period of rapid eye movement to a new location.

We actually see with our mind.

What we see depends not only on what is actually there, but also on what we expect to see and where our attention is directed.

“What you see is what you need”

Colour Perception

2.2 Visual Input takes Priority

Sight overrides hearing (McGurk effect).

Sight can override touch (rubber hand).

2.3 Selective Attention

The eyes only see what the mind attends to.

Visual Working Memory

The capacity of visual working memory is limited to 3–4 simple shapes [Vogel, Woodman and Luck, 2001].

2.4 Pre-Attentive Attributes (Pop-Out Features)

Certain attributes can be processed pre-attentively.

They “pop out” of the screen at you (without conscious effort).

The following attributes are pre-attentive:

- Colour intensity (luminance).
- Colour hue.
- 2d spatial position.
- Size.
- Orientation.
- Line length.
- Line width.
- Shape.
- Curvature.
- Closure.
- Added marks.
- Enclosure.
- 3d depth.
- Focus (vs. blur).
- Direction of motion.
- Velocity of motion.
- Flicker (blinking).

Some attributes are perceived more readily (are perceptually stonger) than others.

Encoding Quantitative Values

Only two of the pre-attentive attributes can be perceived quantitatively:

- 2d spatial position.
- Line length.

Only these two can be used to accurately encode continuous quantitative numerical values:

- location on a line graph (2d spatial position).
- location on a scatter plot (2d spatial position).
- length of a bar in a bar graph (line length).

Perceiving Continuous Differences

Differences in colour intensity, colour hue, and size can be perceived only to a certain degree (one shade of grey is lighter than another).

It is hard to compare them accurately on a continuous scale:

- This shade of grey is 10% lighter than that one.
- This slice of a pie chart is 5% smaller than that one.

Some attributes such as shape are more naturally non-continuous (say, there are five distinct glyphs). [Chernoff faces would be an exception, because they vary continuously.]

These pre-attentive attributes are better used for encoding categories.

Encoding Categories

The following pre-attentive attributes are particulary useful for encoding categories:

- Colour hue.
- Colour intensity.
- Shape.
- Size.

Again, some of these attributes are perceived more readily (are perceptually stonger) than others.

Conjunctions

Beware when using multiple encodings in one display.

Most pre-attentive attributes cannot be combined and remain pre-attentive.

Conjunctions of motion, depth, colour, and orientation can remain pre-attentive.

Chapter 3

History of Information Visualisation

References

+ Theodore W. Pietsch; *Trees of Life*; Johns Hopkins University Press, 02 May 2013. ISBN 1421411857 (com, uk) [Pietsch, 2013]

+ Manuel Lima; *The Book of Trees*; Princeton Architectural Press, 08 Apr 2014. ISBN 1616892188 (com, uk) [Lima, 2014]

+ 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/`

3.1 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 3.1.

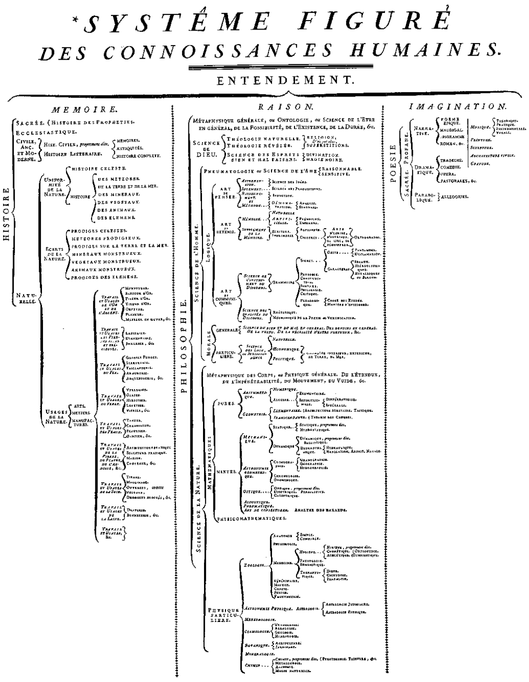

Figure 3.1: The tree of Diderot and d'Alembert. [Image from Wikimedia Commons [Diderot and le Rond d'Alembert, 1751c]]

3.2 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).

- 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 3.2), 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.

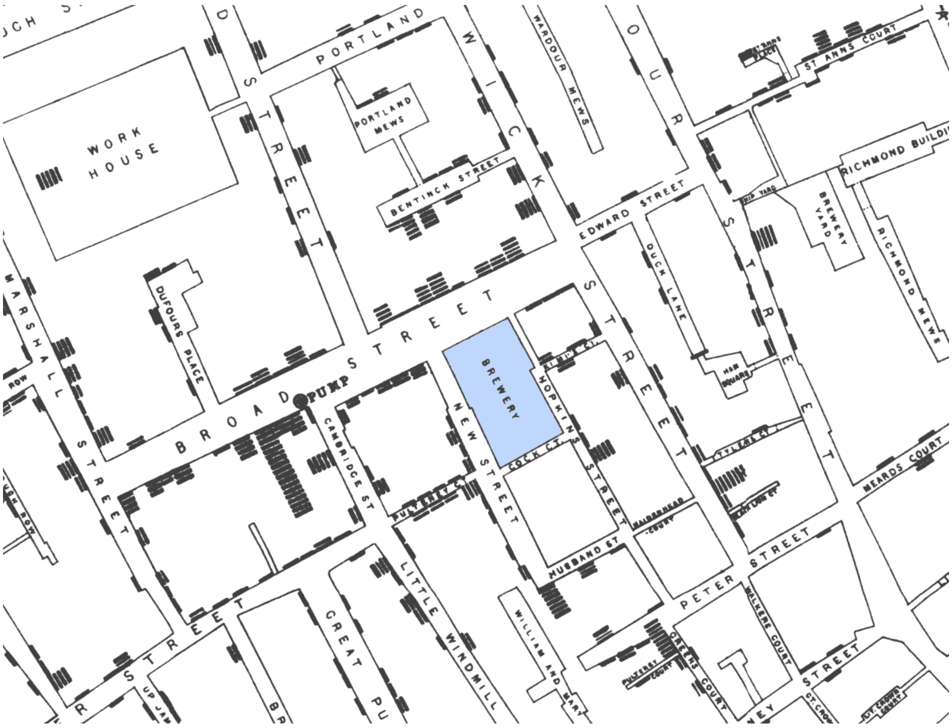

Figure 3.2: Snow's London cholera map.

- 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.

3.3 William Playfair

3.4 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.

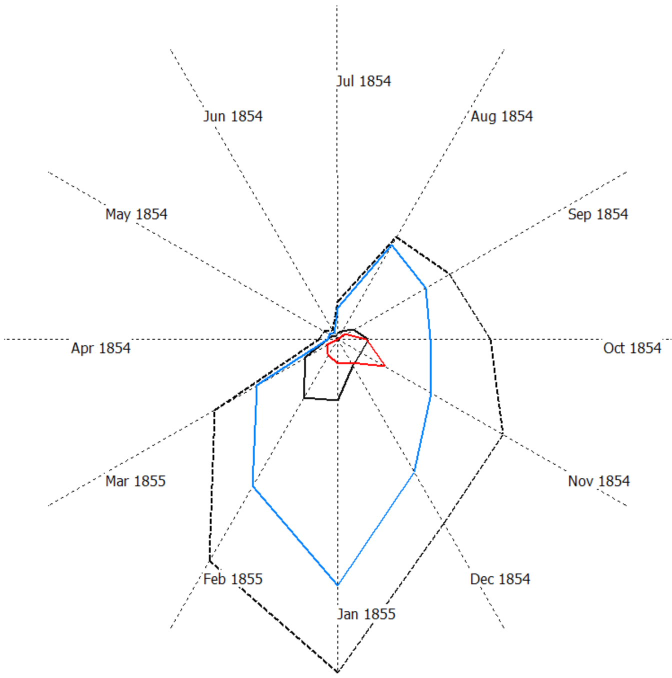

Figure 3.3: Bat's Wing Diagram.

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].

3.5 Charles Minard

Diagram of Napoleon's Russian Campaign (1861)

- Charles Joseph Minard, 1861.

3.6 Paul Otlet

3.7 Jaques Bertin

Reorderable Matrix

- Jaques Bertin created a physical device for reordering matrices called Domino, see Figure 3.7.

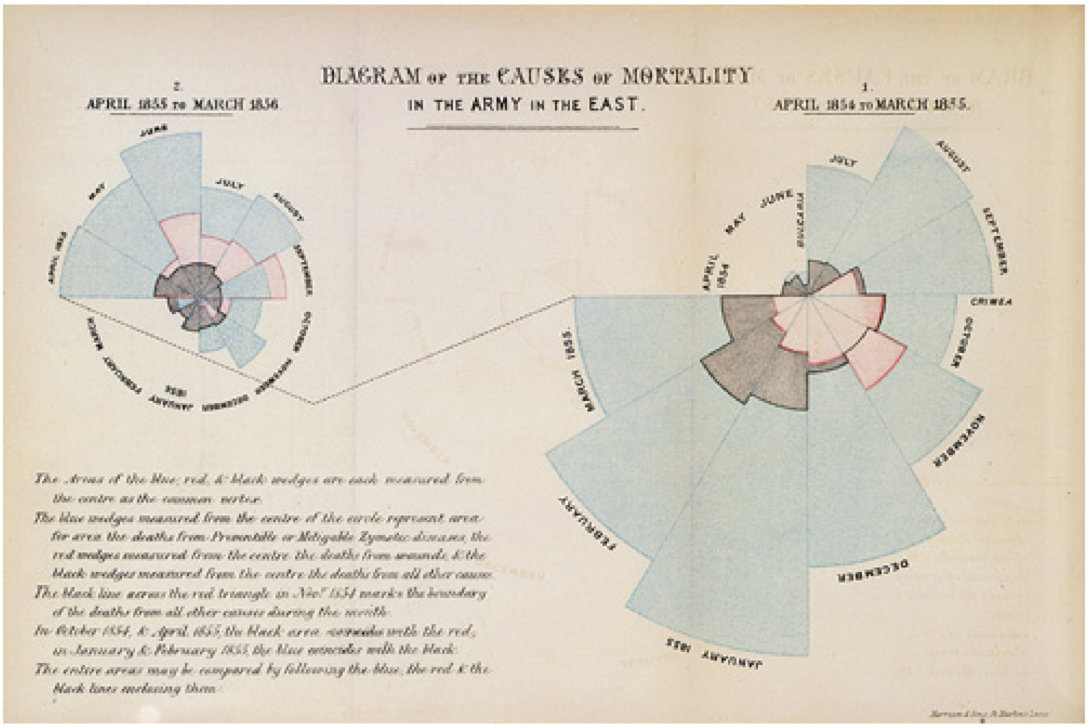

Figure 3.4: Florence Nightingale's original polar area diagram. [Image from Wikimedia Commons [Nightingale, 1858]]

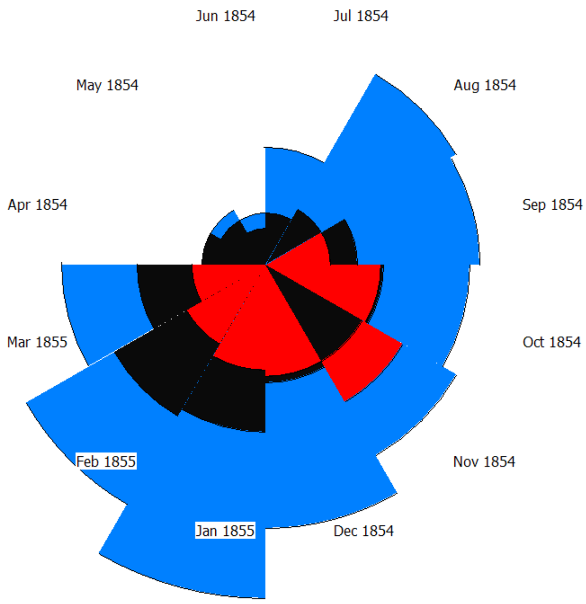

Figure 3.5: Polar Area Diagram.

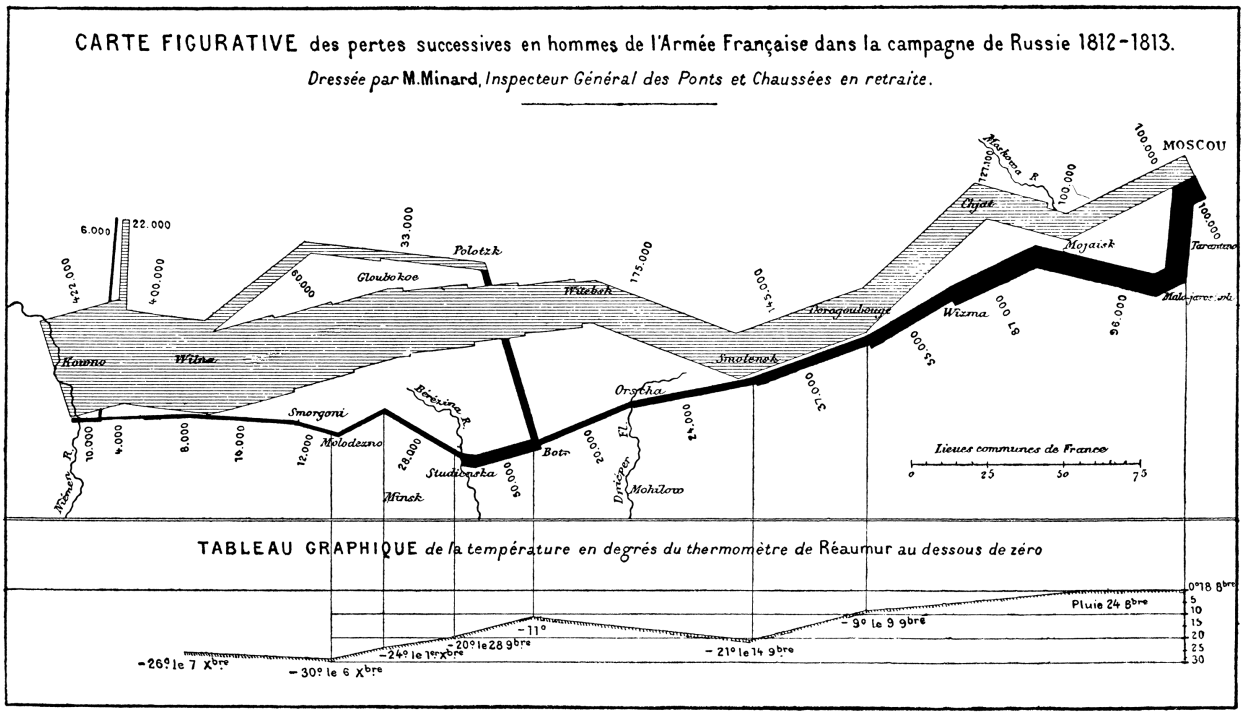

Figure 3.6: Minard's Map

- It is decribed in more detail by Henry [2008, page 78].

Figure 3.7: Bertin's reorderable matrix. [Photograph used with kind permission of Jean-Daniel Fekete.]

Chapter 4

Visualising Linear Structures

Linearly structured information:

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

4.1 Bipolar Display

4.2 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 [J. D. Mackinlay, Robertson and S. K. Card, 1991] and video [Robertson, J. D. Mackinlay and S. K. Card, 1991b].
- US Patent 5339390 [Robertson, J. Mackinlay and S. K. Card, 1994b].

4.3 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 4.2.
- Like hanging program listings on a wall several metres away.
- Zooming window supports several levels of zoom, from overview to lines of code.

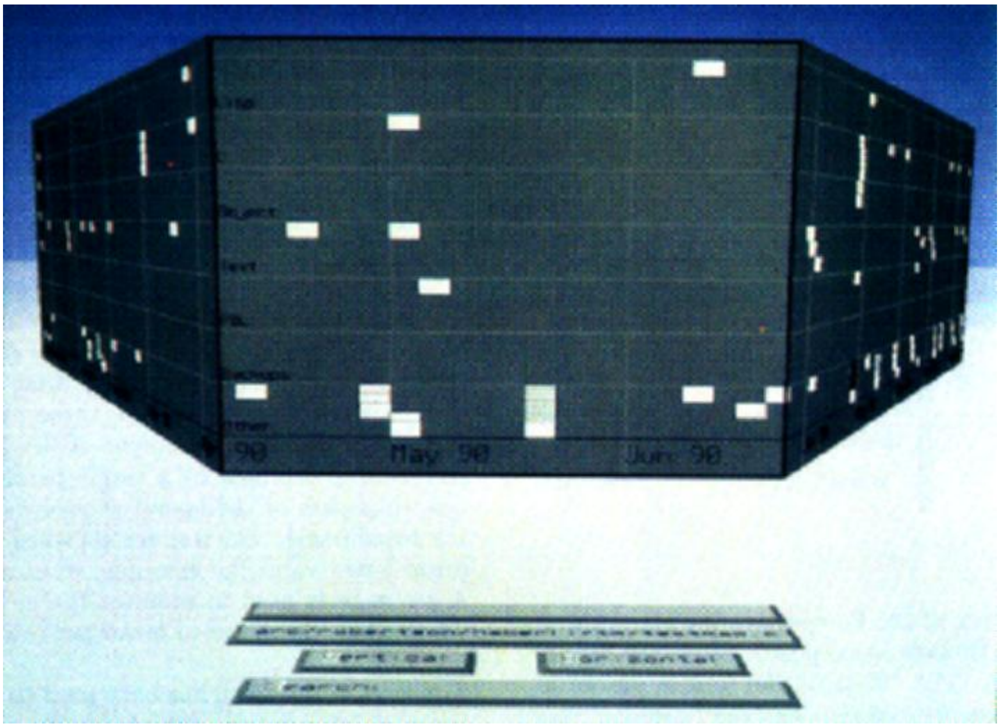

Figure 4.1: The perspective wall spreads linearly structured information across a wall from left to right. 3d perspective provides focus on the central segment of interest.

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

4.4 Lifestreams

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

4.5 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 4.4.
- 1994 draft version of paper for ED-MEDIA 95 [McCahill and Erickson, 1994].

