

Information Visualisation

Course Notes

Version of 04 Jun 2020



Ao.Univ.-Prof. Dr. Keith Andrews

ISDS
Graz University of Technology
Inffeldgasse 16c
A-8010 Graz

kandrews@iicm.edu

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Preface

I first starting working on information visualisation in 1992 as part of my PhD thesis [Andrews 1996], continuing through my professorial thesis (Habilitation) [Andrews 2002b]. I helped organise the very first conference in the field, the IEEE Symposium on Information Visualization in 1995, was programme co-chair in 2001 and 2002, and general chair in 2005.

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, and at various conferences.

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

References in Association with Amazon

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

Thanks and happy reading,

Keith

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Chapter 1

Introduction

“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, together with accompanying interactions, so as to facilitate their rapid assimilation and understanding.

Visualisation

The broader field of visualisation has three main sub-fields:

- *SciVis*: Scientific Visualisation (SciVis) typically involves concrete (3d) objects, for example a medical scan of part of the body, or a simulation of air flow around an aircraft wing. SciVis visualisations often depict flows, volumes, and surfaces in (3d) space.
- *GeoVis*: Geographic Visualisation (GeoVis) is map-based. The data typically has inherent 2d or 3d spatial coordinates, and is generally shown in relation to a map.
- *InfoVis*: Information Visualisation (InfoVis) deals with *abstract* information structures, such as hierarchies, networks, or multidimensional spaces.

Data Visualisation (DataVis) = InfoVis + GeoVis.

Visual Analytics = DataVis (frontend) + Analytics (backend).

Information Visualisation

InfoVis \neq SciVis or GeoVis:

- In SciVis, the visual representation (geometry) is generally given, suggested by objects in the data. [concrete objects, geometry is given]
- In GeoVis, the visual representation (geometry) is generally given, determined by spatial coordinates within the data. [spatial coordinates, geometry is given]
- In InfoVis, an appropriate visual representation must be (carefully) designed or “invented”. [abstract structures, geometry is *chosen*]

Visual Representation + Interaction

- The visual representation is only half the story.
- Interaction (navigational and manipulation) facilities are the other half.

Two Main Purposes

Interactive data visualisations are used for two main purposes:

- *Analysis*: Exploratory visualisations help researchers to explore and analyse unfamiliar datasets.
- *Presentation*: Explanatory visualisations present results and insights to a wider audience.

For numerous examples of each kind, see my talk at TEDxGraz 2015 [Andrews 2015].

1.1 References

Books (InfoVis)

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- ++ Ward, Grinstein, and Keim; *Interactive Data Visualization: Foundations, Techniques, and Applications*; 2nd Edition, CRC Press, 29 May 2015. ISBN 1482257378 (com, uk) [Ward et al. 2015]
- ++ Bob Spence; *Information Visualization: An Introduction*; Springer, 3rd Edition, 14 Dec 2014. ISBN 3319073400 (com, uk) [Spence 2014] doi:10.1007/978-3-319-07341-5 [PDF + epub free via TU Graz.]
- ++ Colin Ware; *Information Visualization: Perception for Design*; 4th Edition, Morgan Kaufmann, 11 Mar 2020. ISBN 0128128755 (com, uk) [Ware 2020]
- + Alberto Cairo; *The Functional Art*; New Riders, 2012. ISBN 0321834739 (com, uk) [Cairo 2012]
- + Alberto Cairo; *The Truthful Art*; New Riders, 2016. ISBN 0321934075 (com, uk) [Cairo 2016]
- + Card, MacKinlay, Shneiderman; *Readings in Information Visualization : Using Vision to Think*; Morgan Kaufman, 1999. ISBN 1558605339 (com, uk) [Card et al. 1999]

Books (Practical Guides)

- + Stephen Few; *Show Me the Numbers*; 2nd Edition, Analytics Press, 01 Jun 2012. ISBN 0970601972 (com, uk) [Few 2012]
- + Stephen Few; *Signal: Understanding What Matters in a World of Noise*; Analytics Press, 01 Jun 2015. ISBN 1938377052 (com, uk) [Few 2015]
- + Stephen Few; *Information Dashboard Design*; 2nd Edition, Analytics Press, 15 Aug 2013. ISBN 1938377001 (com, uk) [Few 2013]
- + Stephen Few; *Now You See It: Simple Visualization Techniques for Quantitative Analysis*; Analytics Press, 01 Apr 2009. ISBN 0970601980 (com, uk) [Few 2009]

- + Cole Nussbaumer Knaflic; *Storytelling with Data*; Wiley, 02 Nov 2015. ISBN 1119002257 (com, uk) [Nussbaumer Knaflic 2015]
- + Danyel Fisher and Miriah Meyer; *Making Data Visual: A Practical Guide to Using Visualization for Insight*; O'Reilly, 12 Jan 2018. ISBN 1491928468 (com, uk) [Fisher and Meyer 2018]
- + Andy Kirk; *Data Visualisation*; 2nd Edition, Sage Publications, 20 Aug 2019. ISBN 1526468921 (com, uk) [Kirk 2019]
- Edward Tufte; *Beautiful Evidence*; Graphics Press, 2006. ISBN 0961392177 (com, uk) [Tufte 2006]
- + Edward Tufte; *The Visual Display of Quantitative Information*; 2nd Edition, Graphics Press, 2001. ISBN 0961392142 (com, uk) [Tufte 2001]
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- + Edward Tufte; *Envisioning Information*; Graphics Press, 1990. ISBN 0961392118 (com, uk) [Tufte 1990]
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Books (Applications)

- Julie Steele and Noah Iliinsky; *Beautiful Visualization: Looking at Data Through the Eyes of Experts*; O'Reilly, 21 Jun 2010. ISBN 1449379869 (com, uk) [Steele and Iliinsky 2010]
- James J. Thomas and Kristin A. Cook; *Illuminating the Path: The Research and Development Agenda for Visual Analytics*; 184-page report, August 2005. <http://nvac.pnl.gov/agenda.stm> ISBN 0769523234 (com, uk)
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- Teuvo Kohonen, T. S. Huang, and M. R. Schroeder; *Self-Organizing Maps*; 3rd Edition, Springer, 2000. ISBN 3540679219 (com, uk) [Kohonen 2000]
- Okabe et al; *Spatial Tessellations*; 2nd Edition, Wiley, 2000. ISBN 0471986356 (com, uk) [Okabe et al. 2000]

Podcasts

- ++ Enrico Bertini and Moritz Stefaner; *Data Stories*; Podcast about data visualisation. datastories.es
- + Cole Nussbaumer Knaflc; *Storytelling with Data Podcast*; <https://storytellingwithdata.com/podcast>

Online Resources

- ++ Data Visualization Society; datavisualizationsociety.com
[11,000+ members and very active Slack channels (datavizsociety.slack.com after approval)]
- ++ *Nightingale*; The Journal of the Data Visualization Society <https://medium.com/nightingale>
- ++ *Multiple Views: Visualization Research Explained*; <https://medium.com/multiple-views-visualization-research-explained>
- ++ Reddit; *Data Is Ugly*; <https://reddit.com/r/dataisugly/>
- ++ Reddit; *Data Is Beautiful*; <https://reddit.com/r/dataisbeautiful/>
- + David McCandless; *Information is Beautiful*; <https://informationisbeautiful.net/>
- ++ Robert Kosara; *EagerEyes*; eagereyes.org
- + Andy Kirk; *Visualising Data*; visualisingdata.com
- Cole Nussbaumer Knaflc; *Storytelling with Data*; storytellingwithdata.com
- Nathan Yau; *Flowing Data*; flowingdata.com
- + Makeover Monday; www.makeovermonday.co.uk
- Jonathan Schwabish; *HelpMeViz*; <https://policyviz.com/helpmeviz/>
- Lisa Charlotte Rost; *Chartable: A Blog by Datawrapper*; blog.datawrapper.de
- Severino Ribeccar; *The Data Visualisation Catalogue*; datavizcatalogue.com
- Alberto Cairo; *The Functional Art*; thefunctionalart.com
- Manuel Lima; *Visual Complexity*; visualcomplexity.com
- Michael Friendly; *Gallery of Data Visualization*; <http://datavis.ca/gallery/>
- *InfoVis Wiki*; infovis-wiki.net

Journals

- ++ Information Visualization; Sage; ISSN 1473-8716 <https://journals.sagepub.com/home/ivi>

- ++ IEEE Computer Graphics and Applications; ISSN 0272-1716 <https://publications.computer.org/cga/>
- ++ IEEE Transactions on Visualization and Computer Graphics; ISSN 1077-2626 <https://publications.computer.org/tvcg/>
- Visual Informatics; ISSN 2468-502X <https://sciencedirect.com/journal/visual-informatics>

Conferences

- ++ InfoVis (IEEE Conference on Information Visualization). Since 1995, formerly IEEE Symposium on Information Visualization. The main conference in the field, low acceptance rate (23% in 2017), very focussed, high quality papers. ieevis.org
- ++ EuroVis (Eurographics/IEEE Symposium on Visualization). Since 1999, formerly VisSym. high quality, quite low acceptance rate (27% in 2017). eurovis.org
- + OpenVis. Annual conference, open-source tools for datavis. Usually in Boston, USA. openvisconf.com
- IV (International Conference on Information Visualisation). Since 1997, usually in London. Broad in scope, fairly high acceptance rate, papers of mixed quality, multi-track. www.graphicslink.co.uk
Proceedings published with IEEE: <http://ieeexplore.ieee.org/xpl/conhome.jsp?punumber=1000370>
- PacificVis (IEEE Pacific Visualization Symposium). pvis.org
- Information+ Conference; informationplusconference.com
- See Conference, Germany. Largely German-speaking. see-conference.org
- IVAPP (International Conference on Information Visualisation Theory and Applications). ivapp.visigrapp.org
- Some papers at CHI, AVI, UIST.