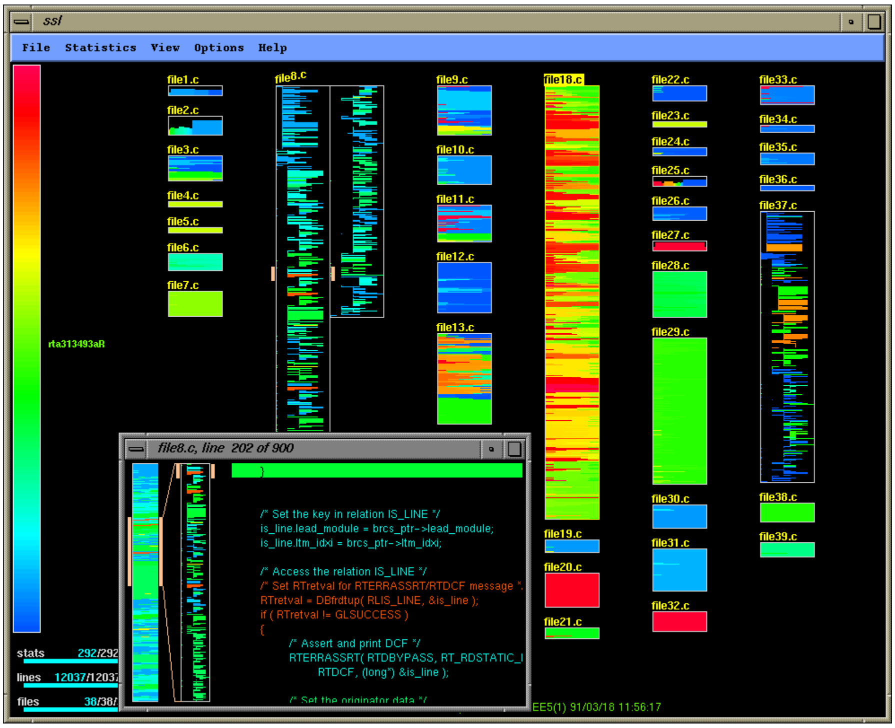

Figure 4.2: Seesoft visualising software consisting of 38 files comprising 12037 lines of code. The newest lines are shown in red, the oldest in blue, with a rainbow colour scale in between. [Image used with kind permission of Steve Eick, Visual Insights.]

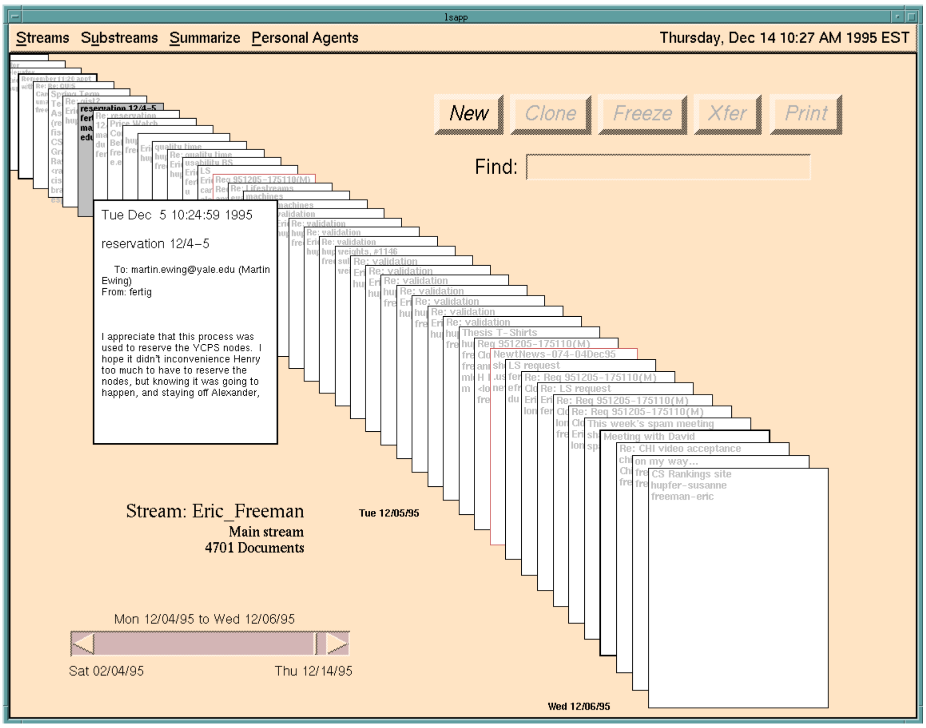

Figure 4.3: Lifestreams orders streams of item chronologically. It is possible to filter items into substreams. [Copyright © by the Association for Computing Machinery, Inc.]

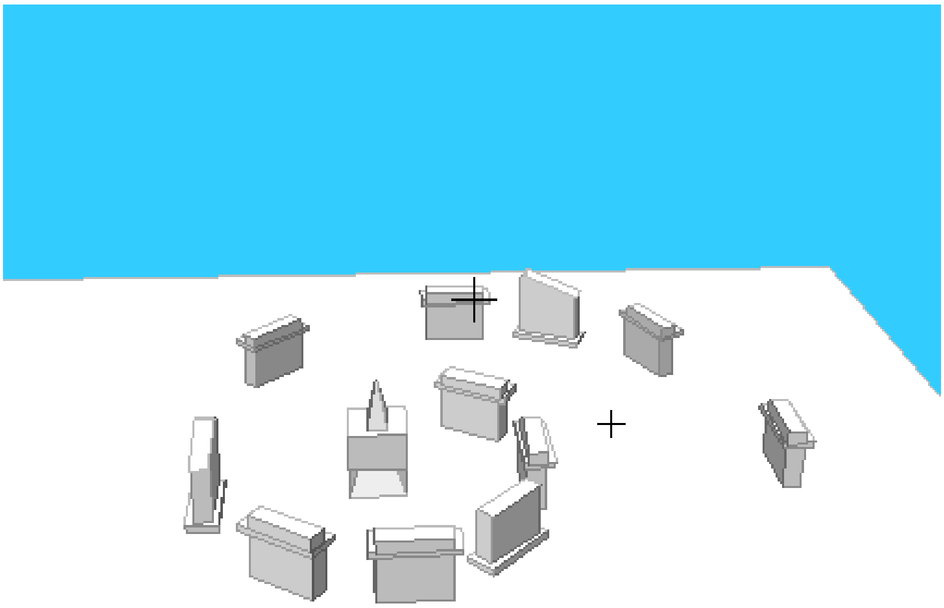

Figure 4.4: GopherVR spiral of search results. [Image used with kind permission of Tom Erickson]

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 visualised in a spiral (in decreasing order of number of publications in that sub-field). See Figure 4.5.
- FIT 2009 paper [Afzal et al., 2009].

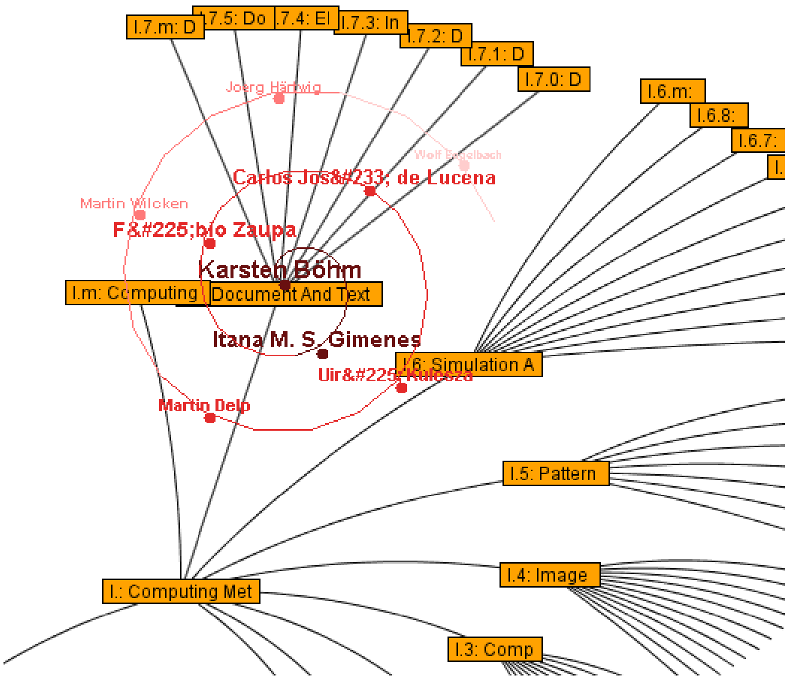

Figure 4.5: JUCS spiral of authors.

Chapter 5

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.

References

++ Hans-Jörg Schulz et al; *A Tree Visualization Reference*; IEEE Computer Graphics and Applications, Vol. 31, No. 6, 2011. doi:10.1109/TVCG.2010.79

++ Jürgensmann and Schulz; *A Visual Survey of Tree Visualization*; best poster at IEEE InfoVis 2010 http://www.informatik.uni-rostock.de/~hs162/treeposter/oldposter/treevis_hires.pdf

Online Resources

- Hans-Jörg Schulz; *A Visual Bibliography of Tree Visualization*; treevis.net/

5.1 Outliners

5.1.1 Tree Views

- Tree view on left shows structure, list view on right shows items (files, documents) at a particular level.
- Windows Explorer.

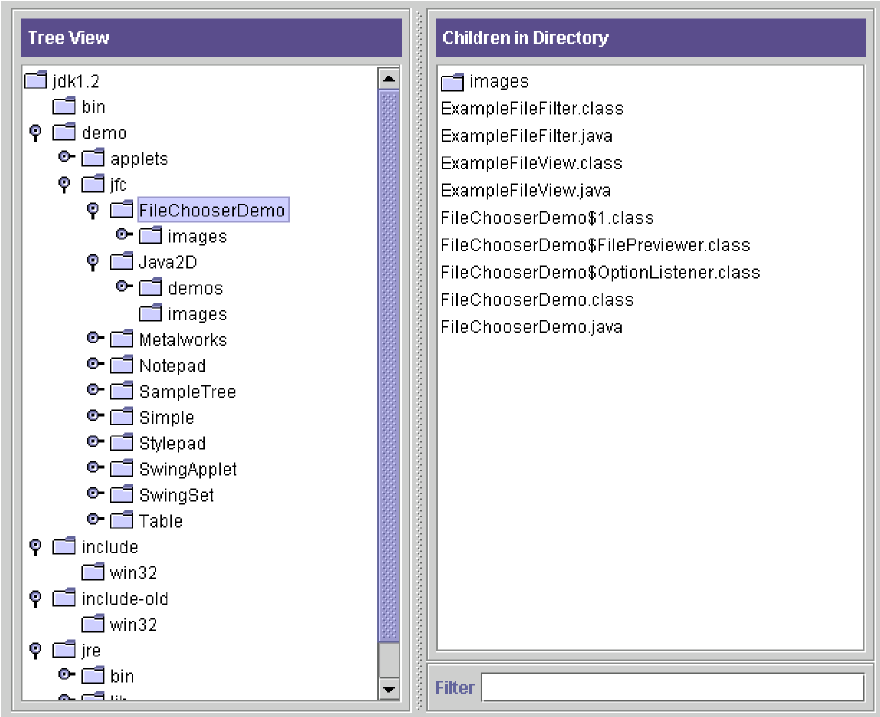

Figure 5.1: The Java Swing JTree tree view component. A view of directories on the left and their contents on the right.

- Java Swing JTree component (see Figure 5.1).
- Harmony Collection Browser [Andrews, 1996].

5.1.2 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].
- 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.

5.1.3 WebTOC

- David Nation, Department of Defense and HCIL, 1997.
- Generates tree view of web site.
- Extends traditional tree view by overlaying supplementary statistical information.

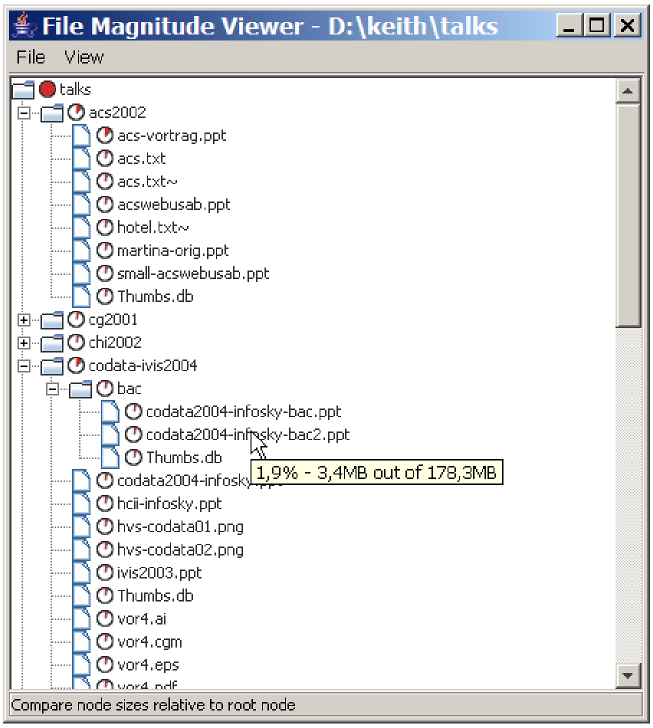

Figure 5.2: MagTree showing part of a file system hierarchy. Here, the sizes are all relative to the root.

- 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].

5.2 Layered Node-Link Tree Browsers

5.2.1 Walker Layout

- Walker [1990], improved by Buchheim, Jünger and Leipert [2002].
- Drawing trees of unbounded degree in linear time.
- The root is at the top, children on successive layers beneath.
- The layout progresses bottom-up, allocating the same amount of space to each leaf node. See Figure 5.4.

5.2.2 File System Navigator (FSN)

- SGI, 1992.
- 3d landscape visualisation of file system.
- Files sit atop pedestals, subdirectories recede into the background. See Figure 5.5.

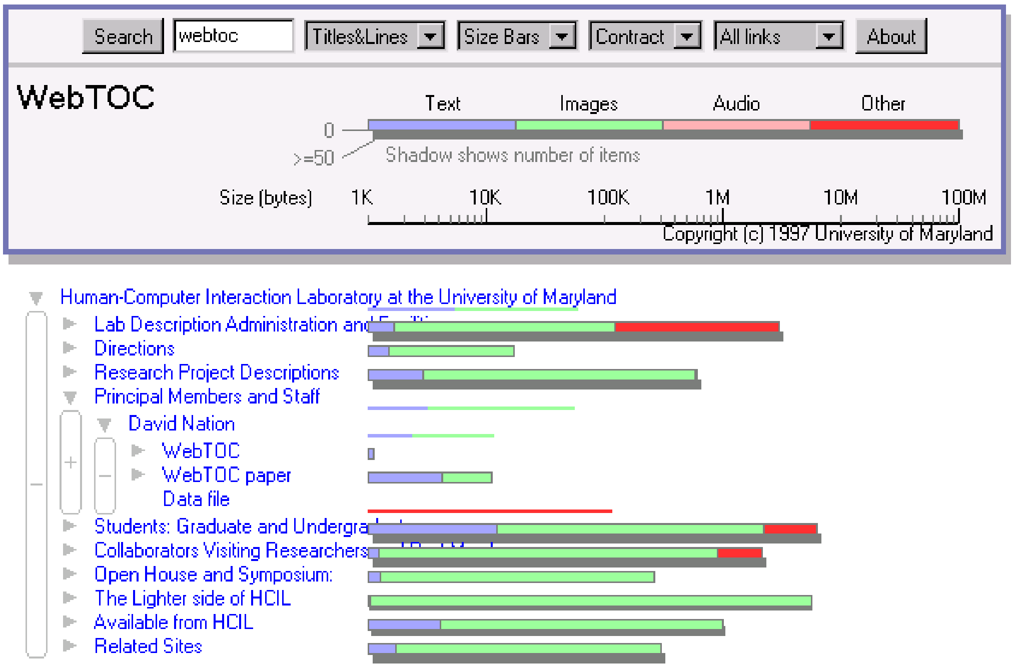

Figure 5.3: A WebTOC table of contents for the University of Maryland's HCI Lab web site.

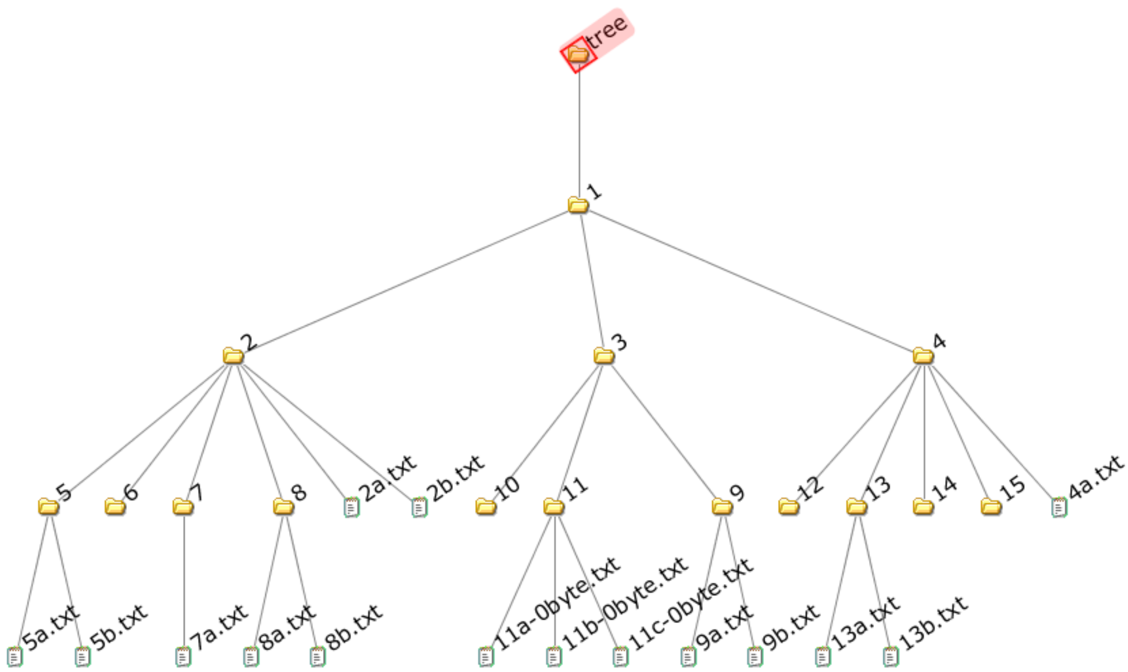

Figure 5.4: The Walker tree browser.

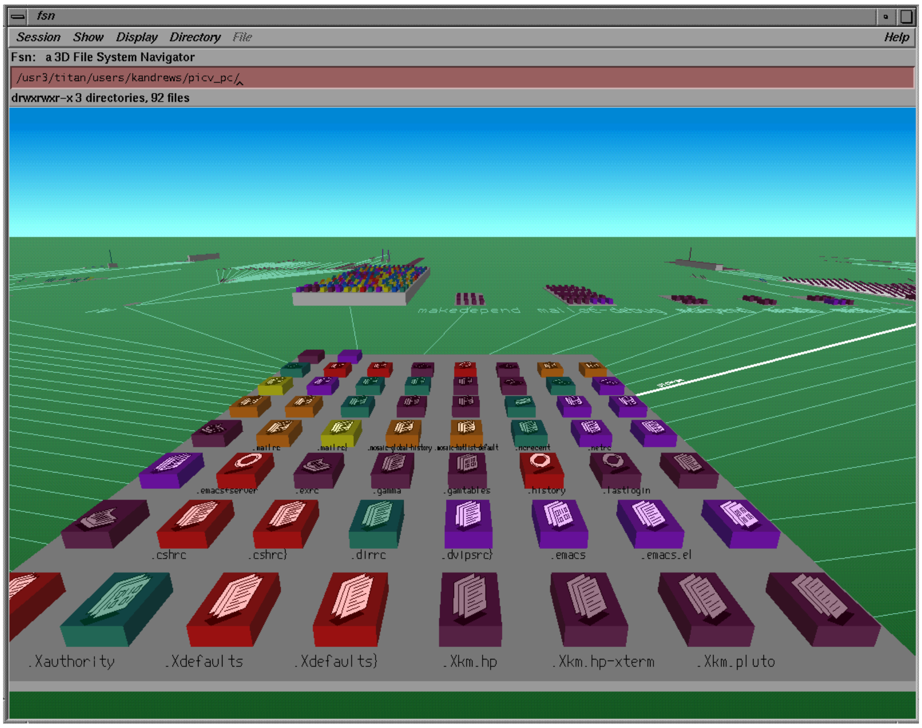

Figure 5.5: FSN landscape visualisation of a file system hierarchy. Files sit atop pedestals, subdirectories recede into the background.

- 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; Strasnick and Tesler, 1996b].

5.2.3 Harmony Information Landscape

- IICM, 1994–1995.
- 3d landscape visualisation of Hyperwave collection structures. See Figure 5.6.
- Similar to FSN, documents sit atop pedestals, subcollections recede into the background.
- Paper at IEEE InfoVis'95 (reprinted in [S. K. Card, J. D. Mackinlay and Shneiderman, 1999]), [Andrews, 1996].

5.3 Radial Node-Link Tree Browsers

5.3.1 The Brain

- Harlan, 1996.

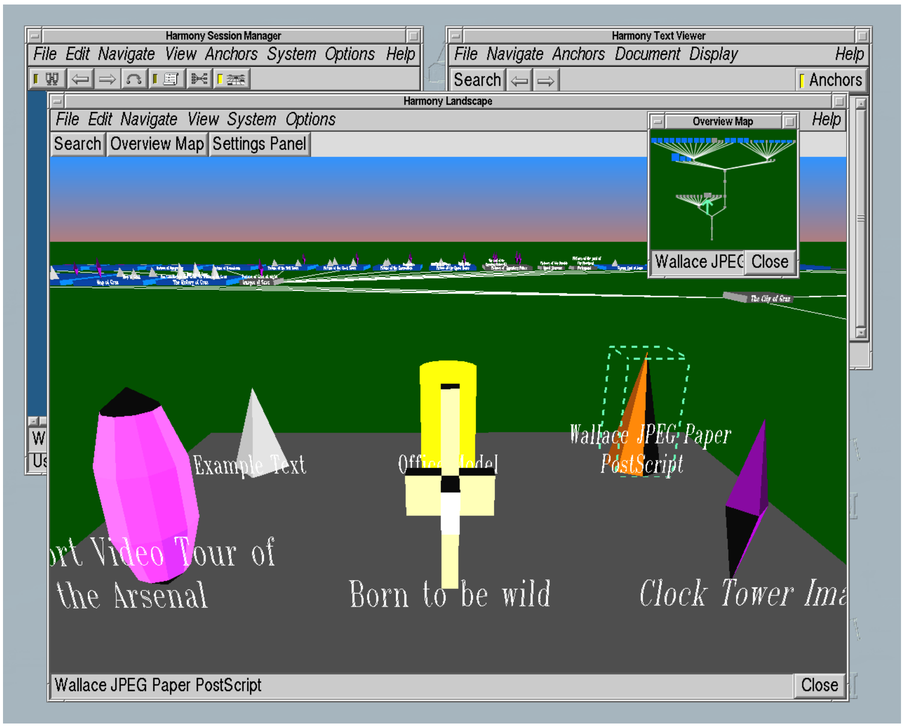

Figure 5.6: The Harmony Information Landscape visualises Hyperwave collection structures.

- Radial layout of web site structure. See Figure 5.7.
- Web site `http://thebrain.com/`
- Patented under [Harlan, 2000a; Harlan, 2000b].

5.3.2 Hyperbolic Browser

- Xerox PARC, 1994–1995.
- Focus+context technique, always displaying the entire hierarchy. See Figure 5.8.
- Layout on a hyperbolic plane, which is then mapped to the unit disc. Each child places its children in a wedge of space.
- Developed as a software component by Inxight, now owned by SAP.
- Papers at UIST'94 and CHI'95 [J. Lamping and R. Rao, 1994; J. Lamping, R. Rao and Pirolli, 1995].
- Video at CHI'96 [J. Lamping and R. Rao, 1996].
- Patented under [J. O. Lamping and R. B. Rao, 1997].
- Won the CHI'97 Great Browse Off !

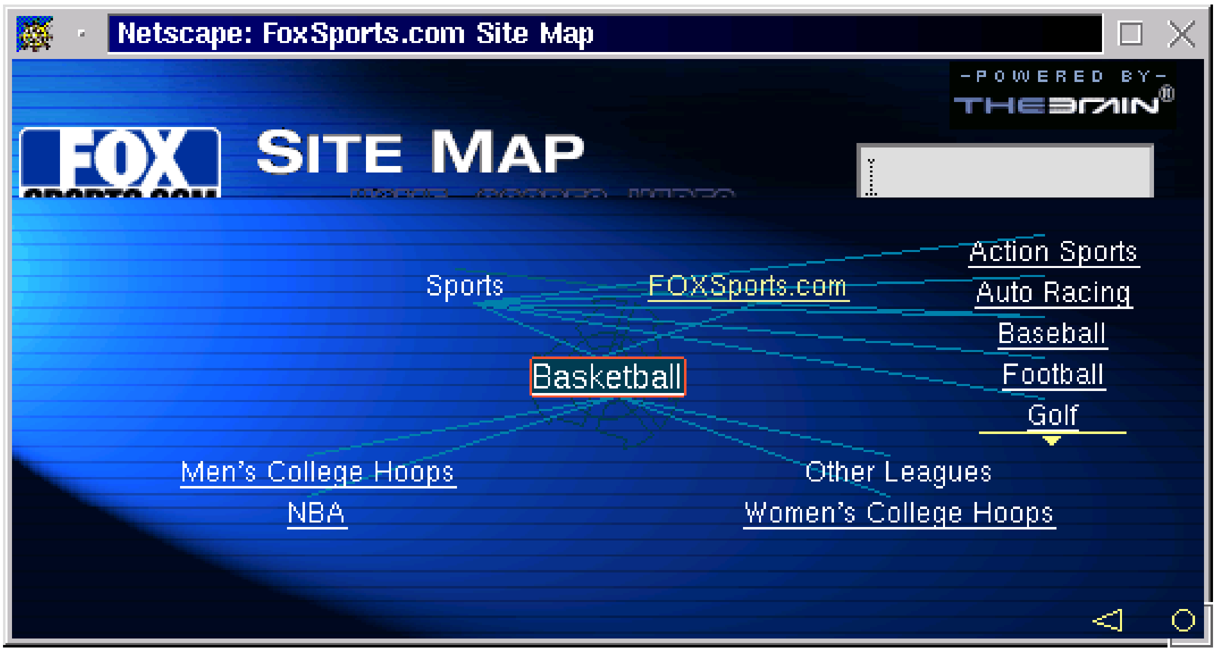

Figure 5.7: The Brain.

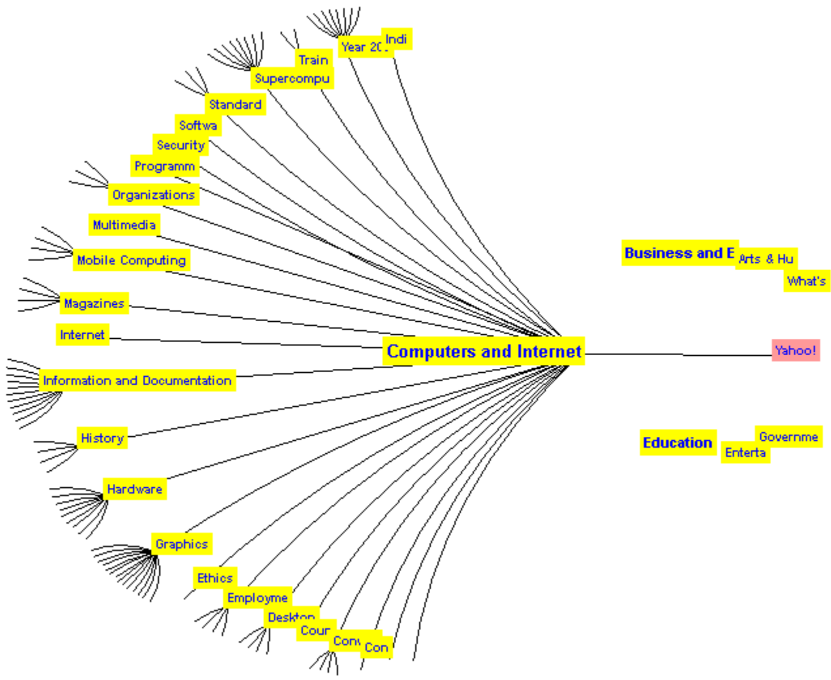

Figure 5.8: The hyperbolic browser always displays the entire hierarchy. However, subtrees around the edge of the disk become so small they are invisible. Here we see the top levels of the Yahoo hierarchy.

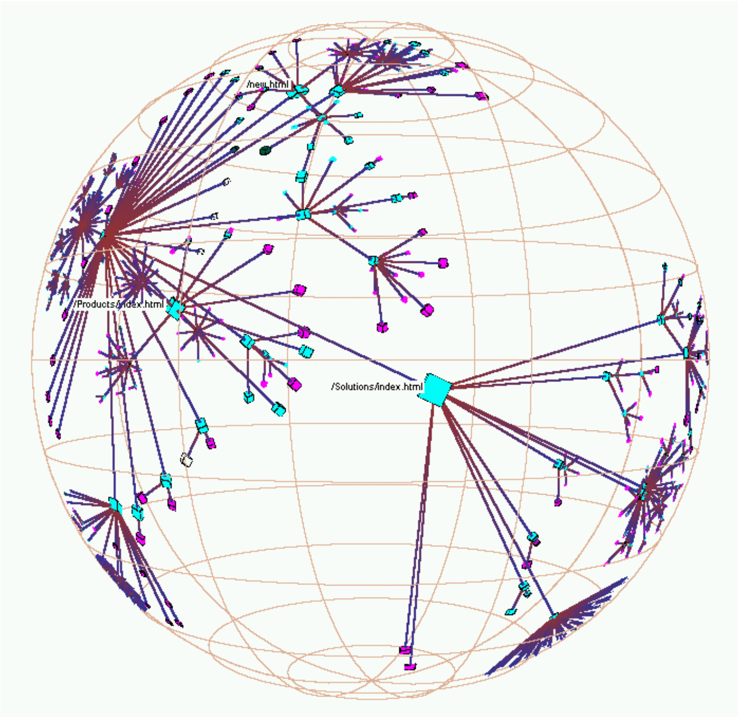

Figure 5.9: The H3 3d hyperbolic browser.

5.3.3 3D Hyperbolic Browser

- Tamara Munzner, University of Minnesota and Stanford University.
- 3D hyperbolic browser. See Figure 5.9.
- 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].

5.3.4 Walrus

- Young Hyun, CAIDA, 2002.
- 3D hyperbolic browser, homegrown implementation of Tamara Munzner's algorithms. See Figure 5.10.
- Paper in BMC Bioinformatics Journal 2004 [Hughes, Hyun and Liberles, 2004], web site [Hyun, 2005].

5.3.5 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, Jünger and Leipert, 2002] algorithm.

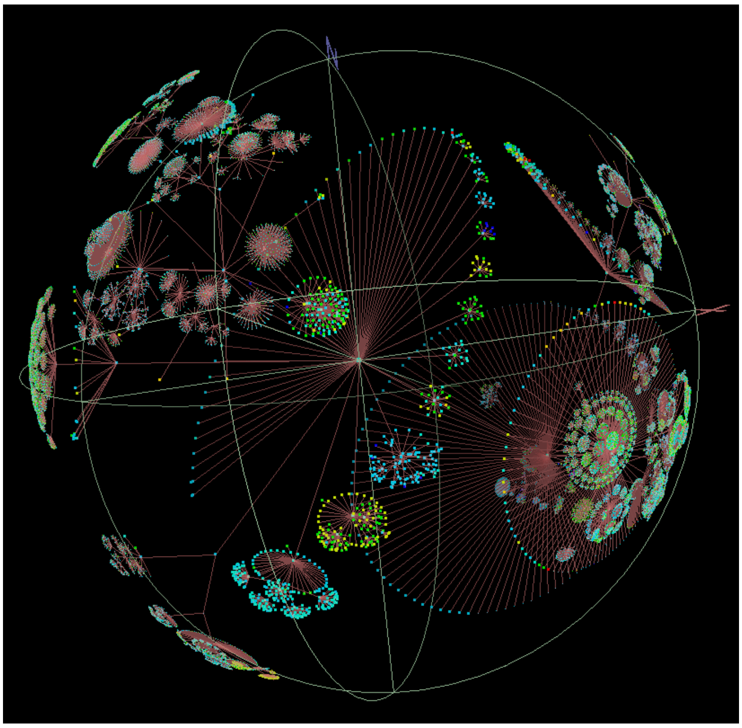

Figure 5.10: The Walrus 3d hyperbolic browser displaying a directory tree. [Image used with kind permission of Young Hyun, CAIDA.]

- It is then mapped geometrically onto the surface of a hemisphere. See Figure 5.11.
- 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, Lopez and Schuhmann, 2000].

5.3.6 Cone Tree

- Xerox PARC, 1990.
- 3d conical representation of tree. See Figure 5.12.
- A horizontal layout (cam tree) allows better labeling of nodes.
- CHI'91 paper [Robertson, J. D. Mackinlay and S. K. Card, 1991a] and video [Robertson, J. D. Mackinlay and S. K. Card, 1991b].
- Patented under [Robertson, J. Mackinlay and S. K. Card, 1994a].

5.3.7 Botanical Visualisation

- Eindhoven University of Technology, 2001.

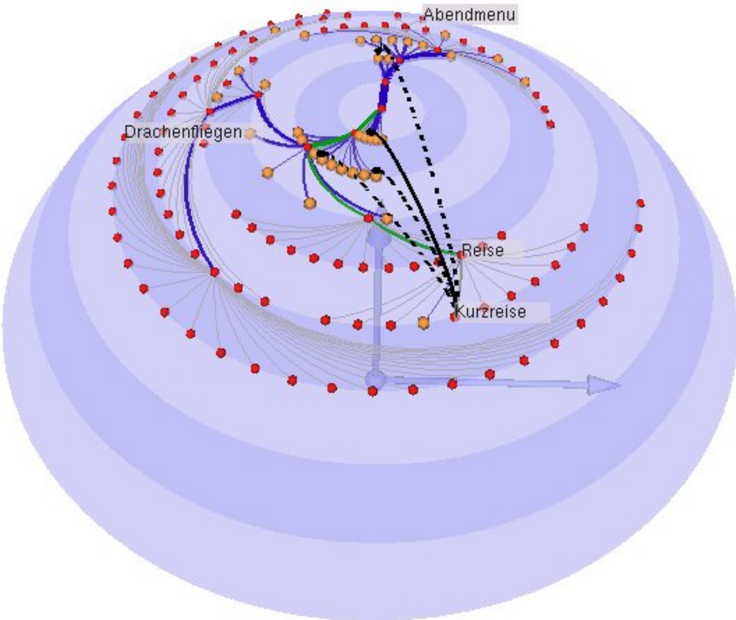

Figure 5.11: The SInVis Magic Eye View. [Image used with kind permission of Matthias Kreuseler, University of Rostock.]

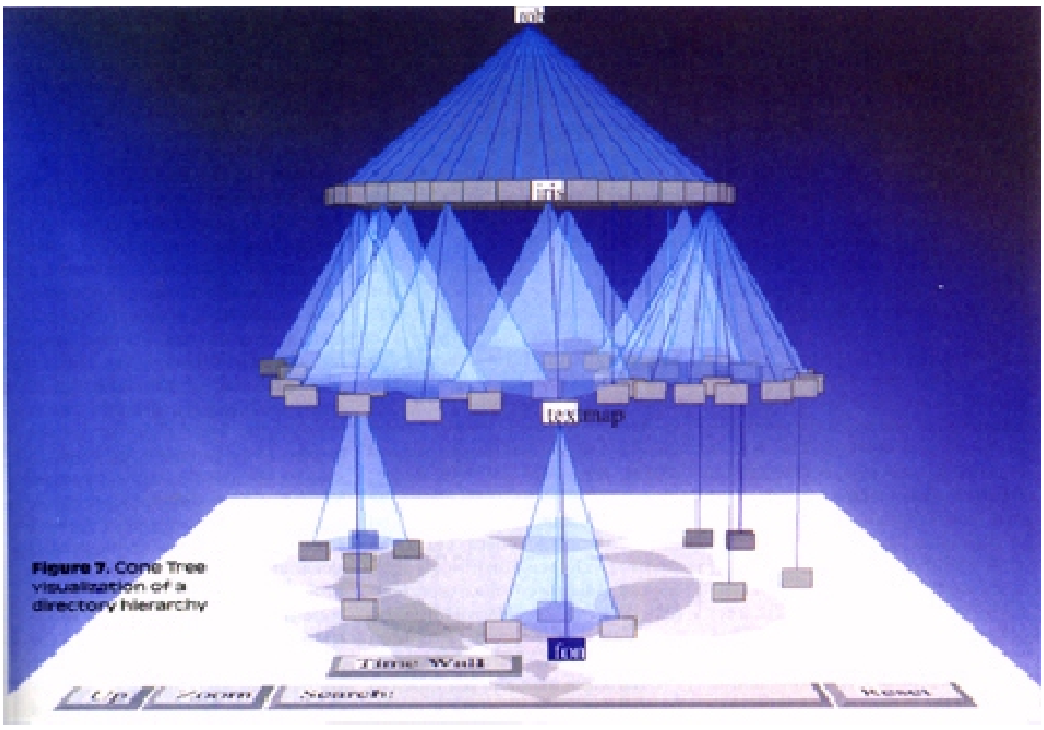

Figure 5.12: The cone tree is a 3d conical representation of a hierarchy. [Copyright © by the Association for Computing Machinery, Inc.]