InfoVis Companies

Suppliers of infovis toolkits and components:

- Tableau; tableau.com [Tableau was acquired by Salesforce on 01 Aug 2019 for \$15.7 billion.]
- Qlik; qlik.com
- Spotfire; [https://tibco.com/products/tibco-spotfire](http://tibco.com/products/tibco-spotfire) [Spotfire was acquired by Tibco in May 2007 for \$195 million.]
- Datawrapper; datawrapper.de
- Flourish; flourish.studio
- Inxight; [https://web.archive.org/web/20080501144431/http://www.inxight.com/](http://web.archive.org/web/20080501144431/http://www.inxight.com/) [Inxight was acquired by BusinessObjects in May 2007. BusinessObjects was acquired by SAP in Oct 2007.]
- The Hive Group; hivegroup.com [The Hive Group was merged into Visual Action in Jan 2015.]
- Panopticon; panopticon.com
- macrofocus; macrofocus.com

- Maya Viz; mayaviz.com [Maya Viz was acquired by General Dynamics in Apr 2005.]
- OmniViz; omniviz.com [OmniViz was acquired by BioWisdom in Feb 2007. BioWisdom was acquired by Instem in Mar 2011.]
- AVS; avs.com
- NComVA; ncomva.com [NComVA was acquired by Qlik in 2013.]
- Advizor Solutions; advizorsolutions.com [Formerly Visual Insights, was renamed Advizor Solutions in 2003.]
- magnaview; magnaview.com
- Uncharted Software; uncharted.software [Formerly Oculus Info, was renamed Uncharted Software in 2015.]
- Tom Sawyer Software; tomsawyer.com
- yWorks; yworks.com
- ILOG; ilog.com [ILOG was acquired by IBM in Jan 2009.]
- Periscopic; periscopic.com
- Stamen Design; stamen.com
- datavisyn; in Linz; datavisyn.io

Video: Stephen Few

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

Video: Hans Rosling

- Hans Rosling; *Stats That Reshape Your World View*; 20-minute video [Rosling 2006] [00:00–18:54]
- Demos are available at gapminder.org.
- Source code (Angular 2, Electron) is available from <https://github.com/Gapminder/gapminder-offline> [Hans Rosling passed away on 07 Feb 2017.]

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).

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 (fictitious sales data). Compare the sales figures of the two salespeople. Can you spot a trend?

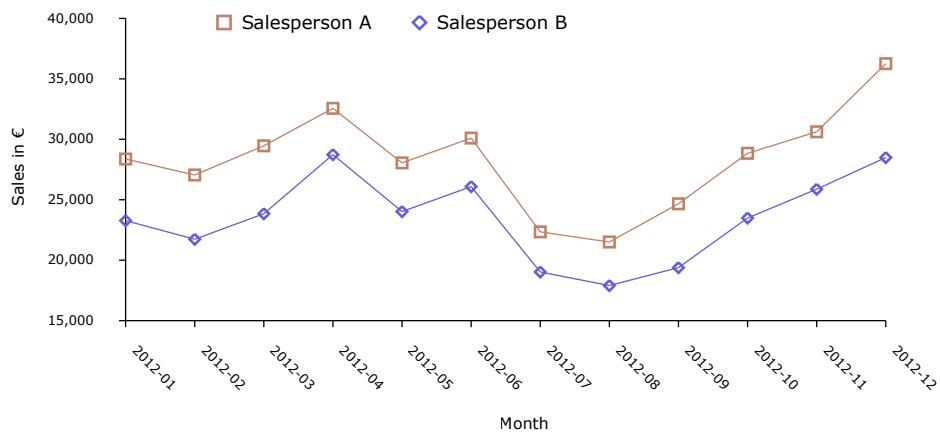


Figure 1.1: Sales for 2012 in € by salesperson. Line chart of the same sales data. It is much easier to see the trends and compare the data, when it is presented visually.

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.
- Standard summary statistics such as mean and standard deviation are almost identical for all four

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.

variables.

- However, when plotted graphically, as shown in Figure 1.4, the four variables are revealed to be very different.

	v₁		v₂		v₃		v₄	
	<i>x₁</i>	<i>y₁</i>	<i>x₂</i>	<i>y₂</i>	<i>x₃</i>	<i>y₃</i>	<i>x₄</i>	<i>y₄</i>
	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.

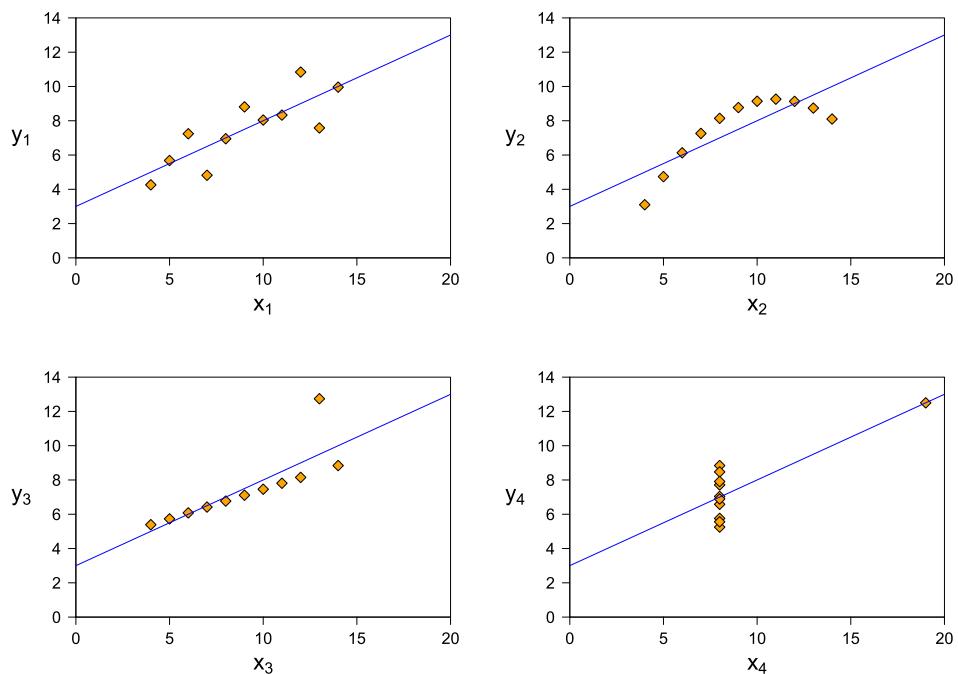


Figure 1.4: The four variables in Anscombe's Quartet have almost identical summary statistics (mean, standard deviation, etc.). However, when plotted graphically, they are revealed to be rather different in nature.

1.3 Visual Lies

Sometimes, visualisations can be (deliberately) deceptive or misleading.

Resources

- ++ Alberto Cairo; *How Charts Lie*; W. W. Norton, 15 Oct 2019. ISBN 1324001569 (com, uk) [Cairo 2019]
- + Alberto Cairo; *Graphics Lies, Misleading Visuals*; Chapter 5 of New Challenges for Data Design, 27 Dec 2014. [Cairo 2014]
- + Nathan Yau; *How to Spot Visualization Lies*; 09 Feb 2017. [Yau 2017]
- + Katie Notopoulos; *13 Graphs That Are Clearly Lying*; 03 Oct 2014. <https://buzzfeed.com/katienotopoulos/graphs-that-lied-to-us> [Notopoulos 2014]
- + *WTF Visualizations*; viz.wtf [WTF 2017]
- + Reddit; *Data is Ugly*; <https://reddit.com/r/dataisugly/>
- David Shere and Hannah Groch-Begley; *A History Of Dishonest Fox Charts*; <http://mediamatters.org/research/2012/10/01/a-history-of-dishonest-fox-charts/190225>
- Mushon Zer-Aviv; *Disinformation Visualization: How to Lie with DataVis*; 31 Jan 2014. [Zer-Aviv 2014]
- + Darrell Huff; *How to Lie with Statistics*; Reissue Edition, W. W. Norton, 17 Oct 1993. ISBN 0393310728 (com, uk) [Huff 1993]

Misuse of 3D Perspective

- Surely, no-one would ever misuse 3d perspective to give a false impression?
- In his Macworld 2008 keynote speech [Jobs 2008, 00:09:42], 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.

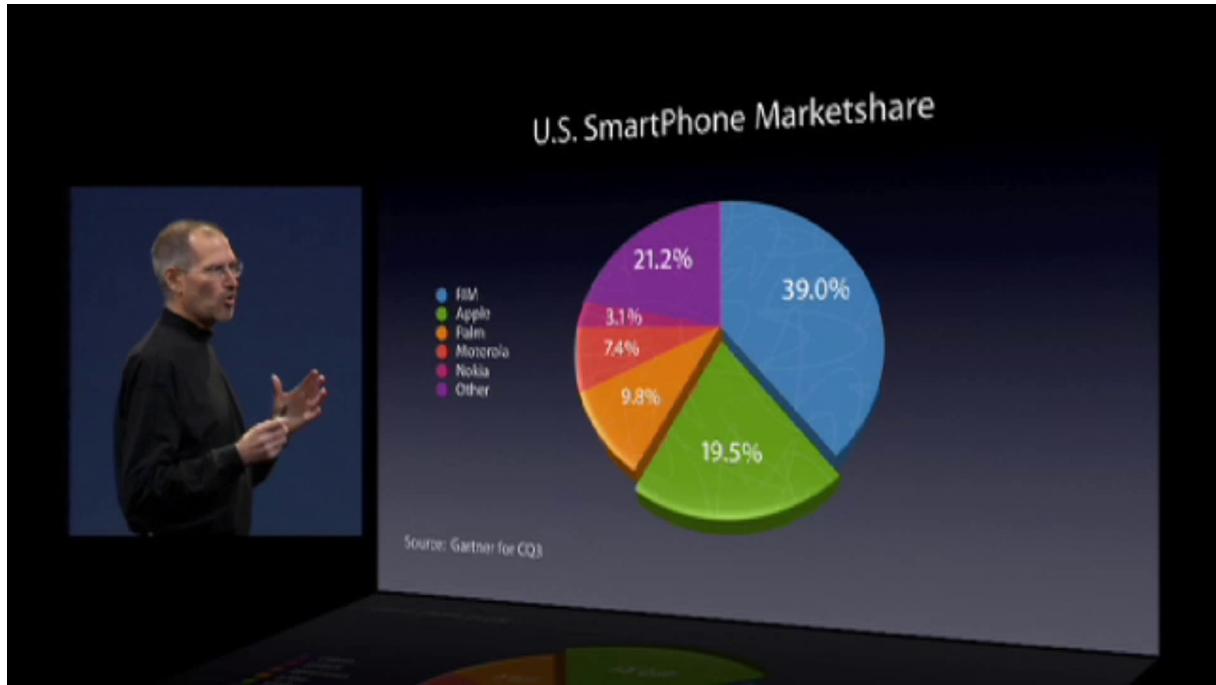


Figure 1.5: Steve Jobs' 3d pie chart [Jobs 2008, 00:09:42].

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.

Video: Noah Iliinsky

- Noah Iliinsky; *Data Visualizations Done Wrong*; ORDcamp 2012 Ignite Talk, 5-minute video [Iliinsky 2012]

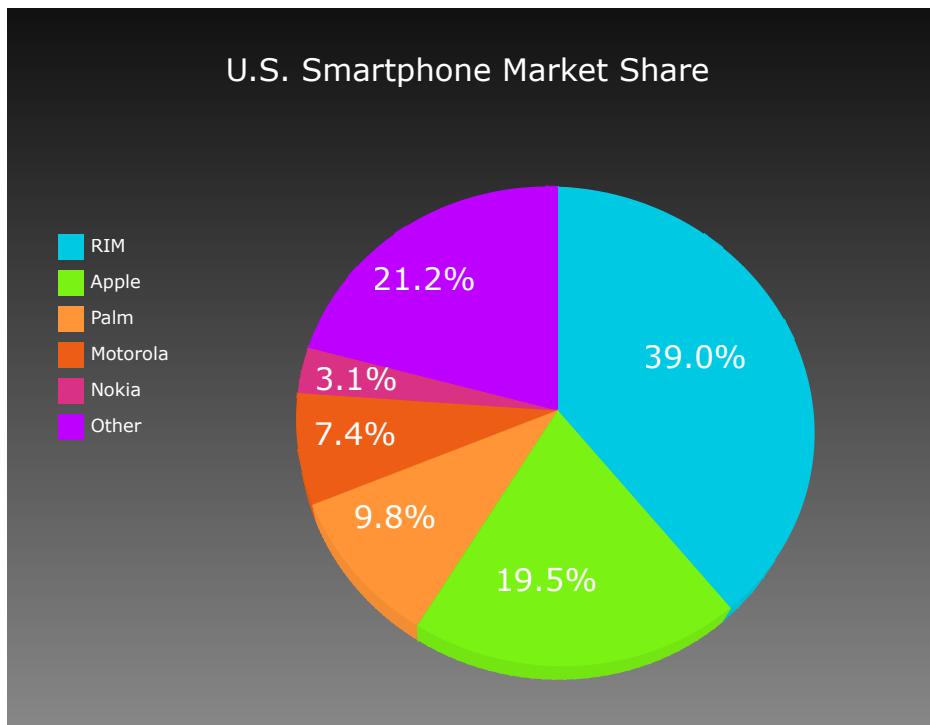


Figure 1.6: A reconstruction of Steve Jobs' 3d pie chart, with 3d perspective making the lower segment appear larger than it should. [Chart created by Keith Andrews with LiquidDiagrams [Andrews and Lessacher 2010].]

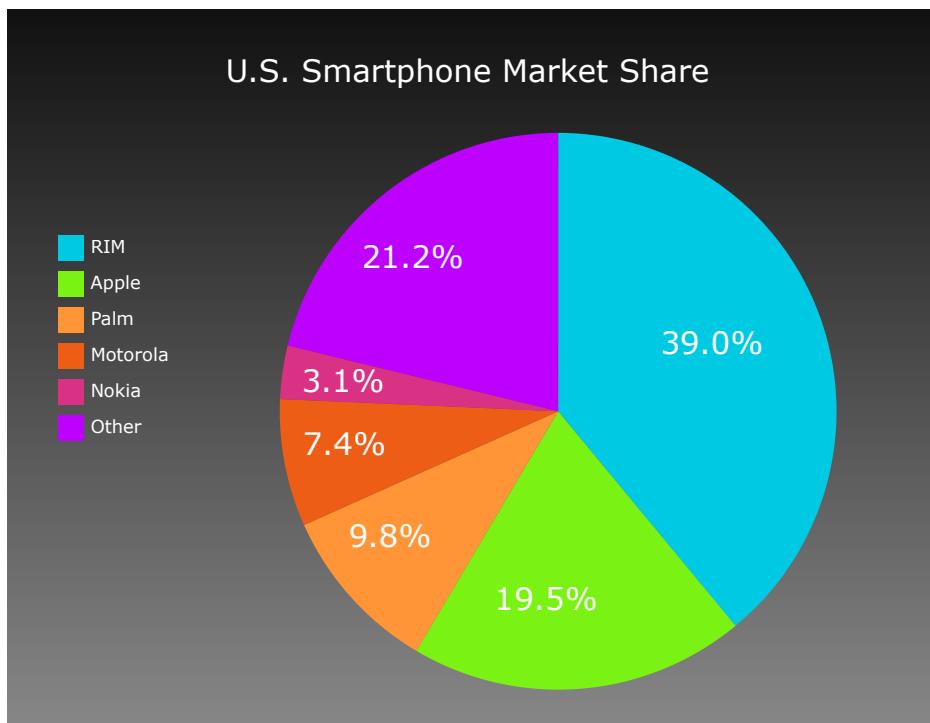


Figure 1.7: A standard, flat 2d pie chart of the data. [Chart created by Keith Andrews with LiquidDiagrams [Andrews and Lessacher 2010].]

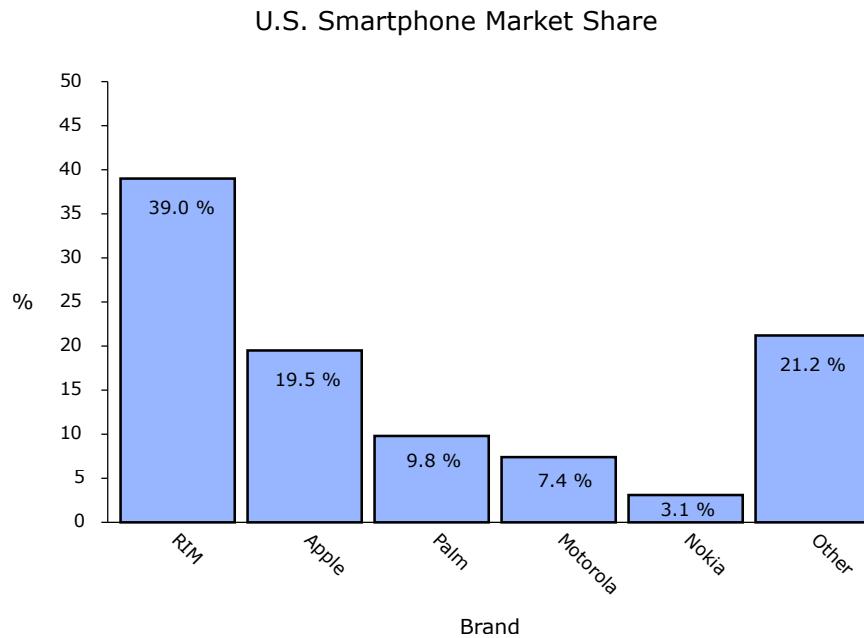


Figure 1.8: A bar chart of the data. [Chart created by Keith Andrews with LiquidDiagrams [Andrews and Lessacher 2010].]