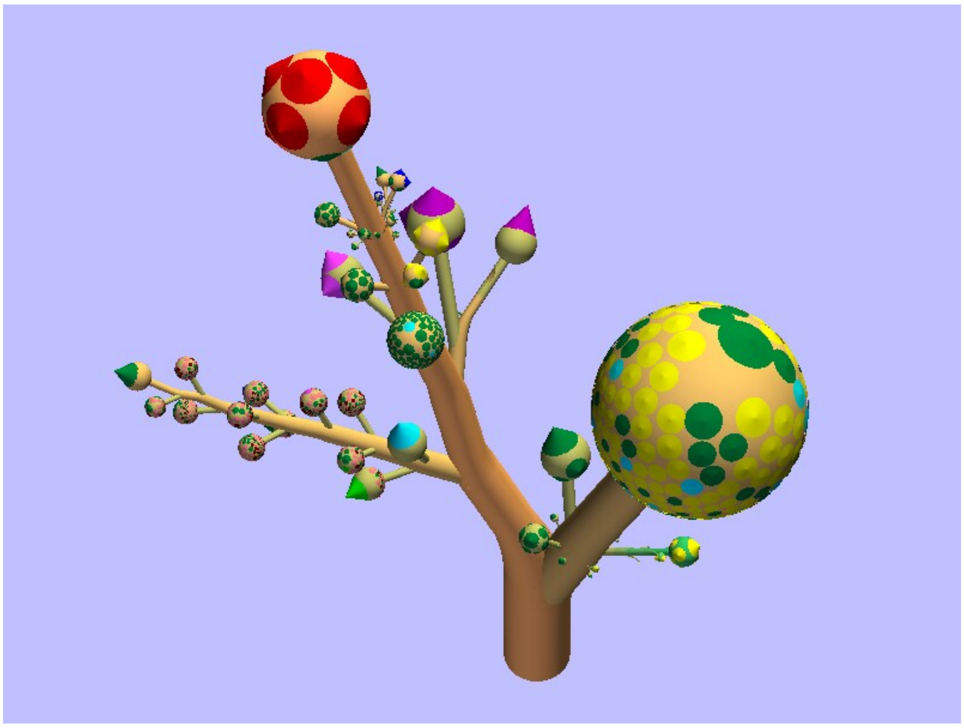

Figure 5.13: Botanical visualisation of a hierarchy. [Image used with kind permission of Jack van Wijk, Eindhoven University of Technology.]

- 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, van de Wetering and J. van Wijk, 2001].

5.4 Layered Space-Filling Tree Browsers

5.4.1 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].

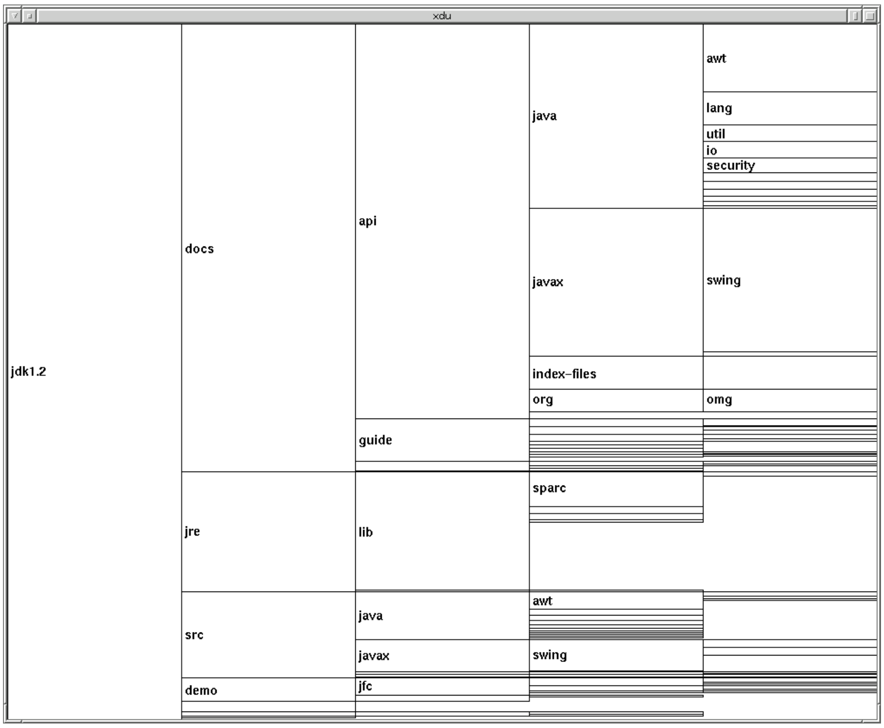

Figure 5.14: An xdu visualisation of the Java JDK 1.2 distribution.

5.5 Radial Space-Filling Tree Browsers

5.5.1 Information Slices

- IICM, 1998–1999.
- The hierarchy is fanned out across one or more semi-circular discs. See Figure 5.15.
- 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.
- 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].

5.5.2 SunBurst

- John Stasko et al, GVU, Georgia Tech, 1999-2000.
- Much more advanced version of InfoSlices. See Figure 5.16.

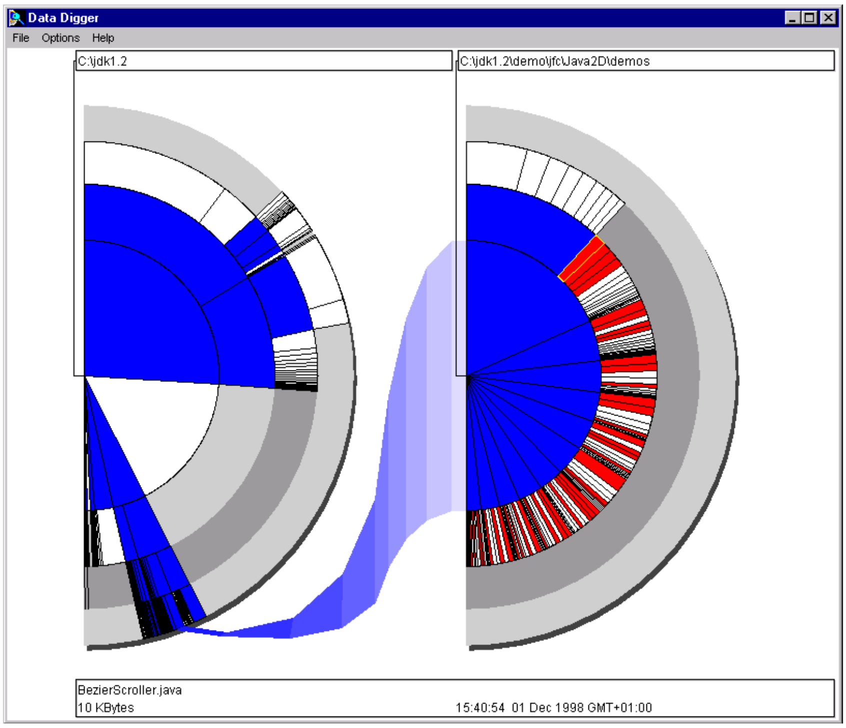

Figure 5.15: An Information Slices visualisation of the JDK 1.2 tree. For deeper hierarchies discs are stacked up in the left margin.

- Uses full disc and implements fan-out of subtrees.
- Papers at IEEE InfoVis 2000 [Stasko and E. Zhang, 2000a] and International Journal of Human-Computer Studies [Stasko, Catrambone et al., 2000].
- Video at InfoVis 2000 [Stasko and E. Zhang, 2000b].

5.6 Inclusive Space-Filling Tree Browsers

5.6.1 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 5.17.
- 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/`.

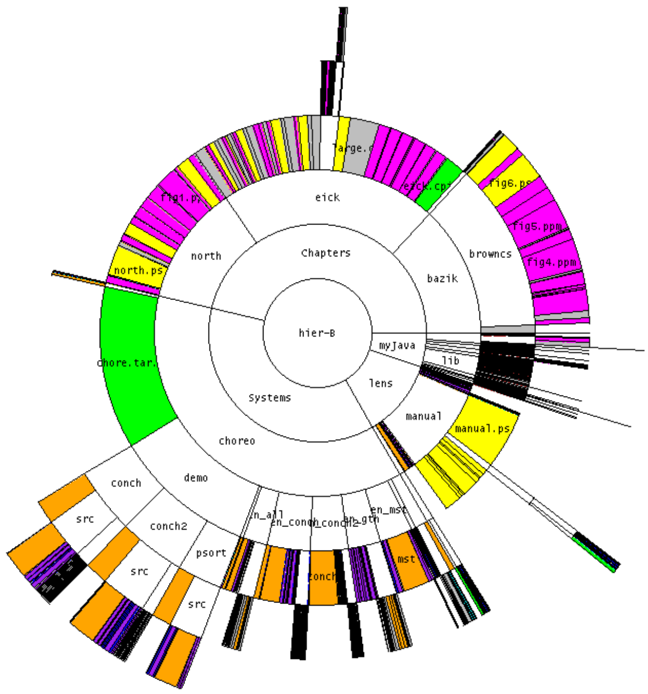

Figure 5.16: The SunBurst directory visualiser. [Image used with kind permission of John Stasko, Georgia Tech.]

Figure 5.17: A tree map of the Dewey Decimal classification hierarchy widely used in libraries. Copyright ©University of Maryland 1984-1994, all rights reserved.

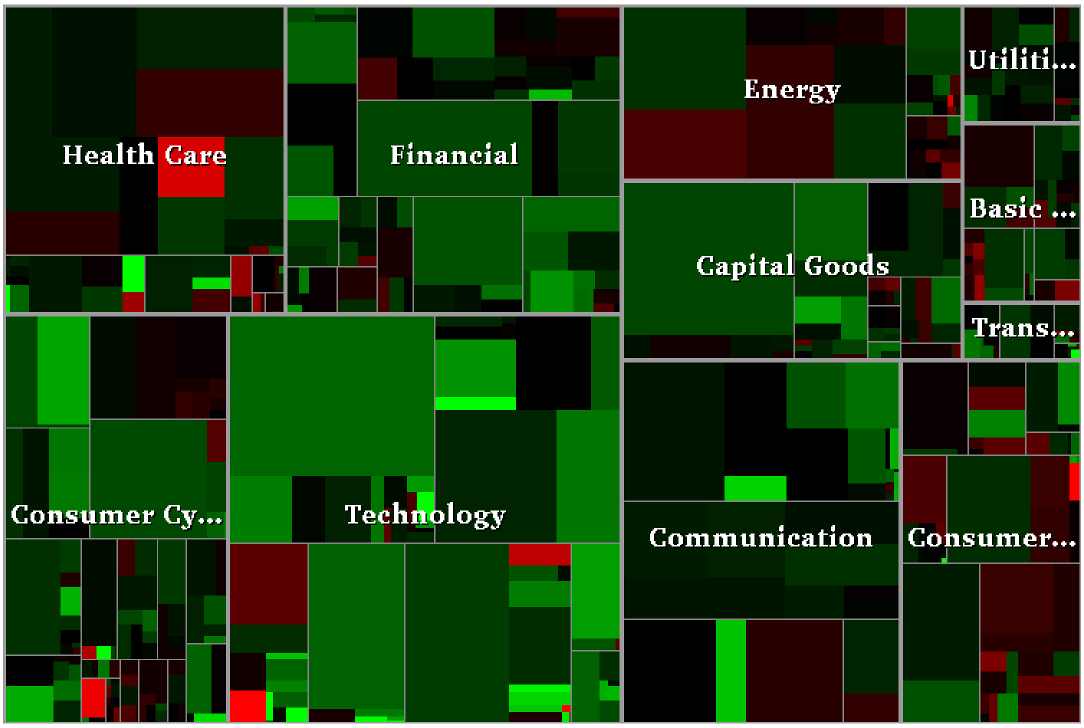

Figure 5.18: A market map of US stocks generated on 17th September 1999.

5.6.2 Market Map

- Martin Wattenberg, SmartMoney, 1999.
- Extension of tree map, avoiding the excessively narrow strips produced by Slice and Dice. See Figure 5.18.
- 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].

5.6.3 Cushion Treemaps

- Cushion treemaps: Three-dimensional shading is used to indicate the borders between treemap regions. See Figure 5.19.
- 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].

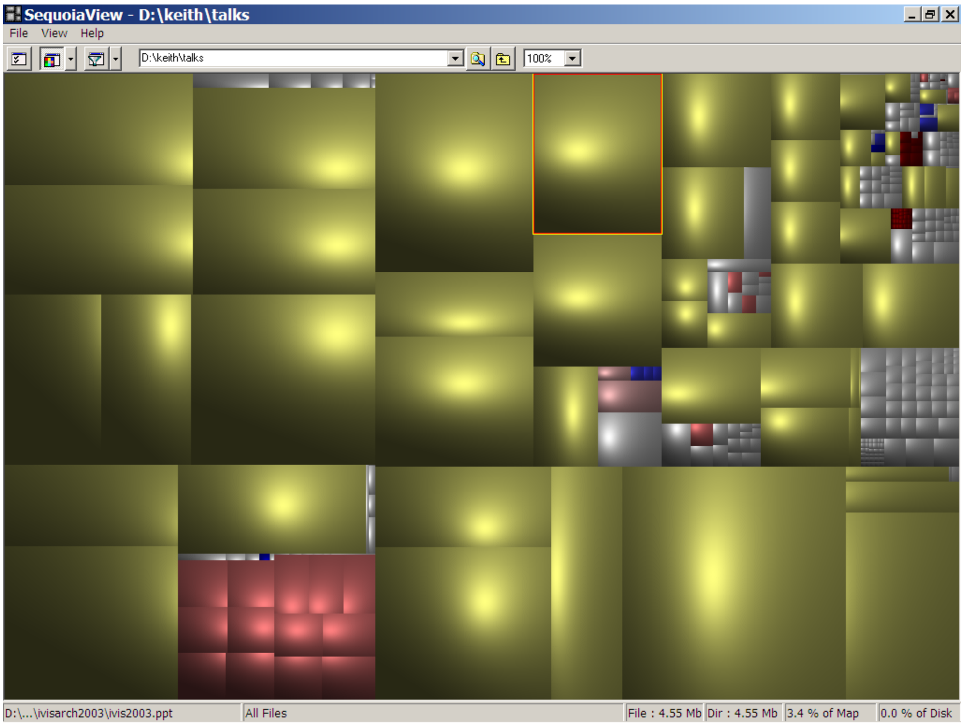

Figure 5.19: SequoiaView produces disk usage maps using squarified cushion treemaps.

- 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 [J. J. van Wijk and van de Wetering, 1999], VisSym 2000 paper [Bruls, Huizing and J. J. van Wijk, 2000].

5.6.4 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 5.20.

- 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 5.21.

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

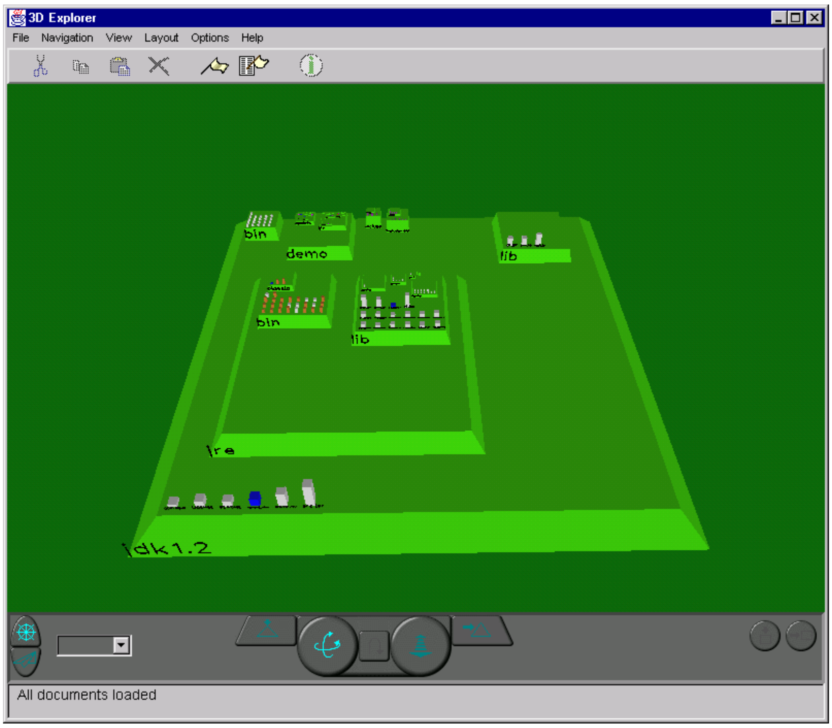

Figure 5.20: An Information Pyramids visualisation of the JDK 1.2 tree. The view from above gives a graphical disk usage. The dashboard provides user navigation. This version uses OpenGL for 3d output.

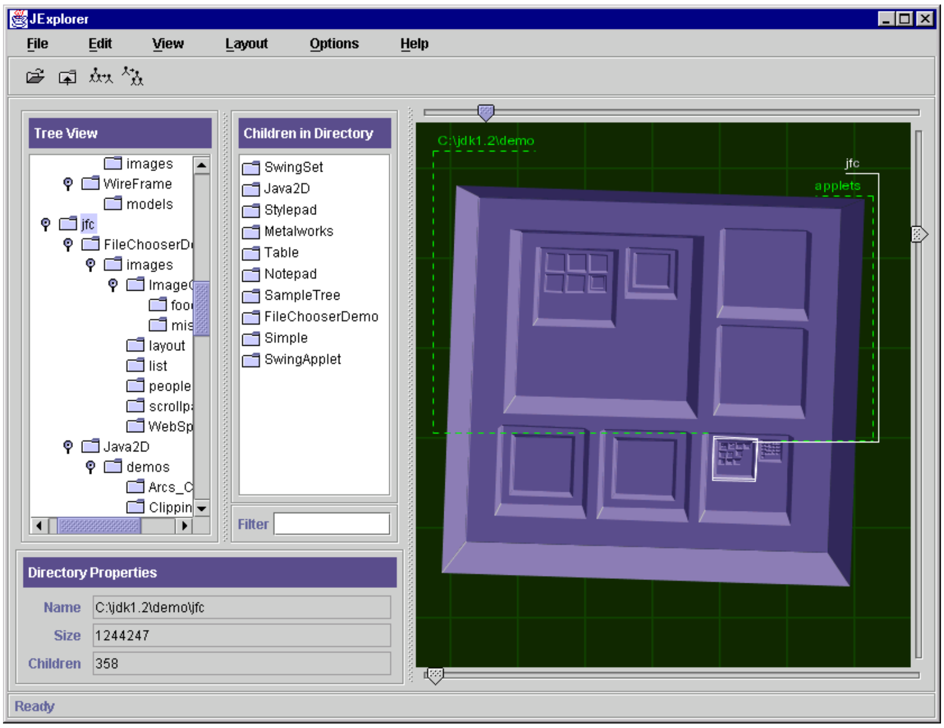

Figure 5.21: The JExplorer combines a Java tree viewer with a synchronised Information Pyramids display.