1.4 General Concepts of Information Visualisation

General concepts which appear over and again in information visualisation.

Visualisation Pipeline

In Chapter 1 of their Readings volume, Card et al. [1999, page 17] describe a reference model for visualisation, shown in Figure 1.9:

- It describes the mapping of data to visual to support human interaction.
- It has become known as the visualisation pipeline.

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].

Utilising Human Visual Perception

Humans have remarkable perceptual abilities:

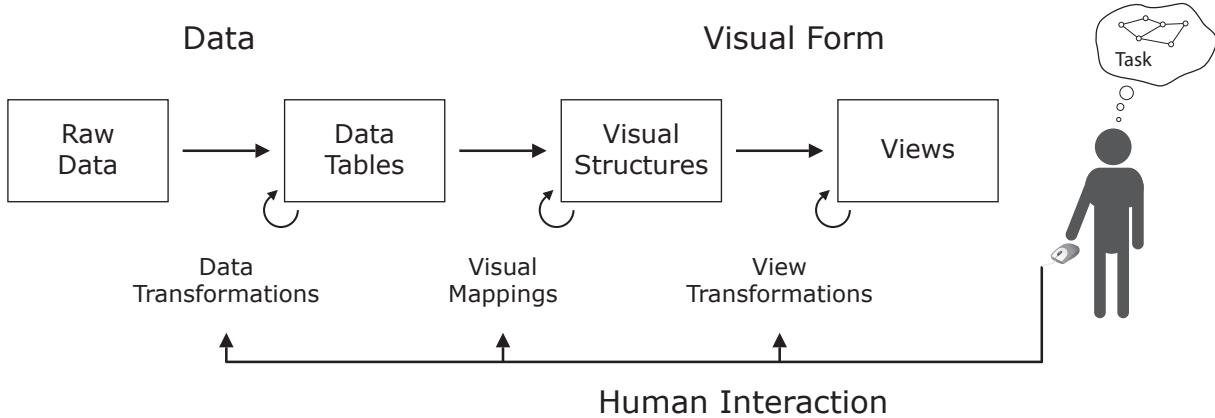


Figure 1.9: The visualisation pipeline. [Redrawn by Keith Andrews from the original in Card et al. [1999, page 17].]

- to scan, recognise, and recall images rapidly.
- to rapidly and *automatically* detect patterns, outliers, 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.

Visualisation + Interaction

- *Interaction*: being able to explore and manipulate the view is just as important as the underlying visual representation.
- *Object Constancy*: Smoothly animate transitions over about 1 sec. Eliminates the need for re-assimilation of the scene [Robertson et al. 1991a].

Focus-plus-Context

Focus on one or more areas of interest, while maintaining the surrounding context (but not in as much detail). Specific examples of focus-plus-context techniques include:

- *Overview-plus-Detail*: Two separate, but synchronised, windows or panes: an overview window (context) and a detail window (focus).
- *3d Perspective*: Focus items are in the foreground, with the context in the background.
- *Fisheye View*: A geometric distortion (like a magnifying glass) is applied over the area of interest [Furnas 1981; Furnas 1986]. The focus in the centre is enlarged, while the surrounding context is made smaller.
- *Focus-and-Blur*: Focus items are (optically) in focus, while context items are blurred.

Guaranteed Visibility

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

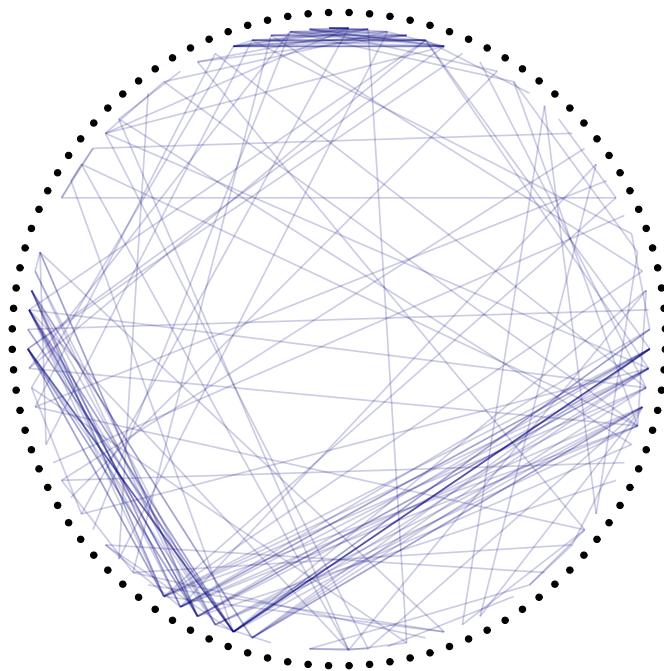


Figure 1.10: Naive straight-line connections. [Figure made by Keith Andrews using sample R code from Holtz [2017]] .

Edge Bundling

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

- Edge bundling [Holten 2006; Lhuillier et al. 2017] 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.
- In Figure 1.10, naive straight-line connections clutter the diagram.
- In Figure 1.11, edge bundling ties edges with similar paths together.

Excentric Labels

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

- To avoid 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 1.12.

Small Multiples

A *small multiple* is a table (lattice or grid) of charts or plots, using the the same axes and scale for comparision. For example:

- The term was coined by Tufte [2001, page 170] and defined as “... a series of graphics, showing the same combination of variables indexed by changes in another variable.”

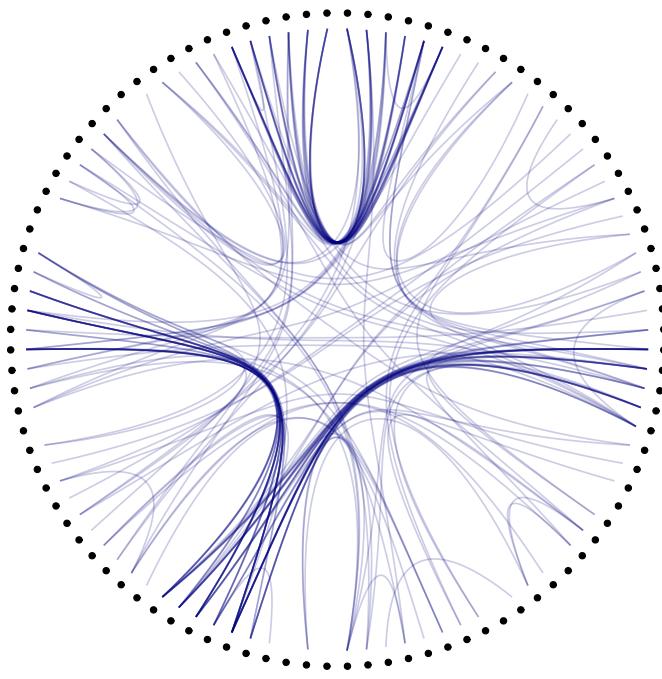


Figure 1.11: Edge bundling ties edges with similar paths together. [Figure made by Keith Andrews using sample R code from Holtz [2017]] .

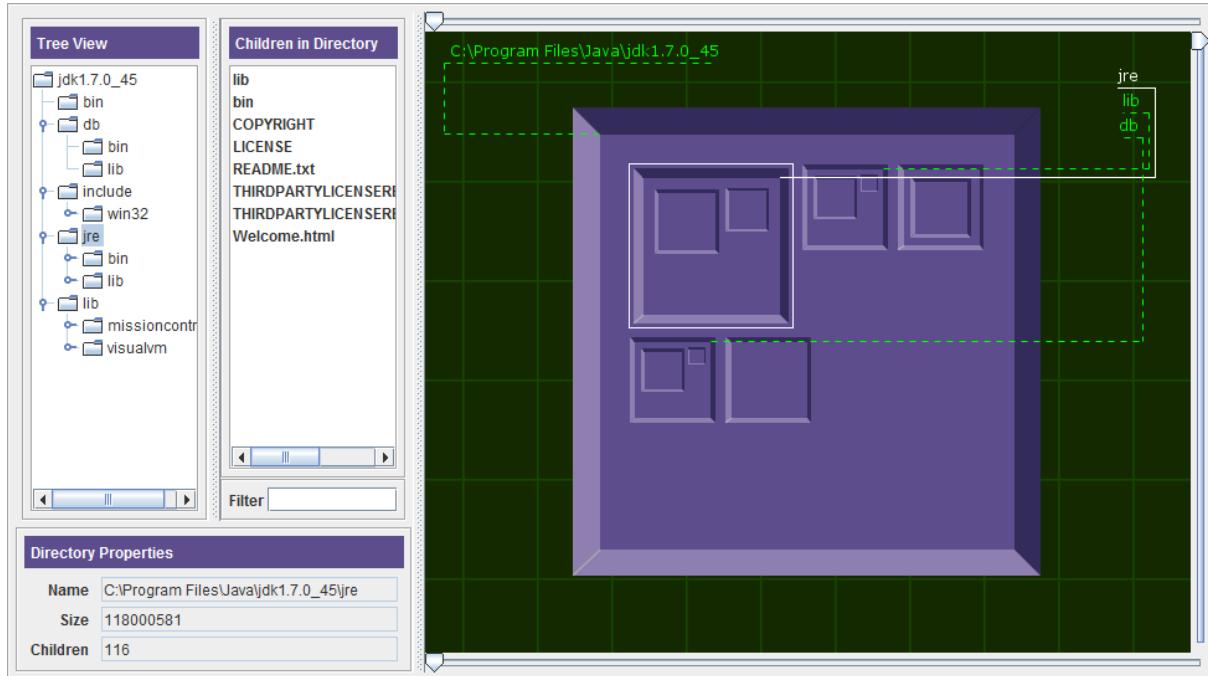


Figure 1.12: Excentric labels are drawn outside of the main visualisation and connected to the corresponding elements by lines. In the JExplorer tree browser, excentric labels are used to label the selected folder, its parent, and (some) siblings. [Screenshot made by Keith Andrews.]

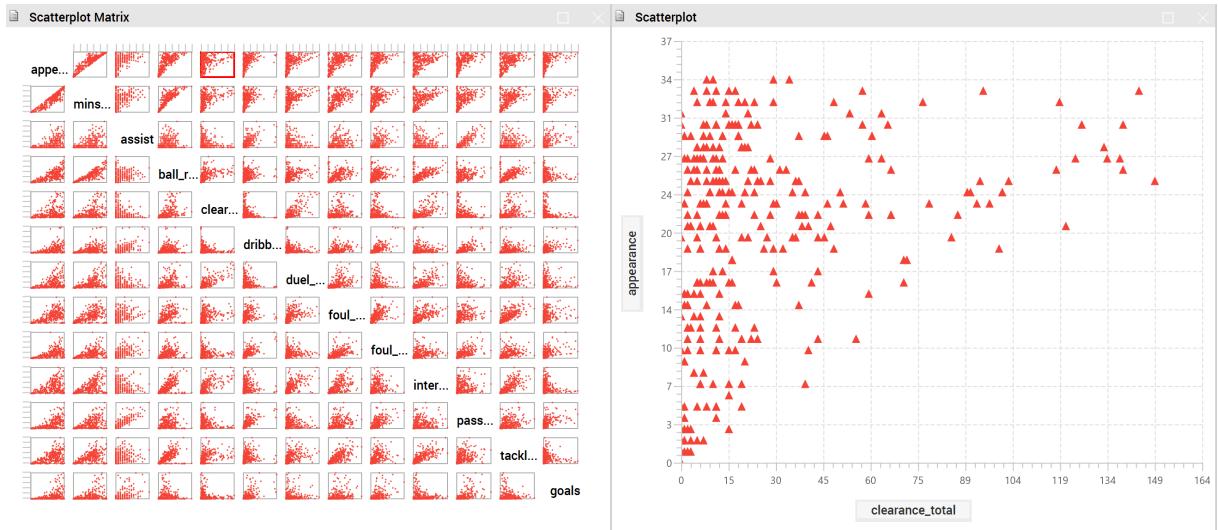


Figure 1.13: The scatterplot matrix on the left shows all pairwise combinations of 13 performance variables about players from 16 clubs in five top European leagues in the 2017/18 season. The scatterplot on the right shows number of appearances plotted against total clearances. Players are represented by red triangles. [Screenshot made by Keith Andrews using mVis [Chegini et al. 2019].]

- For example, a scatterplot matrix is a table of scatterplots showing all pairwise combinations of variables, as shown in Figure 1.13.

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: David McCandless

- David McCandless; *The Beauty of Data Visualization*; 18-minute video [McCandless 2010] [00:00–07:28, 17:09–17:54]
- More examples of his work are at informationisbeautiful.net.

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*; 4th Edition, Morgan Kaufmann, 11 Mar 2020. ISBN 0128128755 (com, uk) [Ware 2020]
- ++ 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 2011b]
- 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 et al. 2003]

Online Resources

- ++ Christopher Healey; *Perception in Visualization*; <http://csc.ncsu.edu/faculty/healey/PP/> [C. Healey 2009]
- ++ Stephen Few; *Tapping the Power of Visual Perception*; Blog article, 04 Sept 2004. https://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://vanseodesign.com/web-design/visual-perception-memory/> [Bradley 2011]

Bandwidth of the Senses

- based on work by Tor Nørretranders.
- McCandless [2010, 00:09:05–00:09:54] TED 2010 video. <https://youtu.be/5Zg-C8AAIGg?t=09m10s>

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”

Selective Attention

We perceive only what the mind attends to:

- Selective Attention Test (basketball passes) by Dan Simons and Chris Chabris [Simons and Chabris 1999a; Chabris and Simons 2011b; Chabris and Simons 2011a].
- Based on work originally done by Ulric Neisser at Cornell University in the 1970s [Bazerman and Tenbrunsel 2016; Neisser 1979].
- Original video [Simons and Chabris 1999b] <https://youtu.be/vJG698U2Mvo>
- The Door Study (workmen with door) by Dan Simons and Dan Levin [Simons and Levin 1998a; Simons and Levin 1998b]. <https://youtu.be/FWSxSQsspiQ>
- Multi-Colour Card Trick by Richard Wiseman [Wiseman 2008]. <https://youtu.be/5HkGSrY1N9Y>

Colour Perception

Colour perception is influenced, among other things, by:

- (Assumed) presence of shadows. <https://youtu.be/XGG01xTYSoo?t=1s> <https://youtu.be/z9Sen1HTu5o?t=24s&mute=1>
- (Assumed) colour of light sources. <https://youtu.be/uBSXjMIOUls> <https://youtu.be/kc1GjIAFdMA>

Depth Perception

- Perspective, chair.
- Perspective, room.
- Perspective, rail lines. <https://dailymotion.com/video/xq1rf1?start=736>

2.2 Visual Input Takes Priority

- Sight overrides hearing (McGurk effect). <https://youtu.be/G-1N8vWm3m0?t=26s>
- Sight can override touch (rubber hand). <https://youtu.be/Qsmkgi7FgEo?t=01m40s>

Visual Working Memory

The capacity of visual working memory is limited to 3–4 simple shapes [Vogel et al. 2001].

2.3 Preattentive Processing

Certain visual attributes can be processed preattentively (in parallel rather than serially) by the human visual system..

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

When a visual target is encoded using a preattentive attribute, the time to locate it remains constant, regardless of the number of distractors.

Preattentive Attributes (Pop-Out Features)

The following attributes are pre-attentive:

- Colour hue (see Figure 2.1).
- Colour intensity (luminance) (see Figures 2.2 and 2.3).
- Line length (see Figure 2.4).
- Line width (see Figure 2.5).
- 2d spatial position (see Figure 2.6).
- Orientation (see Figure 2.7).
- Size (see Figure 2.8).
- Shape (see Figure 2.9).
- Added mark (see Figure 2.10).
- Enclosure (see Figure 2.11).
- Lack of enclosure (see Figure 2.12).

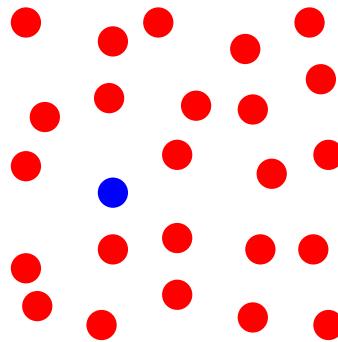


Figure 2.1: Colour hue is preattentive.

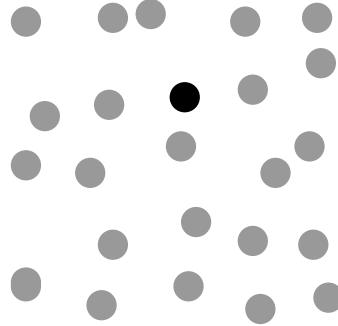


Figure 2.2: Colour intensity is preattentive.

- Curvature (see Figure 2.13).
- Focus and blur (see Figure 2.14).
- 3d depth (see Figure 2.15).
- Flicker (blinking) (see Figure 2.16).
- Velocity of motion (see Figure 2.17).
- Direction of motion (see Figure 2.18).

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

Conjunctions

Beware when using multiple encodings in one display:

- Most preattentive attributes cannot be combined while still remaining pre-attentive.
- Conjunctions of motion, depth, colour hue, and orientation remain pre-attentive.

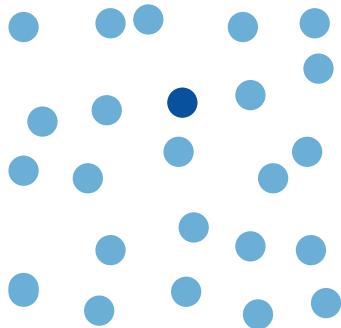


Figure 2.3: Colour intensity is preattentive.