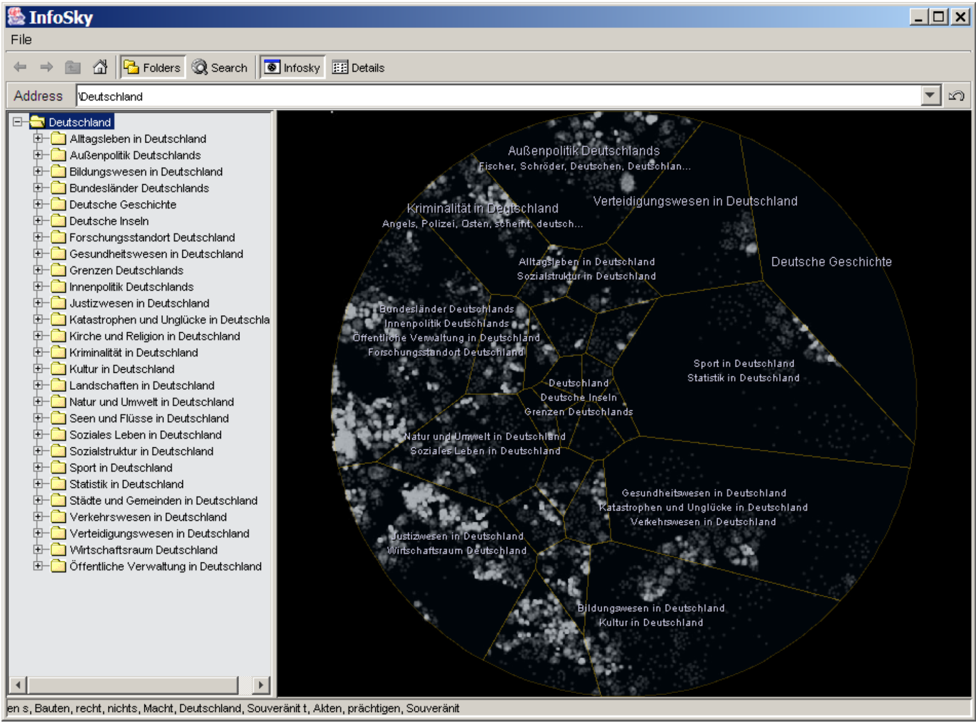

Figure 5.22: The InfoSky Cobweb hierarchy browser.

5.6.5 InfoSky Cobweb Browser

- The InfoSky cobweb browser uses space-filling, recursive Voronoi subdivision to allocate available space to child polygons. See Figures 5.22 and 5.23.
- Paper in journal [Andrews, Kienreich et al., 2002] and at InfoVis 2004 [Granitzer et al., 2004].
- Video and demo application at [KC, 2006].

5.6.6 Voronoi Treemap

- Like the InfoSky Cobweb, uses space-filling, recursive voronoi subdivision to allocate available space to child polygons. See Figure 5.24.
- Papers at SoftVis 2005 [Balzer, Deussen and Lewerentz, 2005] and InfoVis 2005 [Balzer and Deussen, 2005a].
- Video at [Balzer and Deussen, 2005b].

5.7 Overlapping Space-Filling Tree Browsers

5.7.1 Cheops

- Centre du recherche Informatique de Montréal, 1996.

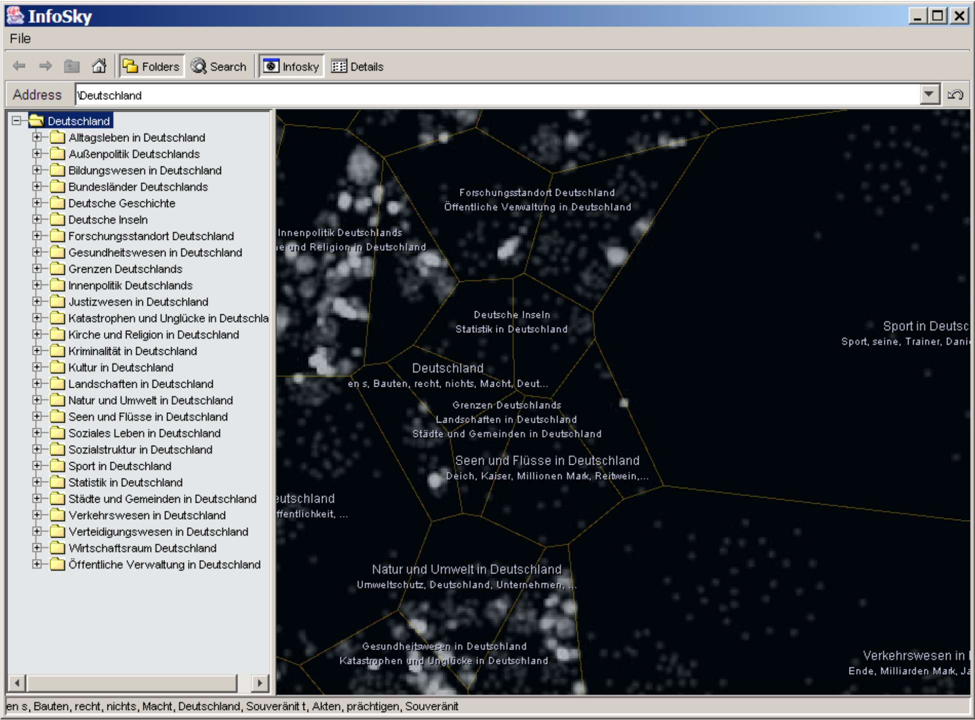

Figure 5.23: The InfoSky Cobweb hierarchy browser, zoomed in for a closer look.

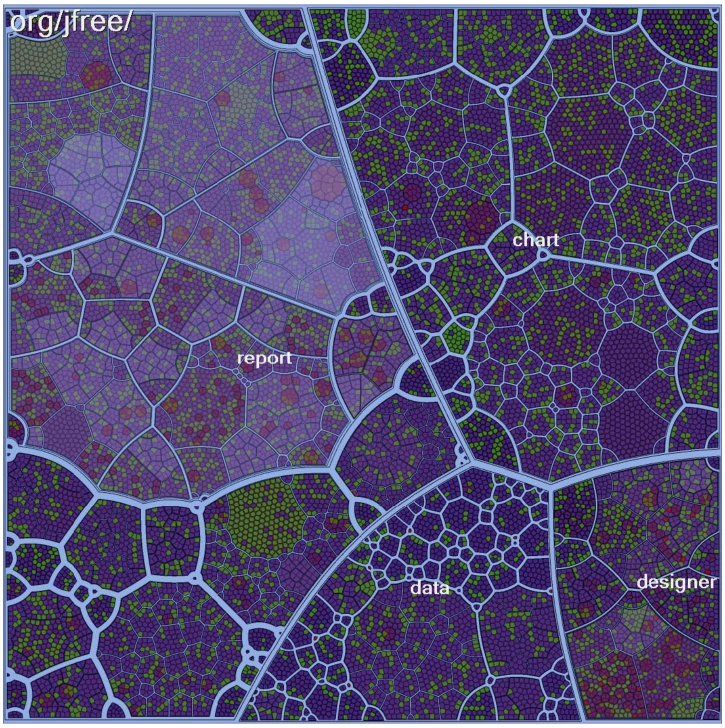

Figure 5.24: The Voronoi Treemap also uses recursive voronoi subdivision. [Image extracted from [Balzer, Deussen and Lewerentz, 2005], Copyright © by the Association for Computing Machinery, Inc.]

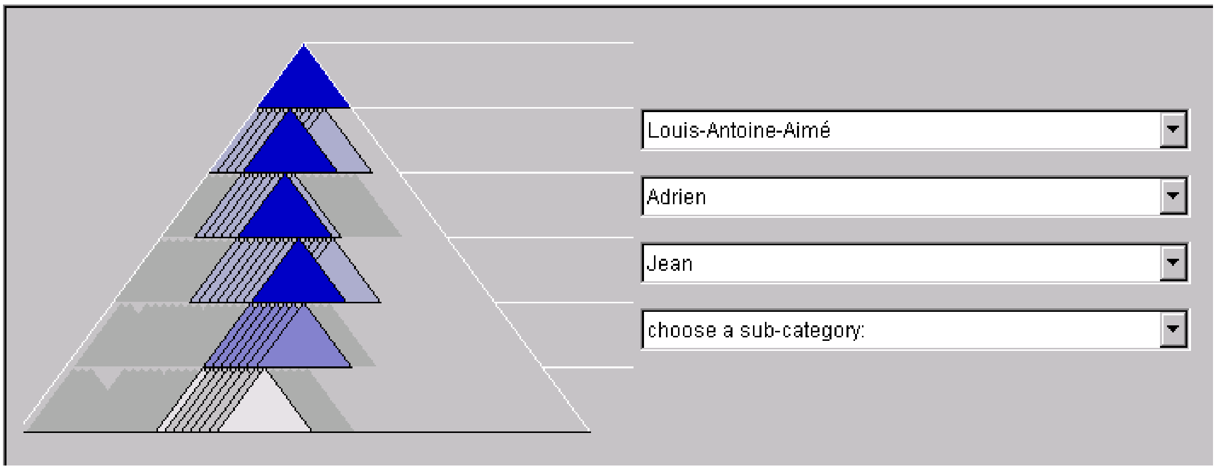

Figure 5.25: Cheops uses stacked triangles to compactly display a hierarchy.

- Compact 2d representation of a hierarchy by overlaying (squashing together) children to save on screen space. See Figure 5.25.
- Paper at Visualization'96 [Beaudoin, Parent and Vroomen, 1996].
- Software (Java classes) at `http://www.crim.ca/hci/cheops/`

5.7.2 BeamTree

- Directories are in blue, files in other colours.
- The root beam is in the background, other beams are laid on top.
- See Figures 5.26 and 5.27.
- InfoVis 2002 paper [van Ham and J. J. van Wijk, 2002].

5.8 Single-Level Tree Browsers

5.8.1 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].

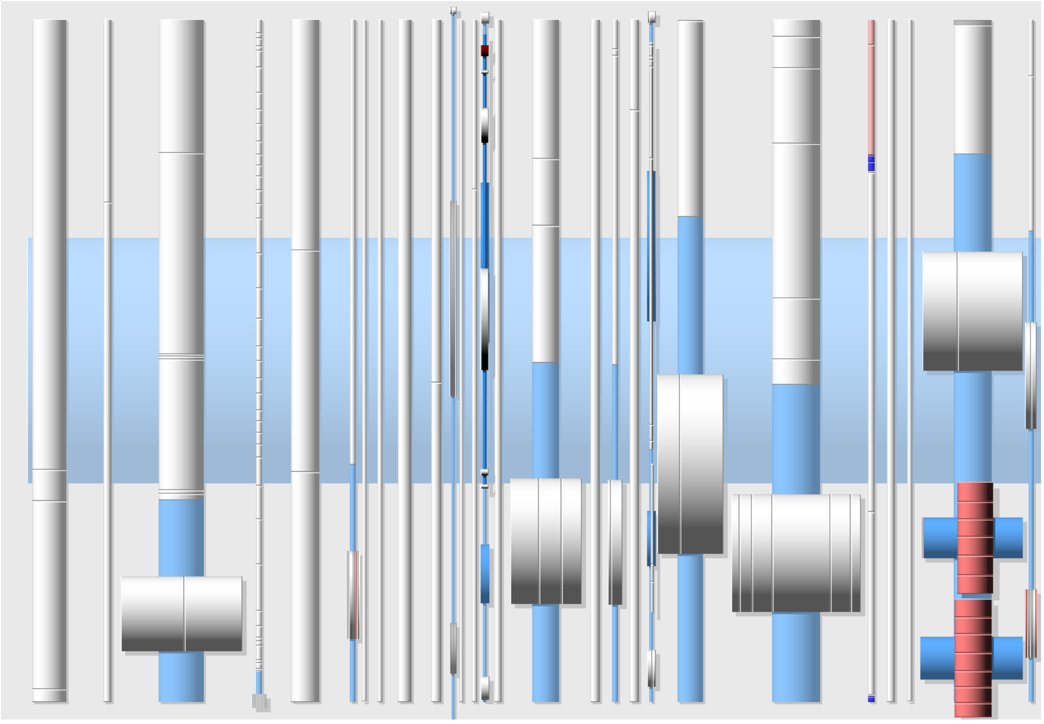

Figure 5.26: BeamTrees are a variation on treemaps using overlapping beams. Directories are coloured blue, files are other colours. The root directory is at the back, other directories are overlaid upon it.

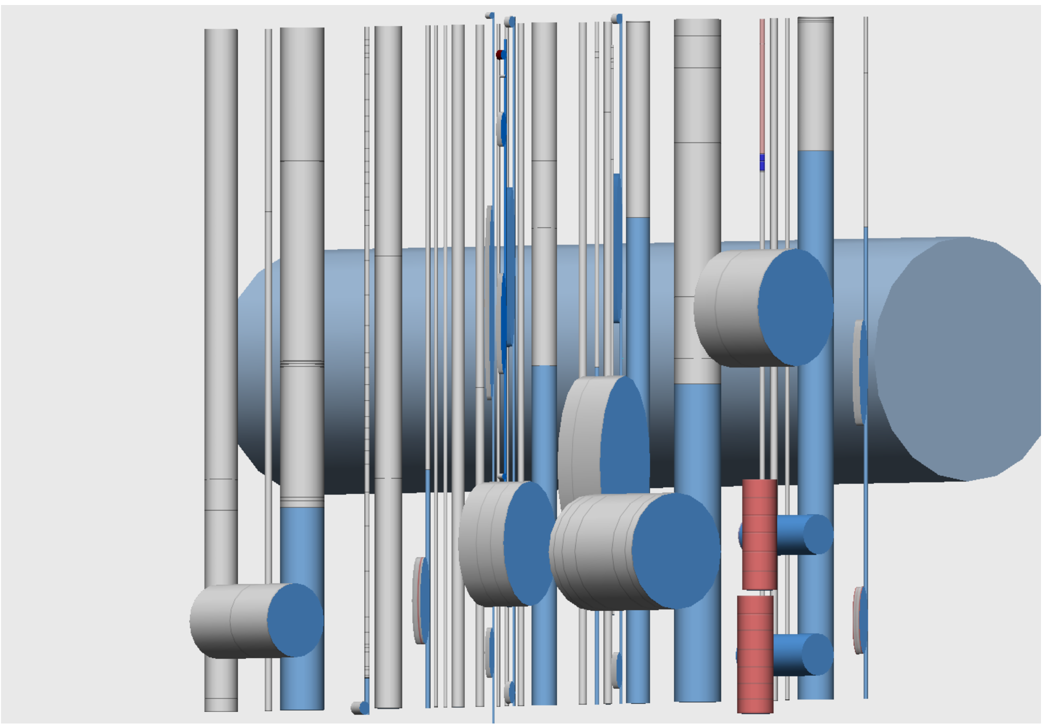

Figure 5.27: The directory structure is only really recognisable when a 3D rendering is used.

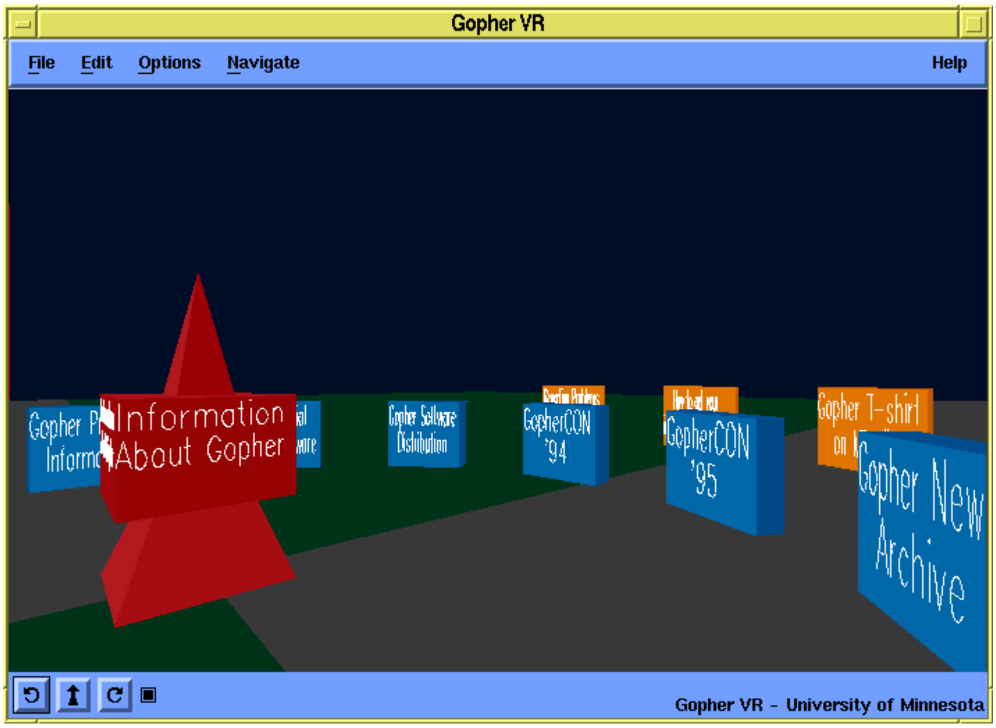

Figure 5.28: GopherVR visualises one level of a Gopher hierarchy at a time. The central pyramid bears the name of the current level, clicking on it returns the user to the next higher level.

Chapter 6

Visualising Networks and Graphs

6.1 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 6.1 shows an example for a graph with five nodes and six edges.

6.2 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.

6.2.1 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 6.2. `http://threadvis.mozdev.org/`

6.2.2 Ring-Based

NetMap

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

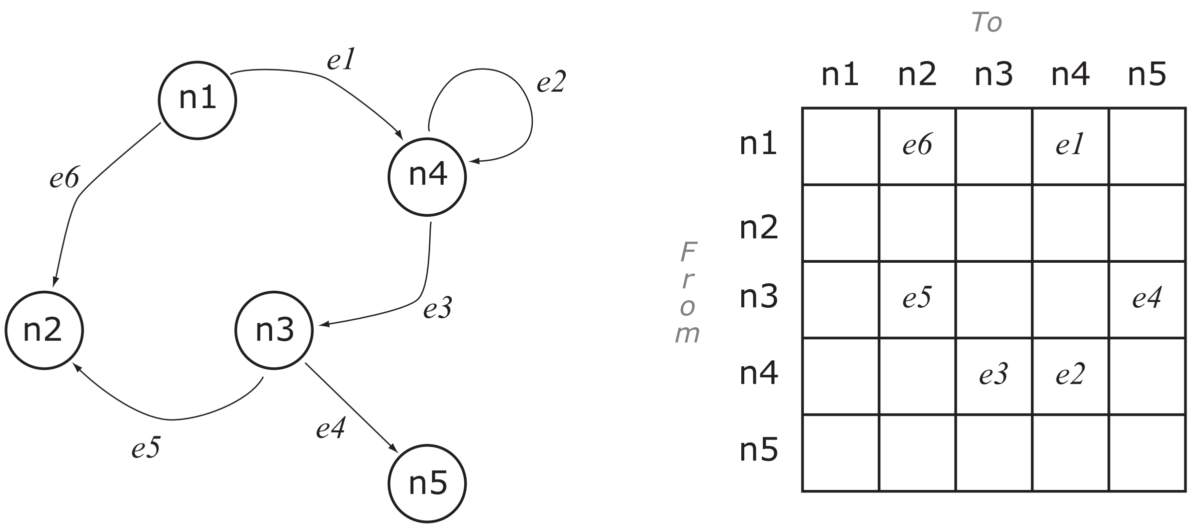

Figure 6.1: A graph with five nodes and six directed edges. The drawing on the left is hand-drawn. The representation on the right shows the same graph in the form of an adjacency matrix.