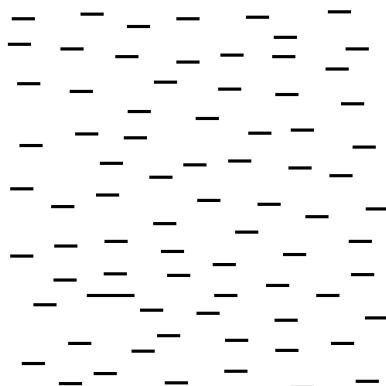


Figure 2.4: Line length is preattentive.

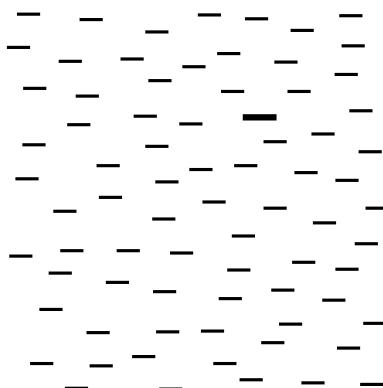


Figure 2.5: Line width is pre-attentive.

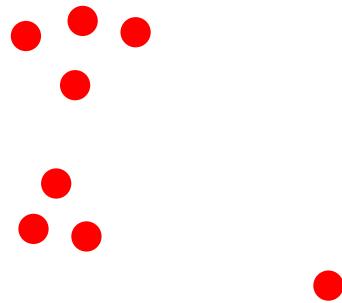


Figure 2.6: 2D spatial position is preattentive.

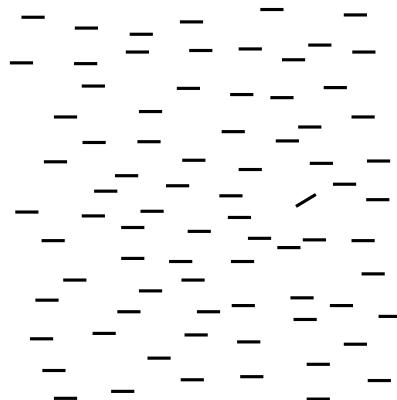


Figure 2.7: Orientation is preattentive.

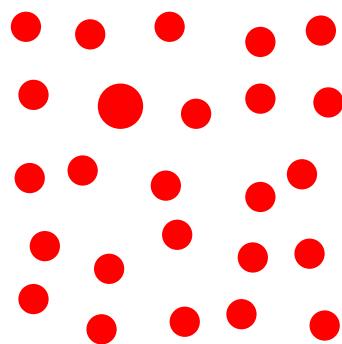


Figure 2.8: Size is preattentive.

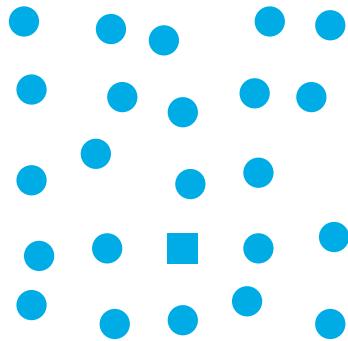


Figure 2.9: Shape is preattentive.

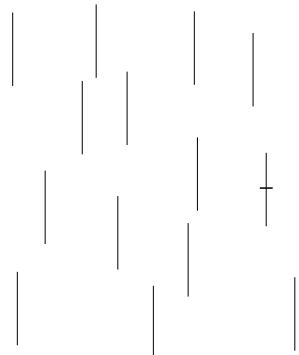


Figure 2.10: An added mark is preattentive.

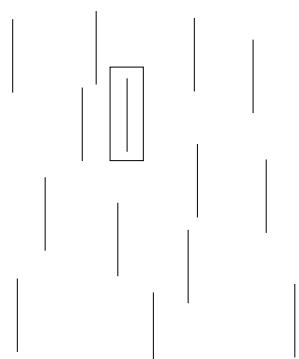


Figure 2.11: Enclosure is preattentive.

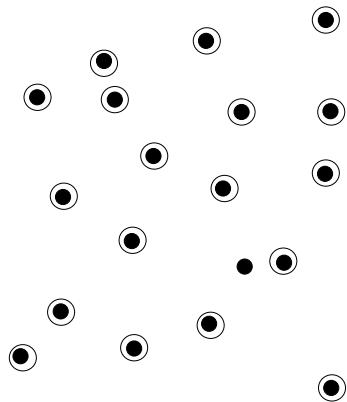


Figure 2.12: Lack of enclosure is preattentive.

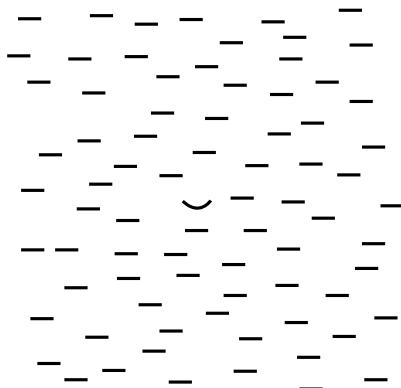


Figure 2.13: Curvature is preattentive.

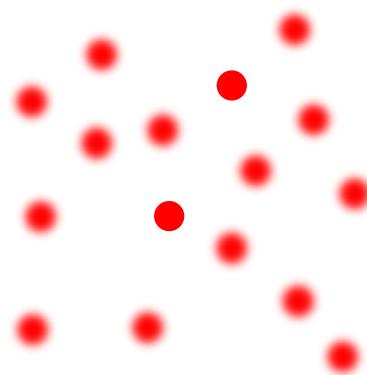


Figure 2.14: Focus and blur is preattentive.

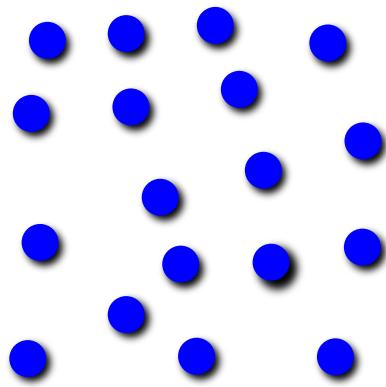


Figure 2.15: 3d depth is preattentive.

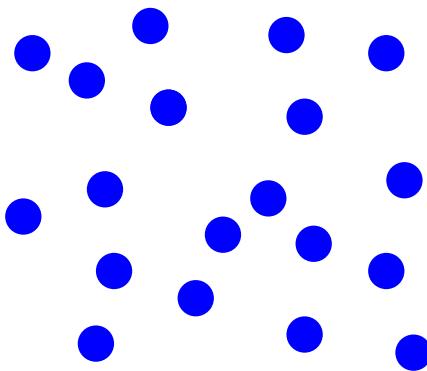


Figure 2.16: Flicker (blinking) is preattentive. [Figure is interactive, only works in HTML slides.]



Figure 2.17: Velocity of motion is preattentive. [Figure is interactive, only works in HTML slides.]



Figure 2.18: Direction of motion is preattentive. [Figure is interactive, only works in HTML slides.]

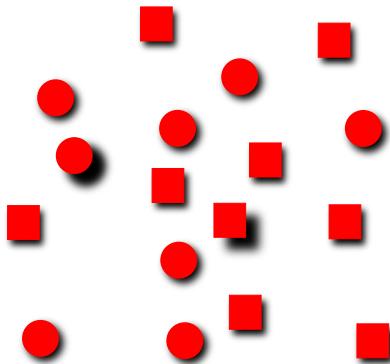


Figure 2.19: The conjunction of shape and depth remains preattentive.

See Figures 2.19 and 2.20.

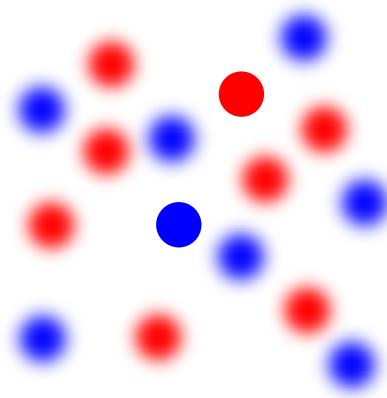


Figure 2.20: The conjunction of blur and colour hue remains preattentive.

2.4 Visual Encoding

References

++ Stephen Few; *The Visual Perception of Variation in Data Displays*; Visual Business Intelligence Newsletter, Oct 2016. https://perceptualedge.com/articles/visual_business_intelligence/the_visual_perception_of_variation.pdf

Encoding Quantitative Values

Only two of the preattentive attributes can be perceived quantitatively with any accuracy:

- Line length.
- 2d spatial position.

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

- 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 and size can be perceived to a limited degree:

- one shade of grey is lighter than another
- one circle is larger than another

but not by how much.

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.

In practice, about 5 distinct shades of gray (or intensities of any single colour hue) can be distinguished.

Encoding Categories

Some preattentive attributes are more naturally non-continuous.

The following preattentive attributes are particularly useful for encoding discrete categories:

- Colour hue (palette).
- Shape (fixed number of distinct glyphs).

Perceptually Distinguishable Colour Palettes

Maureen Stone has proposed a selection of 8 distinguishable colours for colour-coding bar charts or line charts.

<http://ksrowell.com/blog-visualizing-data/2012/02/02/optimal-colors-for-graphs/>

Choose colours from a HCL colour space <http://hclwizard.org/> rather than HSV [Aisch 2011].