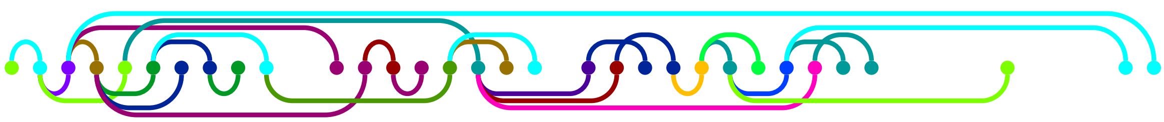

Figure 6.2: ThreadVis implements the Thread Arcs visualisation as an add-on for Thunderbird. Here is a thread from the `alt.gesellschaft.recht` newsgroup containing 32 messages.

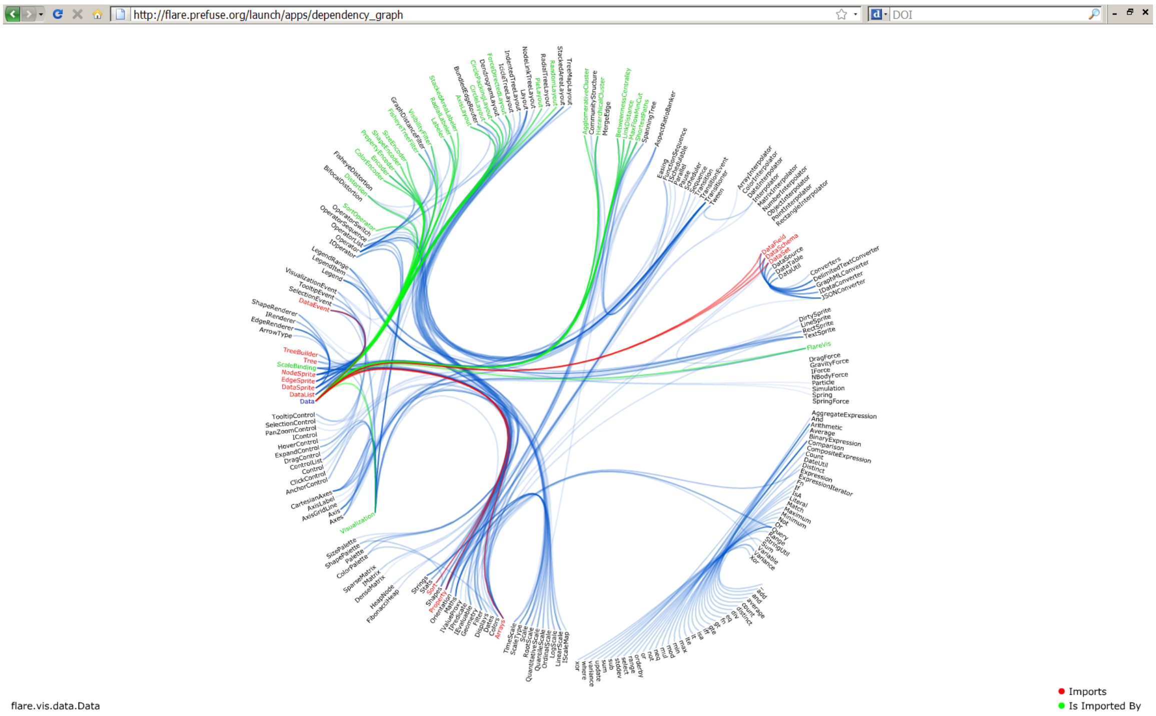

Figure 6.3: The Flare Dependency Graph is a ring-based layout showing the dependencies between classes in the Flare library. Here the class Data has been selected.

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 6.3.

6.2.3 Grid-Based

Intermedia Global Map

- Intermedia was a network hypermedia system developed for Apple 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 6.4.

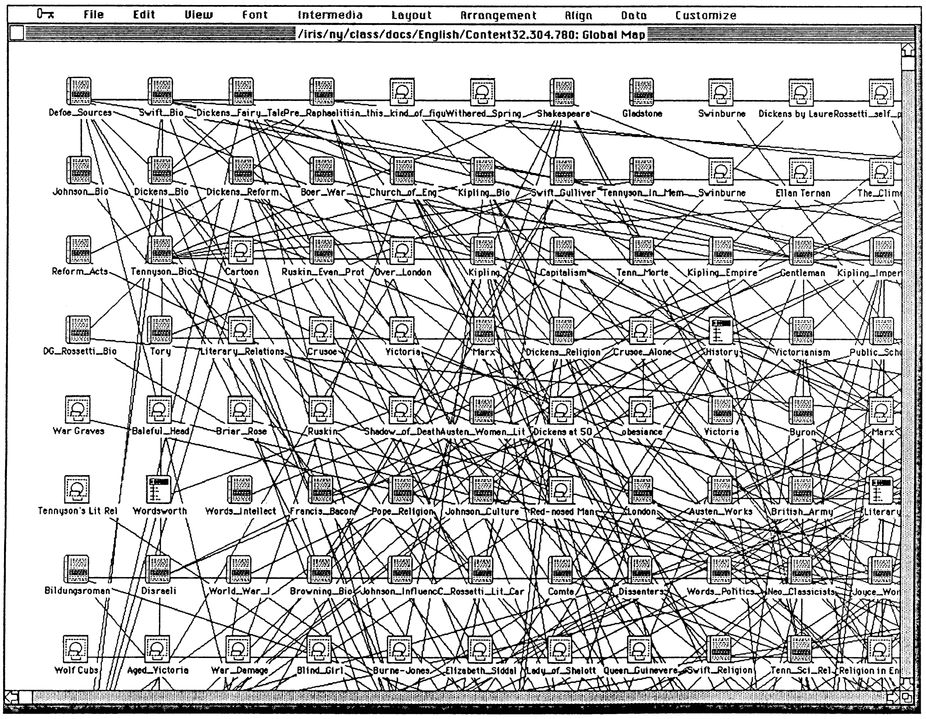

Figure 6.4: The Intermedia Global Map. Hypermedia nodes (documents) are placed on a regular grid and links are drawn between them. [Image extracted from Conklin [1987]. Copyright ©1987 IEEE. Used with permission.]

6.2.4 Geography-Based

Flow Maps

- Historical flow maps created by Charles Minard.
- Layout algorithm described by Doantam Phan et al in InfoVis 2005 paper [Phan, Xiao, Yeh et al., 2005].
- See Figure 6.5 shows migration to California using US Census data from 2000.

6.3 Layered Graph Drawing

Layered Graph Drawing, also called Sugiyama layout. User for (acyclic) directed graphs.

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).

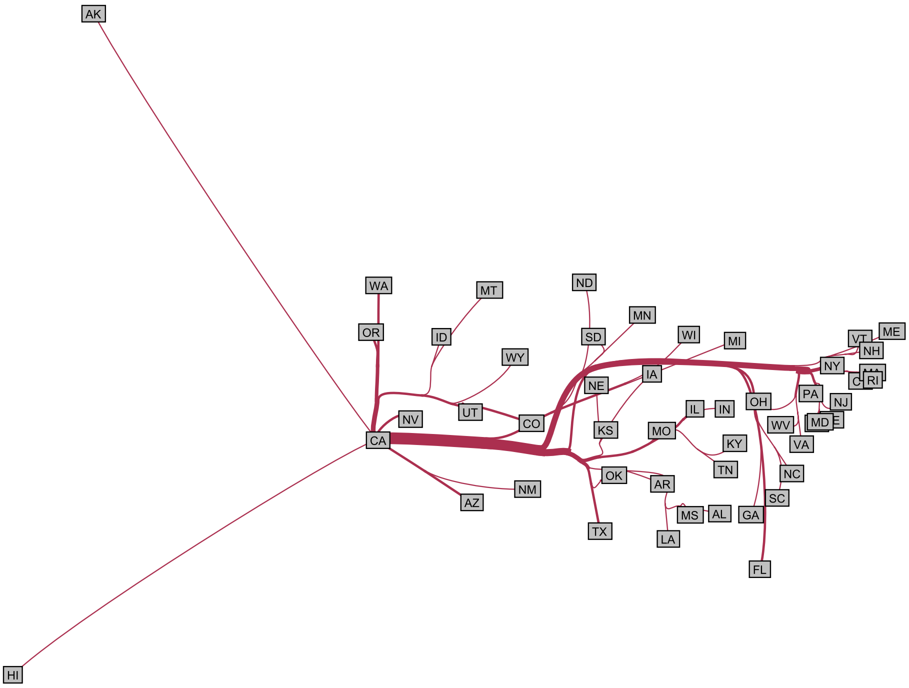

Figure 6.5: A flow map showing migration to California from other US states, using data from the US Census 2000. The map was produced by Keith Andrews using the software available from Phan, Xiao and Yeh [2006].

6.3.1 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].

Harmony Local Map 3D

- IICM, 1995.
- Links in vertical plane superimposed atop information landscape. See Figure 6.7.
- Description in Chapter 8 of [Andrews, 1996].

6.4 Force-Based Layouts

6.4.1 SemNet

- Fairchild, Poltrock, Furnas, MCC, 1988.

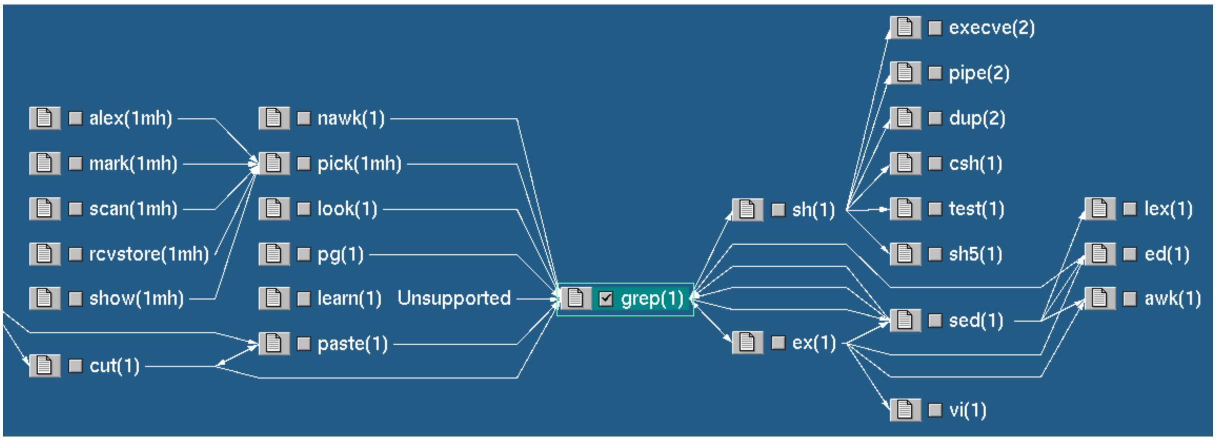

Figure 6.6: The Harmony Local Map uses graph drawing algorithms to lay out a map of the link environment of hypermedia documents. In this example, Unix manual pages one and two links away from the grep manual page are visualised.

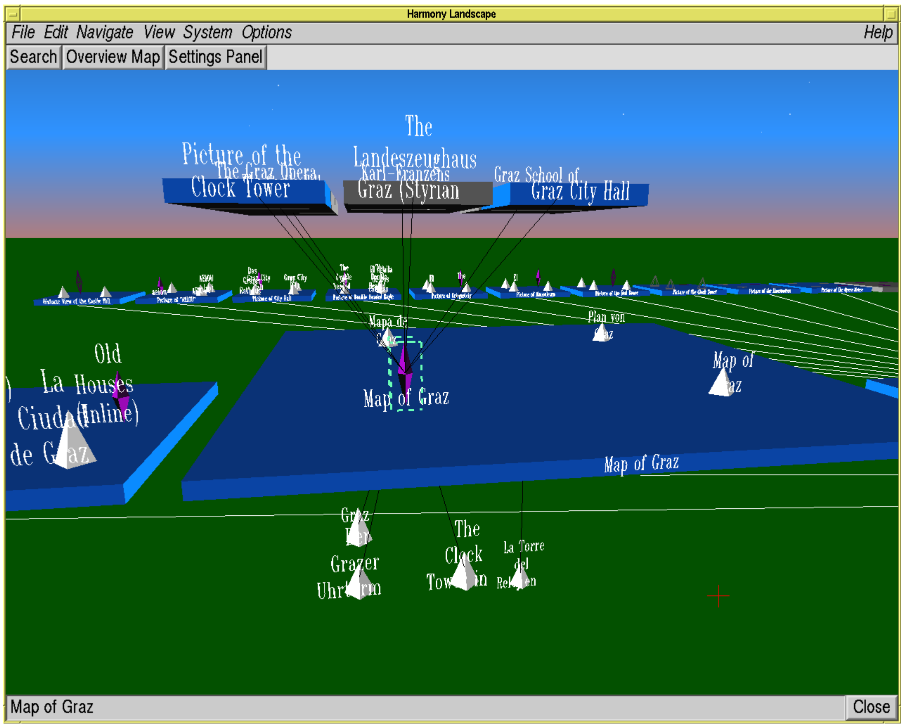

Figure 6.7: The Harmony Local Map 3D display hierarchical structure on the horizontal plane and superimposes hyperlink connections in the vertical plane.

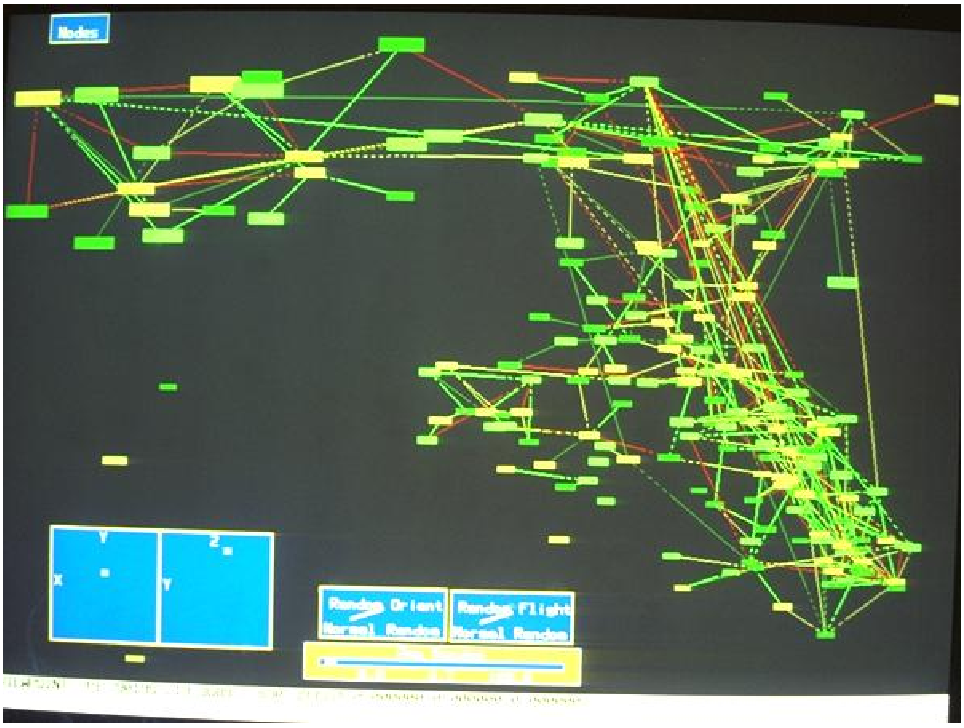

Figure 6.8: SemNet visualised a semantic network in 3d. [Image used with kind permission of Kim Fairchild.]

- The first 3d information visualisation.
- 3d spatial layout of a semantic network. See Figure 6.8.
- Article [Kim Michael Fairchild, Poltrock and Furnas, 1988].
- Video at CHI ’87 [K. Fairchild, 1987].
- Patented under [Wexelblat and Kim M. Fairchild, 1991].

6.4.2 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 7

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.]

7.1 Interactive Tables

7.1.1 Table Lens

- Xerox PARC, 1994.
- Focus + context technique for large tables.
- Rows and columns are squeezed down to pixel and subpixel sizes. See Figure 7.1.
- CHI’94 paper [R. Rao and S. K. Card, 1994] and CHI’95 video [R. Rao and S. K. Card, 1995].
- US Patent 5632009 [R. B. Rao and S. K. Card, 1997].

7.2 Interactive Scatterplots

7.2.1 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, Williams and Shneiderman, 1992] and video [Shneiderman, Williams and Ahlberg, 1992], CHI’94 paper [Ahlberg and Shneiderman, 1994a] and video [Ahlberg and Shneiderman, 1994b].
- Commercialised as part of IVEE’s Spotfire toolkit [Spotfire, 2000].

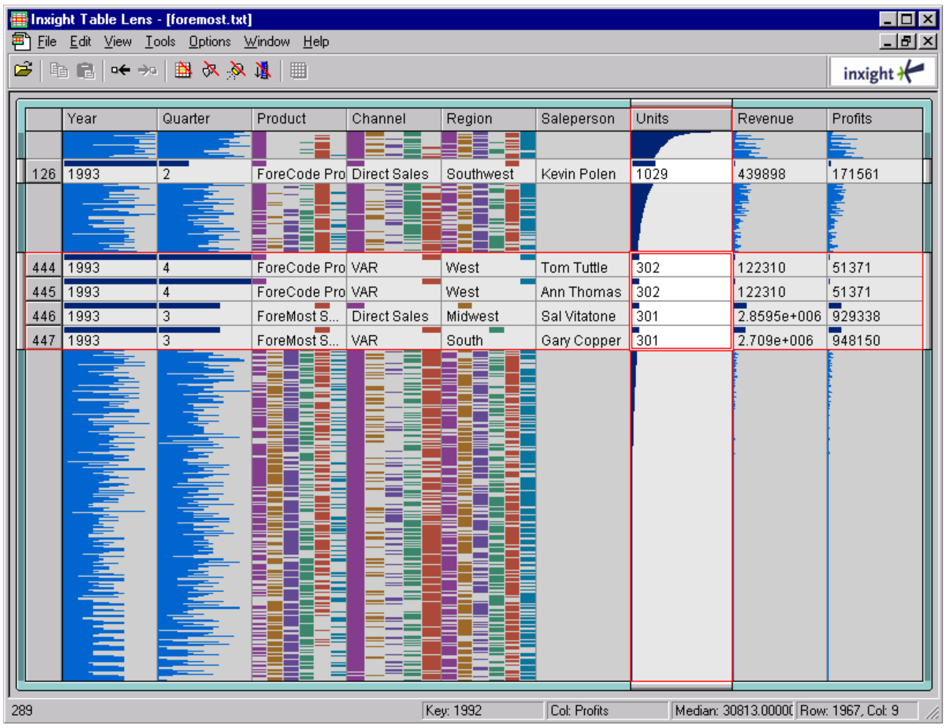

Figure 7.1: The table lens represents rows of a table as rows of pixels. The user can focus and stretch out rows or columns to see the data, whilst maintaining surrounding context.

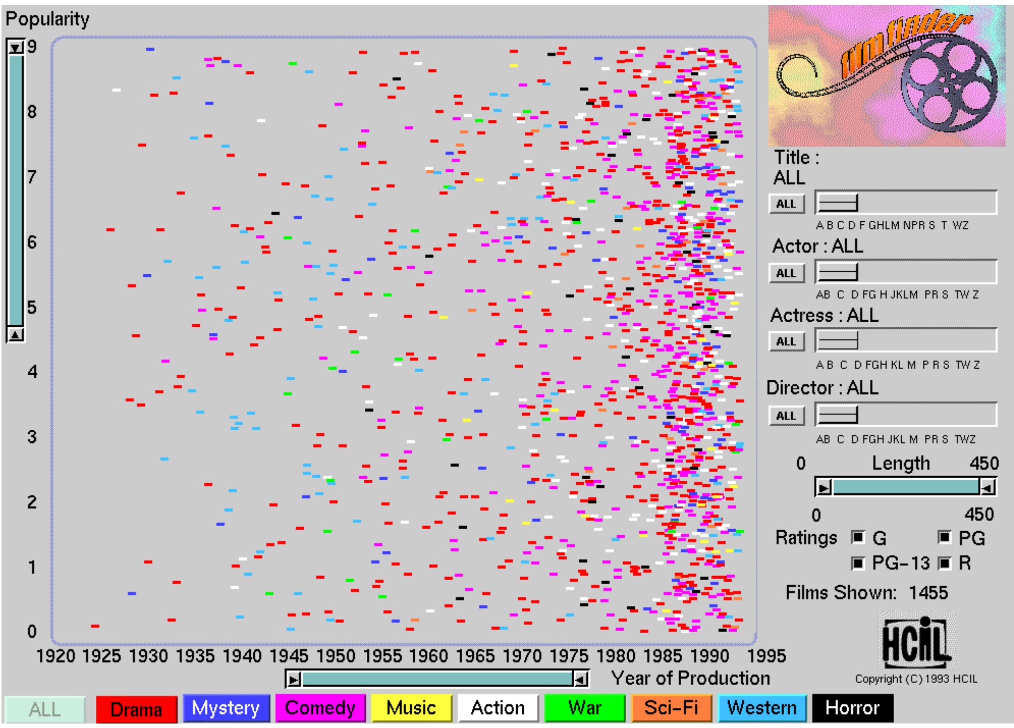

Figure 7.2: The FilmFinder, a starfield display combined with dynamic queries for rapid filtering. [Copyright ©University of Maryland 1984-1994.]

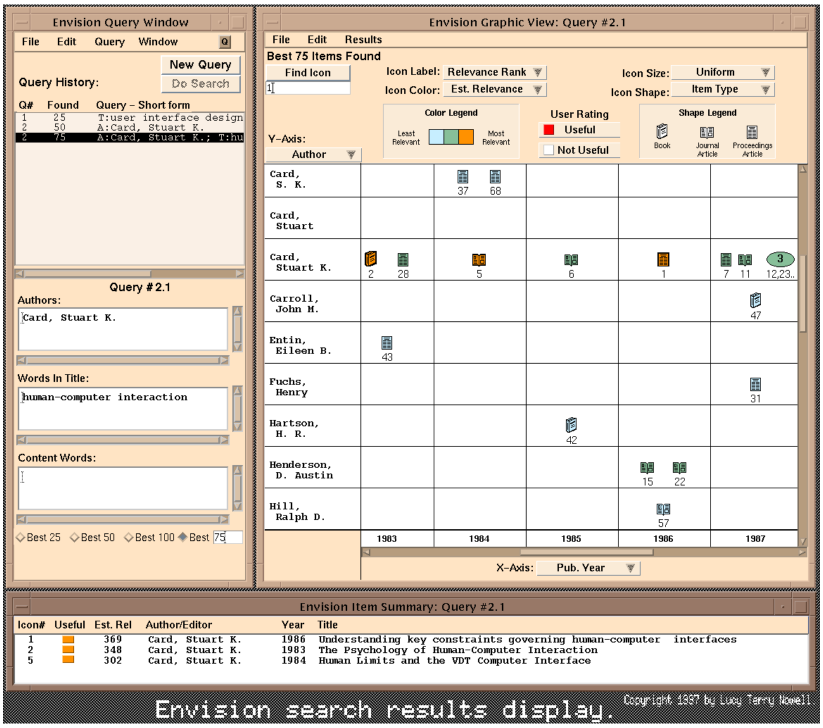

Figure 7.3: Envision visualises a set of search results, by mapping document attributes along two axes. Where too many documents would occupy a cell, an ellipse is used as a container object. Another problem is where to place documents matching multiple categories. [Copyright © by the Association for Computing Machinery, Inc.]

7.2.2 Envision

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

7.2.3 Search Result Explorer

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

7.3 Parallel Coordinates

7.3.1 Original Parallel Coordinates

- Al Inselberg, 1985.

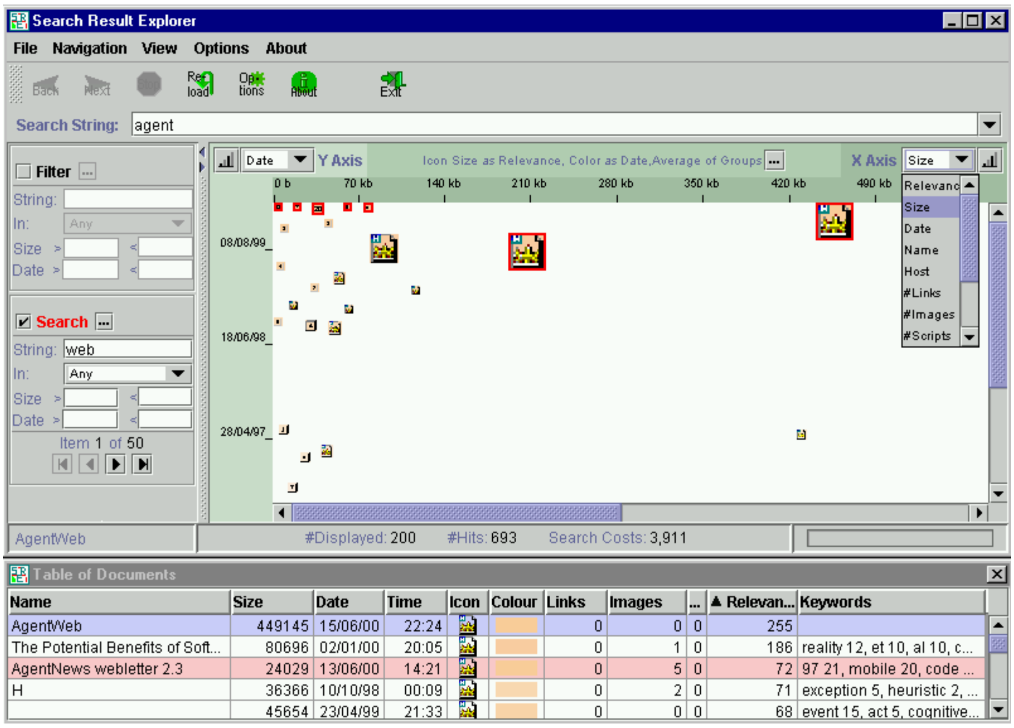

Figure 7.4: Search Result Explorer.

- 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 7.5 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.

7.4 Star Plots

7.5 Chernoff Faces

7.6 Interactive Histograms

7.6.1 Attribute Explorer

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

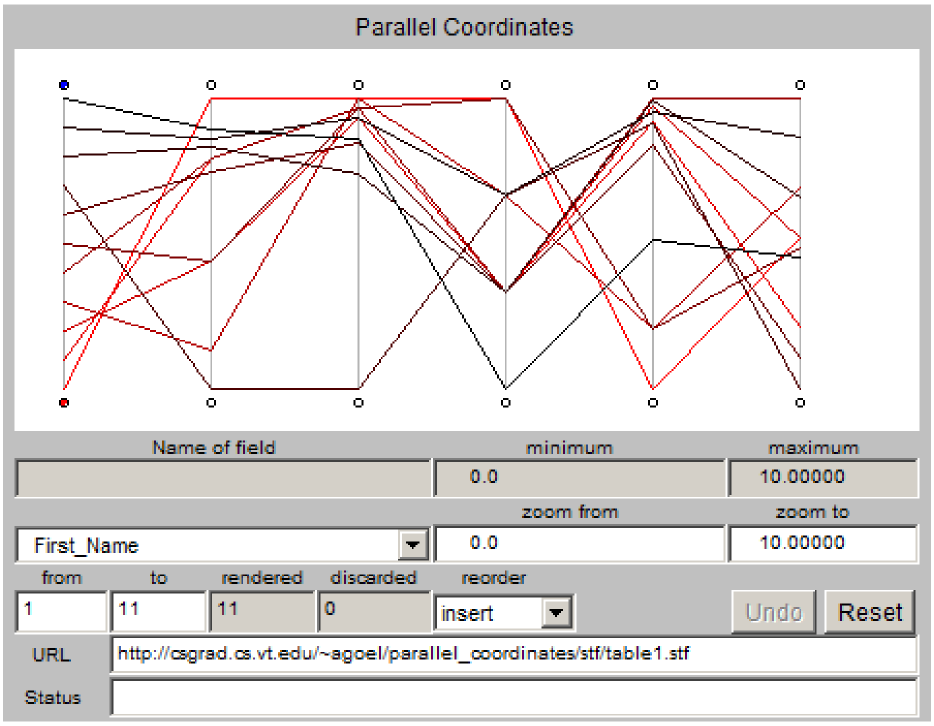

Figure 7.5: Parallel Coordinates. The six vertical lines represent (from left to right) the name and marks of students in five exams. The eleven polylines represent the data from eleven students. Polylines which mirror one another closely from vertical lines 2 to 6 indicate students achieving very similar marks.

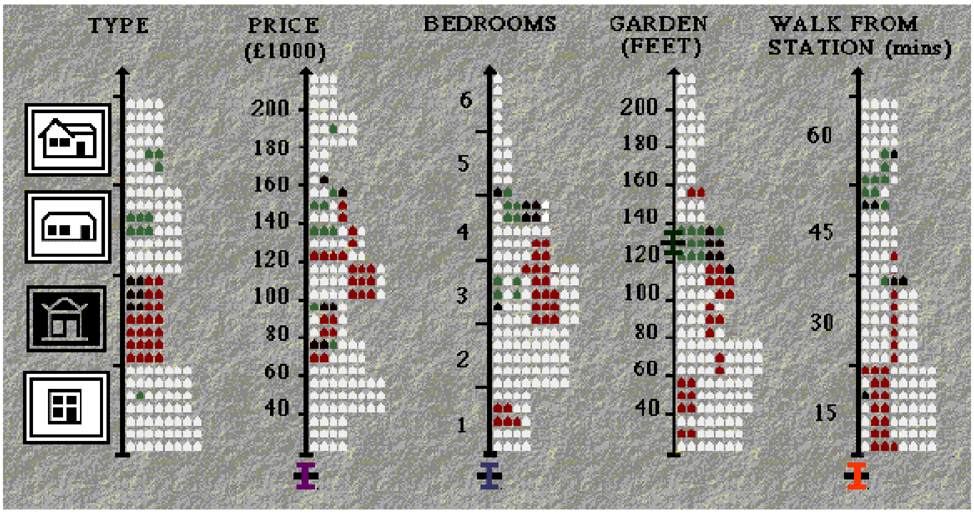

Figure 7.6: The Attribute Explorer. Each attribute is assigned to a scale with histograms showing the population spread running up one side. Initially these display each item in the total population. The user can interact with the scales: using sliders for continuous attributes (e.g. price) and buttons 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.]

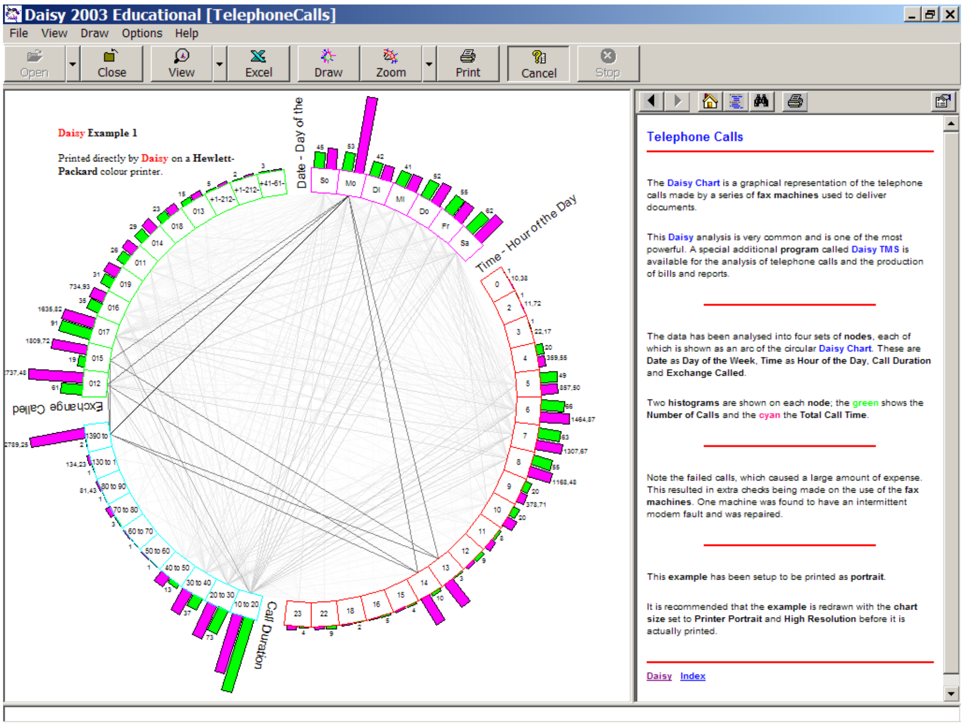

Figure 7.7: The Daisy Chart maps attributes and ranges of their values to positions on the circumference of a circle. Items are represented by polygons connecting attribute values.

7.7 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 7.7.

Chapter 8

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) [T. F. Cox and M. A. A. Cox, 2000]

8.1 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, Minghim and Paulovich, 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.

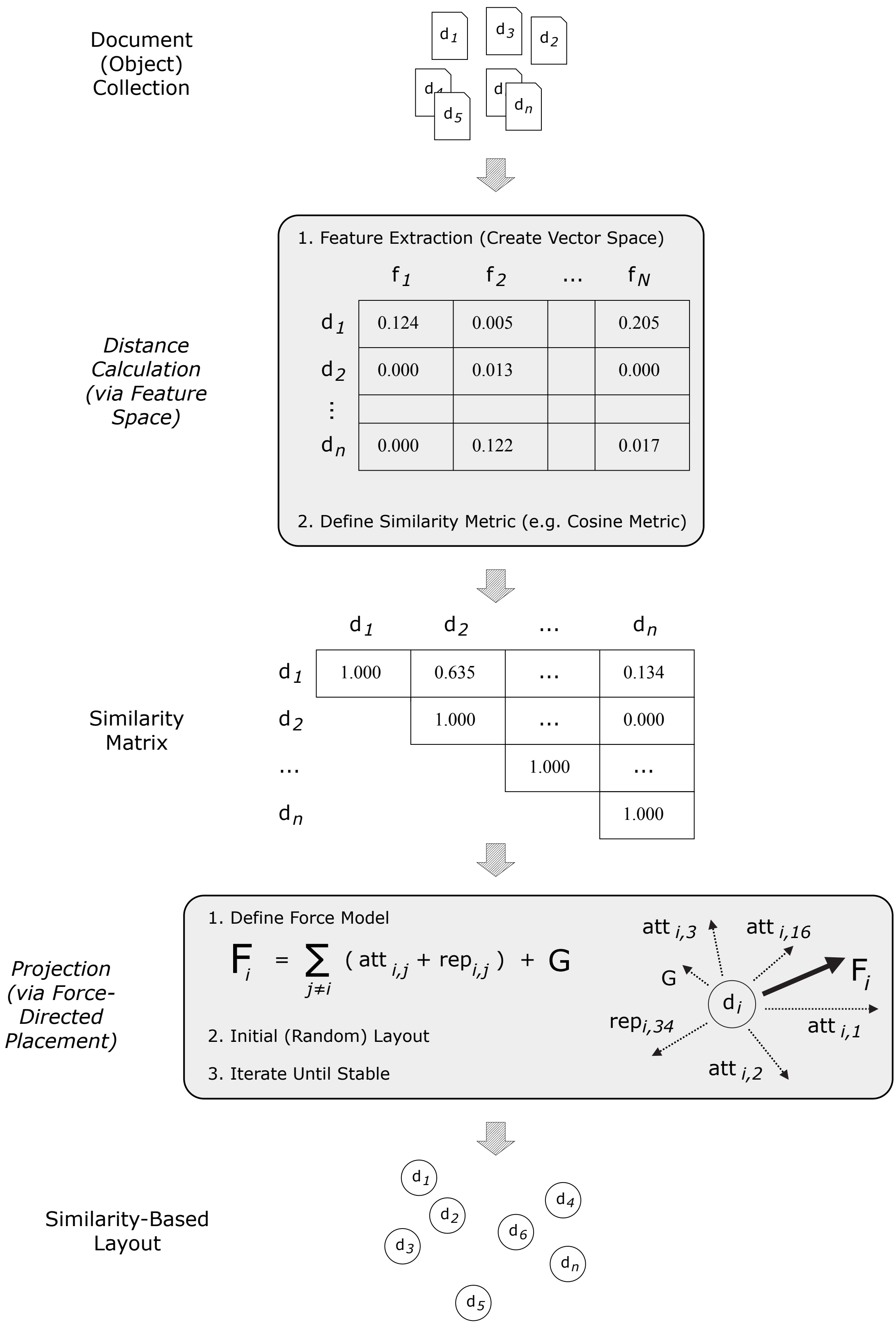

Figure 8.1: The visualisation pipeline for distance-based projection. Here, the vector space model has been chosen as the distance calculation algorithm and force-directed placement has been chosen as the projection algorithm.

8.1.1 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.

8.1.2 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, Minghim and Nonato, 2003].
- Least Squares Projection (LSP) [Paulovich et al., 2008].

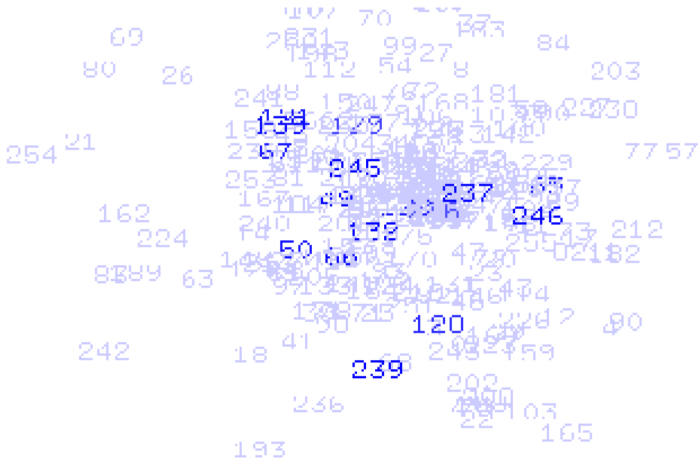

Figure 8.2: Part of the Bead visualisation of 301 entries from the HCI Bibliography. The objects represent articles from the field of HCI. Documents containing similar keywords are placed near each other in the 3d point cloud. A search has been done on the keywords "information retrieval" and the results are highlighted. [Copyright © by the Association for Computing Machinery, Inc.]