Chapter 3

History of Information Visualisation

References

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- + 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]
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- + Jacques Bertin; *Sémiologie graphique*; Editions de l'Ecole des Hautes Etudes en Sciences, 1999. ISBN 2713212774 (com, uk) [Bertin 1999] [In French]

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- Michael Friendly and Daniel J. Denis; *Milestones in the History of Thematic Cartography Statistical Graphics, and Data Visualization*; 2001. <http://datavis.ca/milestones/>
- Pat Hanrahan; *To Draw a Tree*; InfoVis 2001 keynote talk, Oct. 2001
<http://graphics.stanford.edu/~hanrahan/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.

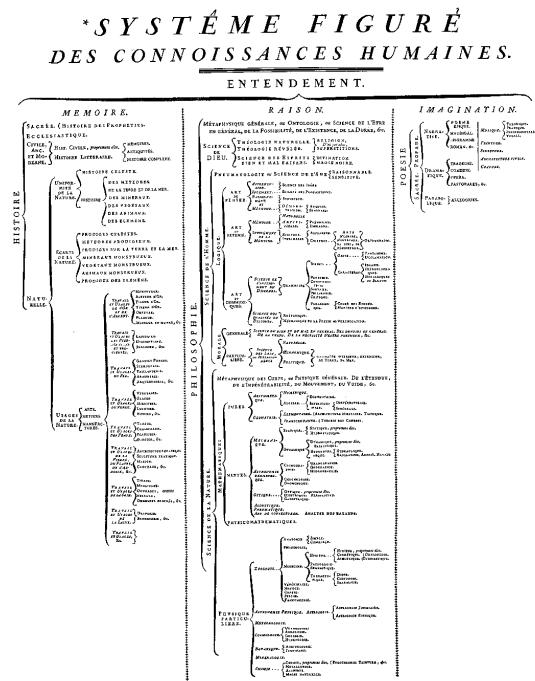


Figure 3.1: The tree of Diderot and d'Alembert. [Image from Wikimedia Commons [Diderot and le Rond d'Alembert 1751c]]

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.

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.
- Up to this time, cholera was thought to be an airborne disease, although Snow himself had long postulated a waterborne link.

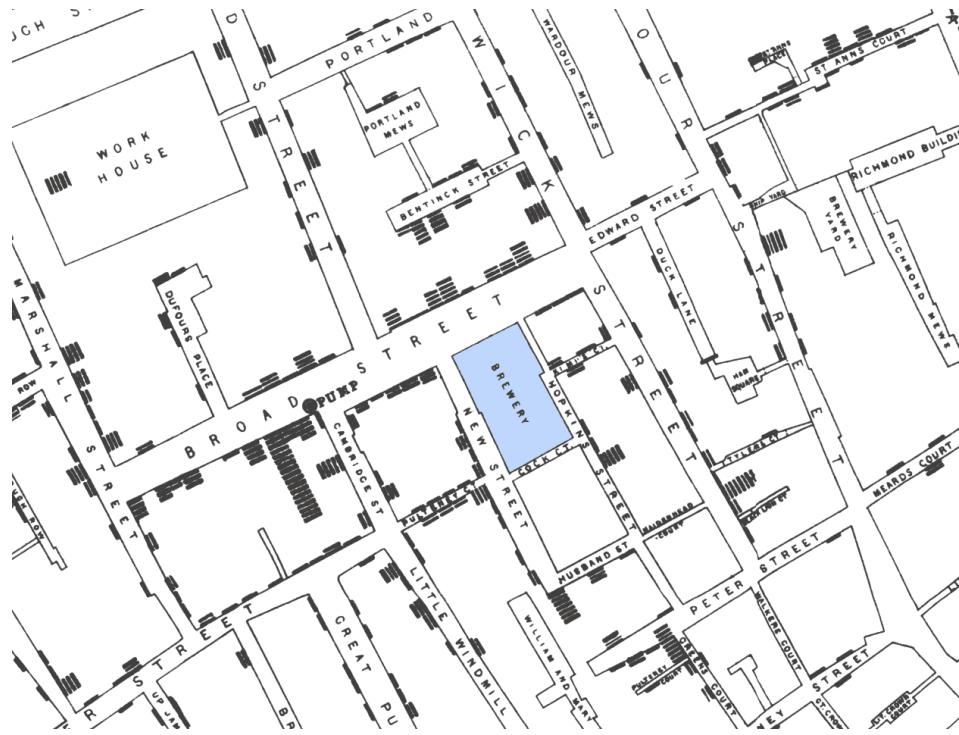


Figure 3.2: Snow's London cholera map.

- In popular retellings, such as Tufte [1997, 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.
- 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 Joseph Priestley

Joseph Priestley was an English scientist and theologian:

- He produced some of the first timeline charts [Sheps 1999].
- In 1765, he produced his Chart of Biography, a historical timeline of around 2000 people, divided into six horizontal bands (categories) such as “Poets and Artists”, “Mathematicians and Physicians”, and “Statesmen and Warriors”.
- In 1769, he produced the New Chart of History, shown in Figure 3.3. It spans 3000 years of history from 1200 BC to 1800 AD with 16 horizontal bands corresponding to geographical regions.

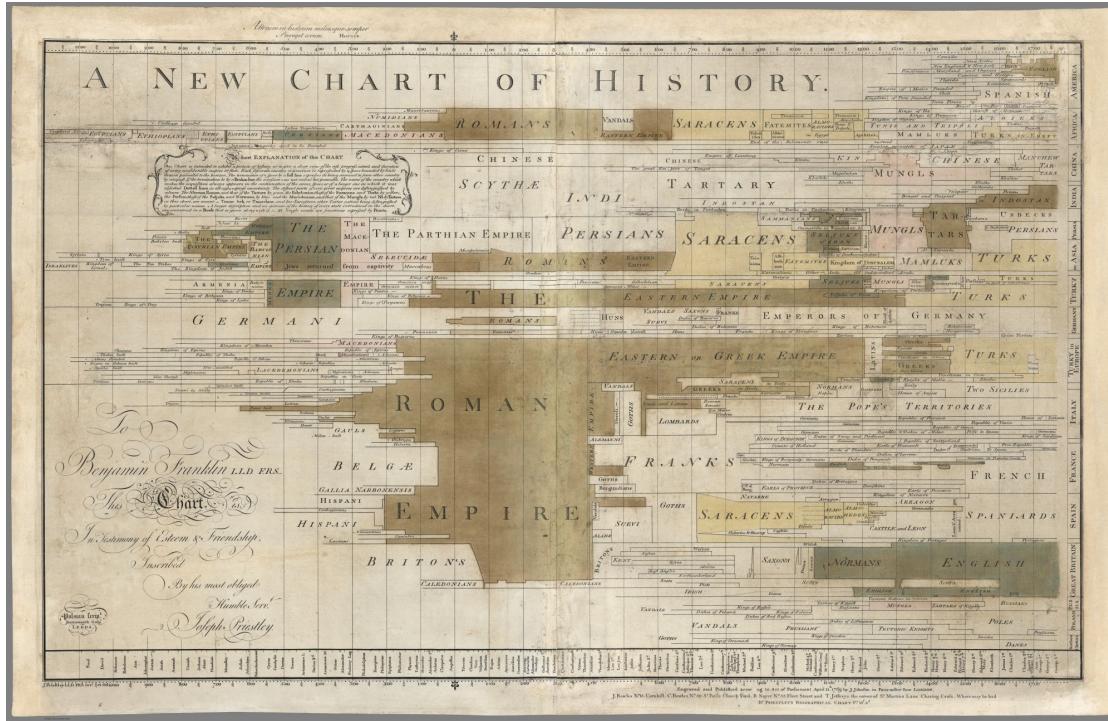


Figure 3.3: Joseph Priestley's New Chart of History from 1769. [Image from the David Rumsey Map Collection. Image copyright © 2000 by Cartography Associates. Used under the terms of Creative Commons CC BY-NC-SA 3.0.]

3.4 William Playfair

William Playfair was a Scottish engineer and economist:

- He is considered the founder of statistical graphics, inventing among other things the line chart, area chart, pie chart, and bar chart.
- An example of an area chart can be seen in Figure 3.4, taken from the 3rd edition of his Commercial and Political Atlas [Playfair 1801a].
- Two examples of a pie chart can be seen in Figure 3.5, taken from his Statistical Breviary [Playfair 1801b].