8.2 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, $O(n^3)$.
- 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 $O(n^2\sqrt{n})$ [Chalmers and Chitson, 1992], 1996 $O(n^2)$ [Chalmers, 1996a], 2003 $O(n^{\frac{5}{4}})$ [Morrison, Ross and Chalmers, 2003].
- Jourdan and Melancon, MultiscaleMDS, in 2004 $O(n \log n)$ [Jourdan and Melancon, 2004].
- Brandes and Pich; PivotMDS, in 2006 $O(n)$ through sampling and approximation [Brandes and Pich, 2006].
- Ingram, Munzner, and Olano; Glimmer, in 2009 theoretically $O(n^2)$, but massively parallel [Ingram, Munzner and Olano, 2009].

8.3 Example Systems

8.3.1 Bead

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

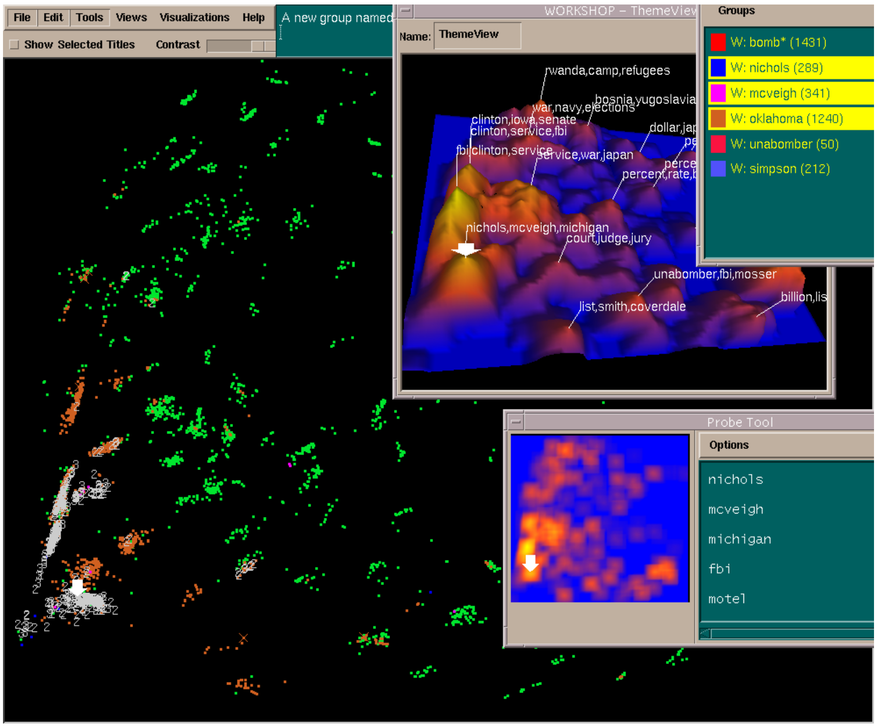

Figure 8.3: SPIRE showing the Galaxy View (below), Themescape (upper right) and Probe Tool. [Image used with kind permission of Pacific Northwest National Laboratory.]

8.3.2 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 8.3.
- 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].

8.3.3 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.

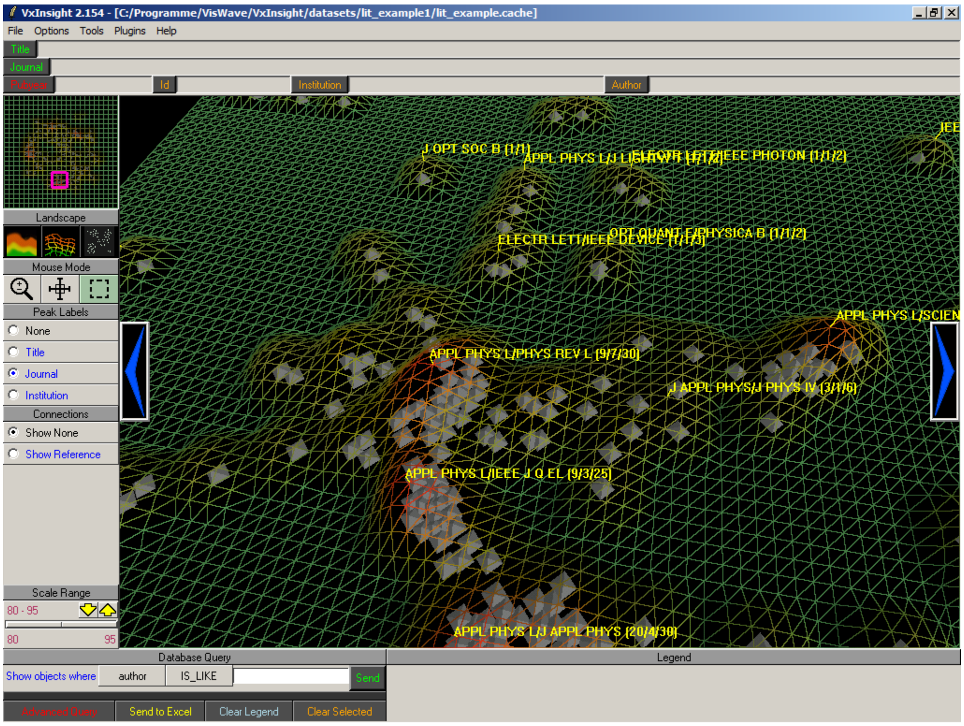

Figure 8.4: VxInsight showing some of 1,231 bibliographic records extracted from the physical sciences portion of the Science Citation Index Expanded. The layout uses similarities based on direct and cocitation links between articles. [Thanks to Brian Wylie, Sandia National Laboratories, for providing a demo version of VxInsight.]

8.3.4 VisIslands

- IICM, 2001 [Andrews, Gütl 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.

8.3.5 InfoSky

- IICM + Know-Center + Hyperwave, 2002 [Andrews, Kienreich 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.

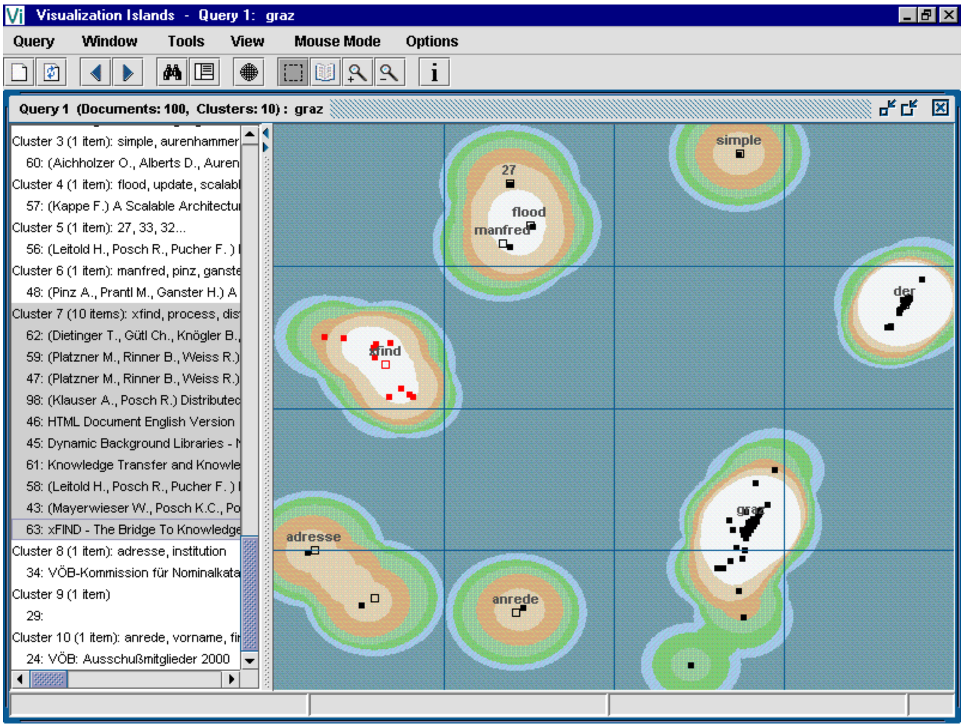

Figure 8.5: VisIslands forms visual clusters of search result sets.

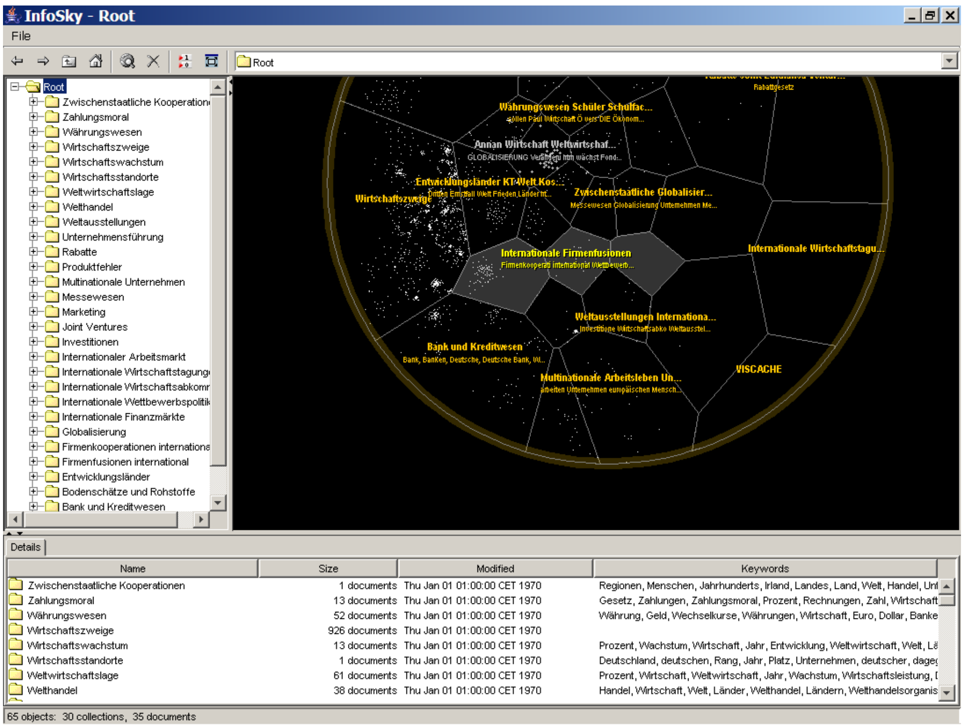

Figure 8.6: InfoSky showing a collection of newspaper articles from the German newspaper Sudeutscher Zeitung. The articles have previously been manually placed within a topical hierarchy by the newspaper editors.

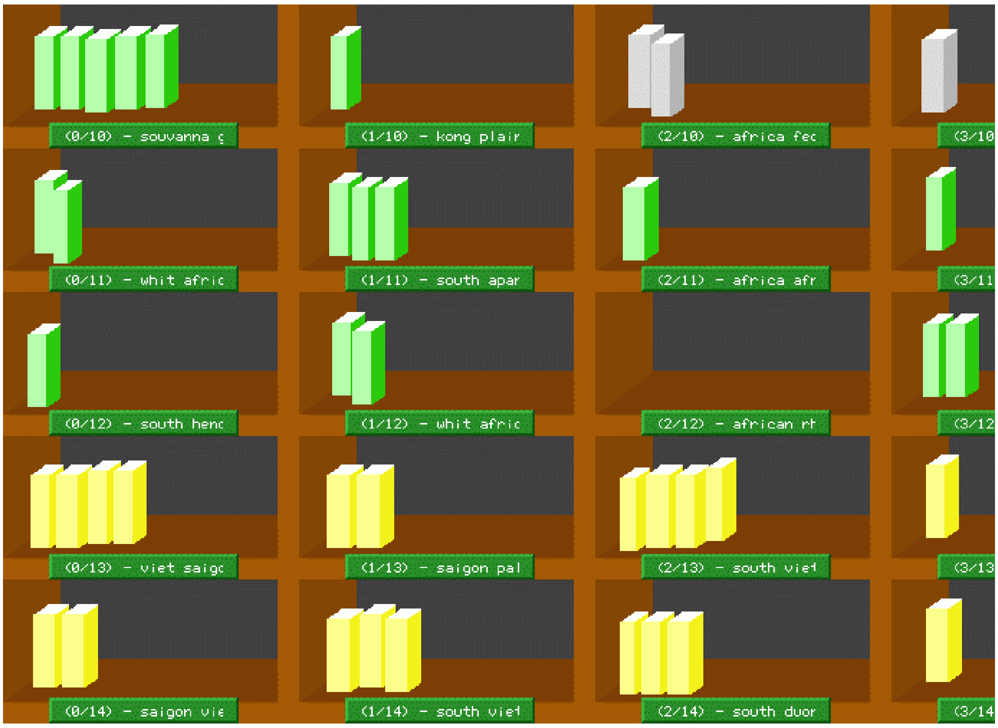

Figure 8.7: The SOMLib system with the libViewer interface. Documents are assigned to sections of a bookshelf (or post boxes) according to their content. [Image used with kind permission of Andreas Rauber.]

8.4 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.

8.4.1 SOMLib

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

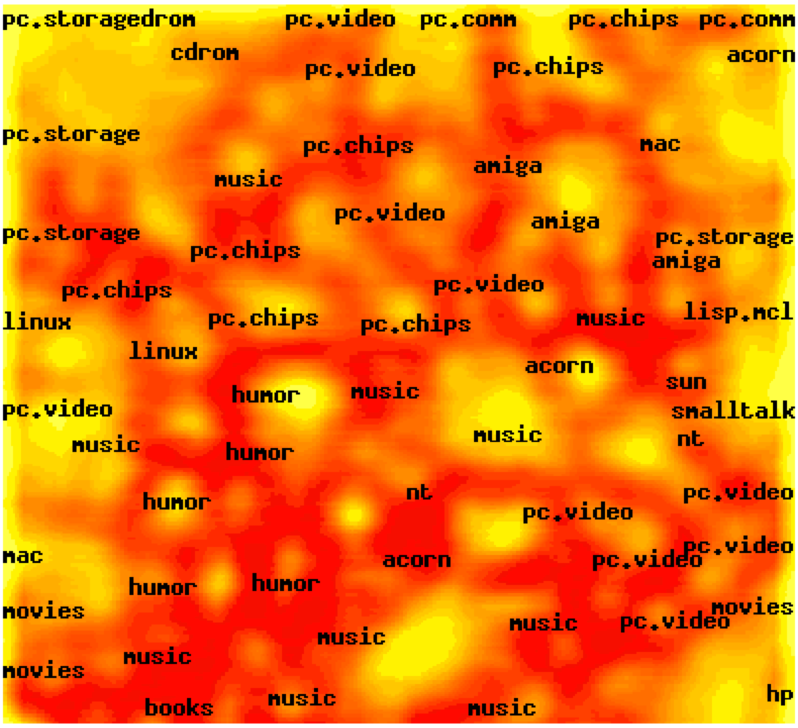

Figure 8.8: WEBSOM.

8.4.2 WEBSOM

- Self-organizing map (SOM) algorithm [Kohonen, 2000].
- Papers in IEEE Transactions on Neural Networks [Kohonen et al., 2000] and Information Sciences [Lagus, Kaski and Kohonen, 2004]

Chapter 9

Other Kinds of Visualisation

9.1 Visualising Query Spaces

9.1.1 InfoCrystal

- Anselm Spoerri, MIT, 1993.
- n boolean query terms at corners of regular polygon, icons representing documents are placed towards the corners they satisfy.
- Papers at Vis'93 [Spoerri, 1993a], CIKM'93 [Spoerri, 1993b], and VL'93 [Spoerri, 1993-08], as well as PhD thesis [Spoerri, 1995].

9.1.2 LyberWorld

- Matthias Hemmje, GMD-IPSI, 1993.
- Cone tree with documents and terms at alternate levels.
- Paper at SIGIR'94 [Hemmje, Kunkel and Willet, 1994], video at CHI'95 [Hemmje, 1995].

9.2 Internal Document Visualisation (Content Analysis)

9.2.1 TileBars

- Marti Hearst, Berkeley 1993-94, Xerox PARC, 1994–95.
- Visualisation of distribution of search terms within matching documents in a search result list.
- The structure of longer text documents is analysed, and the document is broken down into topical units.
- Each topical unit is a contiguous block of say a few paragraphs discussing the same themes.
- For each search term, a row of tiles indicates how frequently that term occurs in each topical unit (dark = very frequent). See Figure 9.1.
- Paper at CHI'95 [Hearst, 1995], video at CHI'96 [Hearst and Pedersen, 1996].

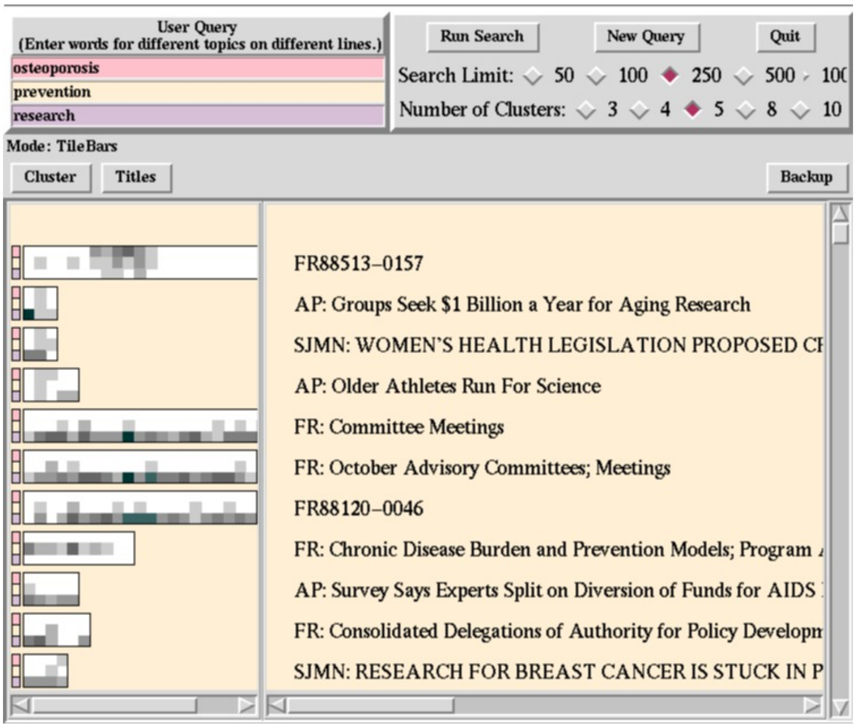

Figure 9.1: TileBars visualisation of the distribution of three search terms “osteoporosis”, “prevention”, and “research” within matching documents. The top-ranked document has some disussion of all three terms in the middle of the document. The fifth, sixth, and seventh matching documents all discuss research but have no mention of osteoporosis. [Image used with kind permission of Marti Hearst.]

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