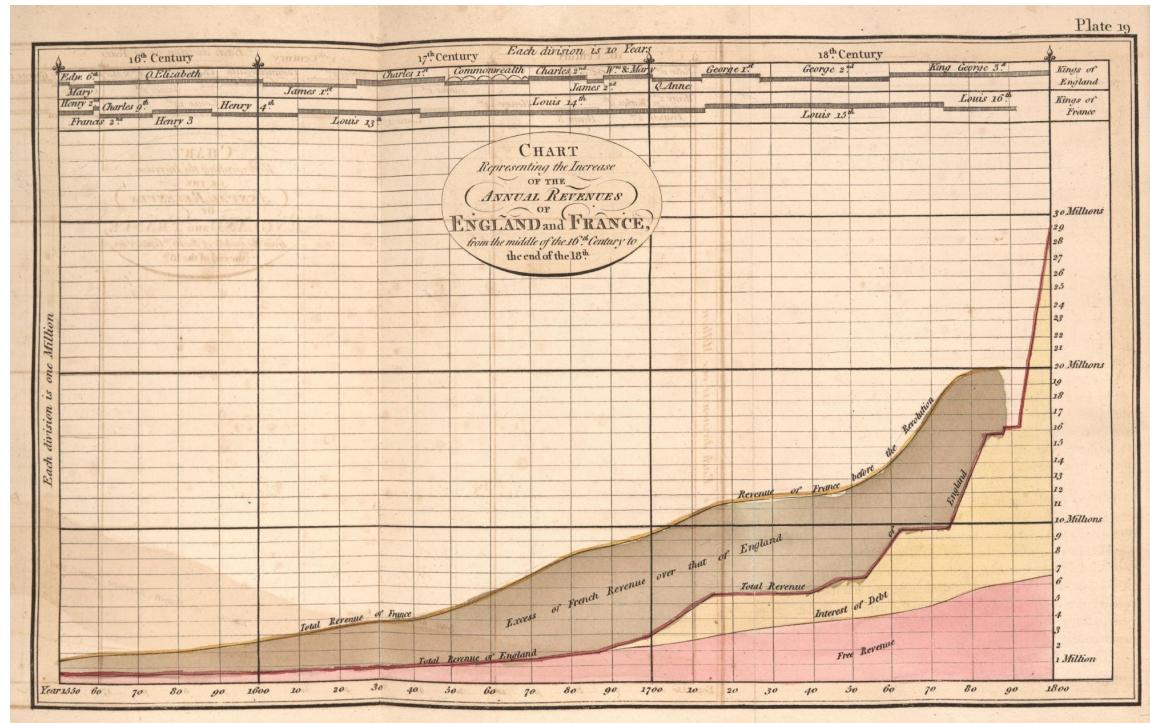


Figure 3.4: One of William Playfair's area charts, this example from the 3rd edition of his Commercial and Political Atlas. [Schoenberg Center for Electronic Text and Image (SCETI). Used under the terms of Creative Commons CC BY 2.5.]

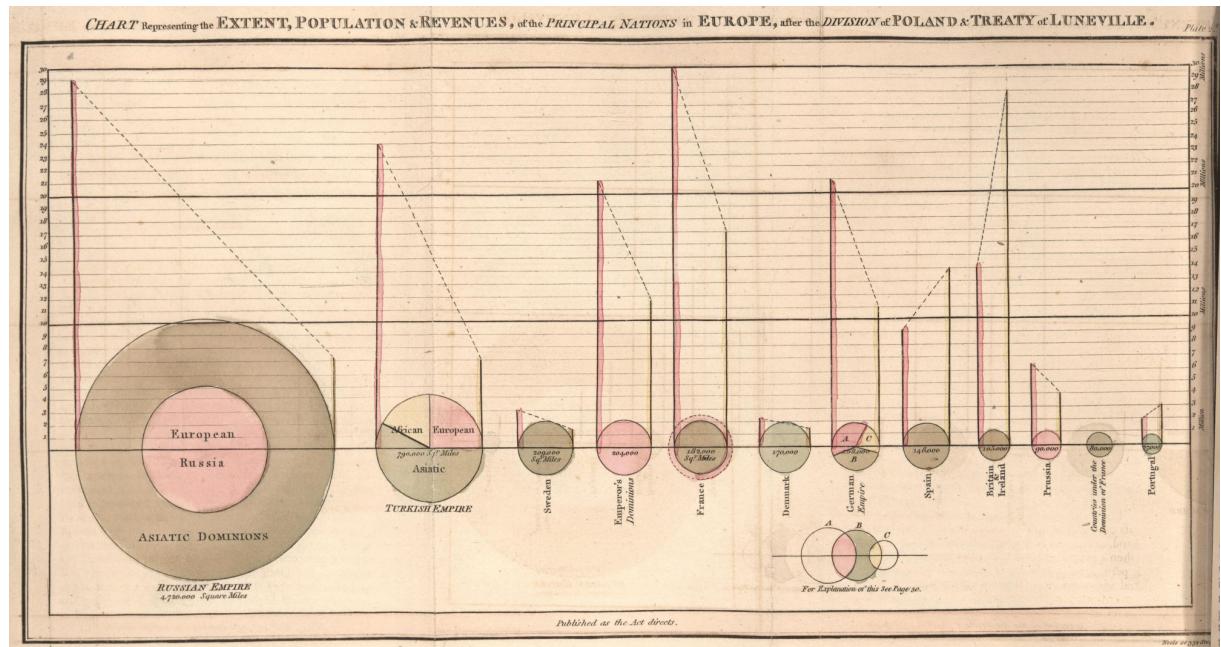


Figure 3.5: Two examples of a pie chart within this graphic from William Playfair's Statistical Breviary. [Schoenberg Center for Electronic Text and Image (SCETI). Used under the terms of Creative Commons CC BY 2.5.]

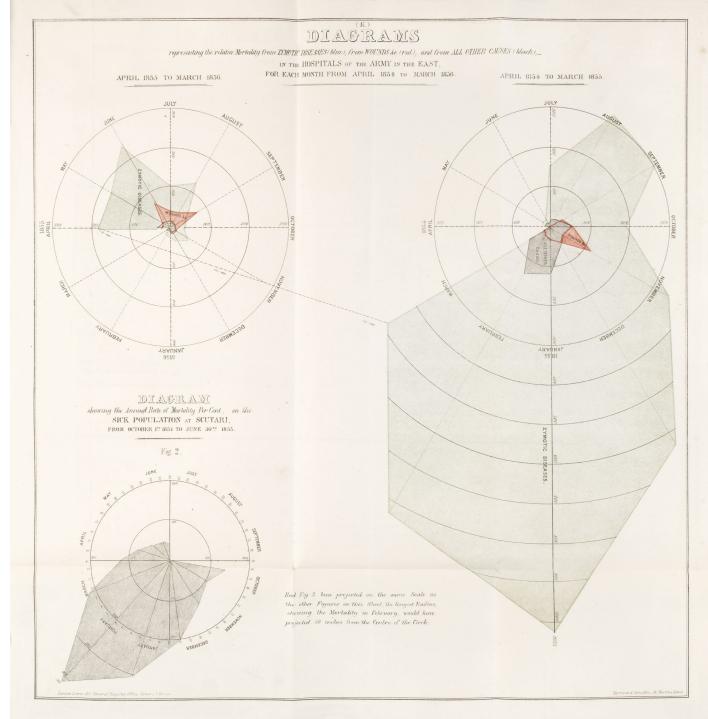


Figure 3.6: Florence Nightingale's original bat's wing diagram. [Image from the Wellcome Library, London.
Used under the terms of Creative Commons CC BY-NC 2.0 UK.]

3.5 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, as shown in Figure 3.6.
- The time points are shown as 12 equally spaced radial lines (one for each month, winter at the bottom).
- The number of deaths is proportional to the length of the radial line (length-proportional).
- However, the coloured shading in of the areas (incorrectly) suggests to the viewer that the diagram is area-proportional.

Wedge Diagram (1858)

- Florence Nightingale, 1858.
- After criticism that her bat's wing diagram could be misleading, Nightingale redesigned it as a wedge diagram, shown in Figure 3.8.

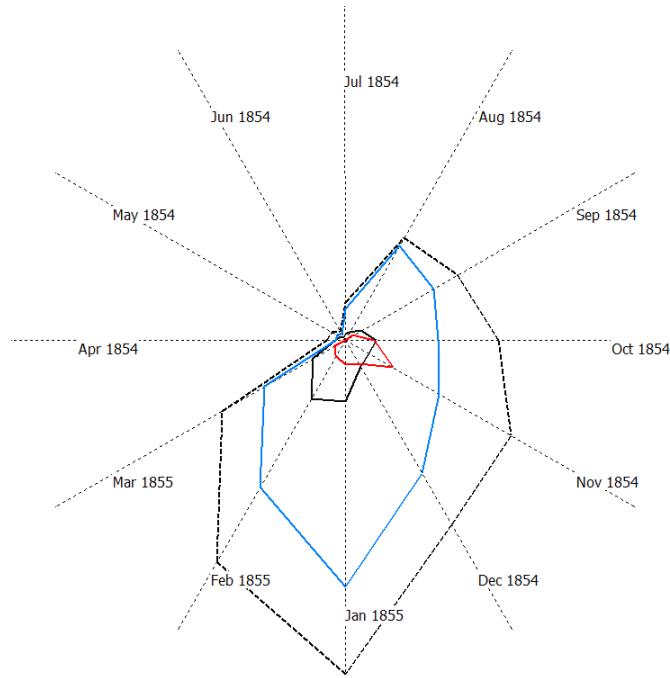


Figure 3.7: Modern bat's wing diagram.

- Now, the number of deaths is actually proportional to the coloured shaded areas.
- However, there are some problems with occlusion, depending on the drawing order of the wedges.
- I use the name wedge diagram, following Small [1998]. It is sometimes also called a polar area diagram or a rose diagram. [It is also sometimes *incorrectly* referred to as a coxcomb diagram [Small 1998].]

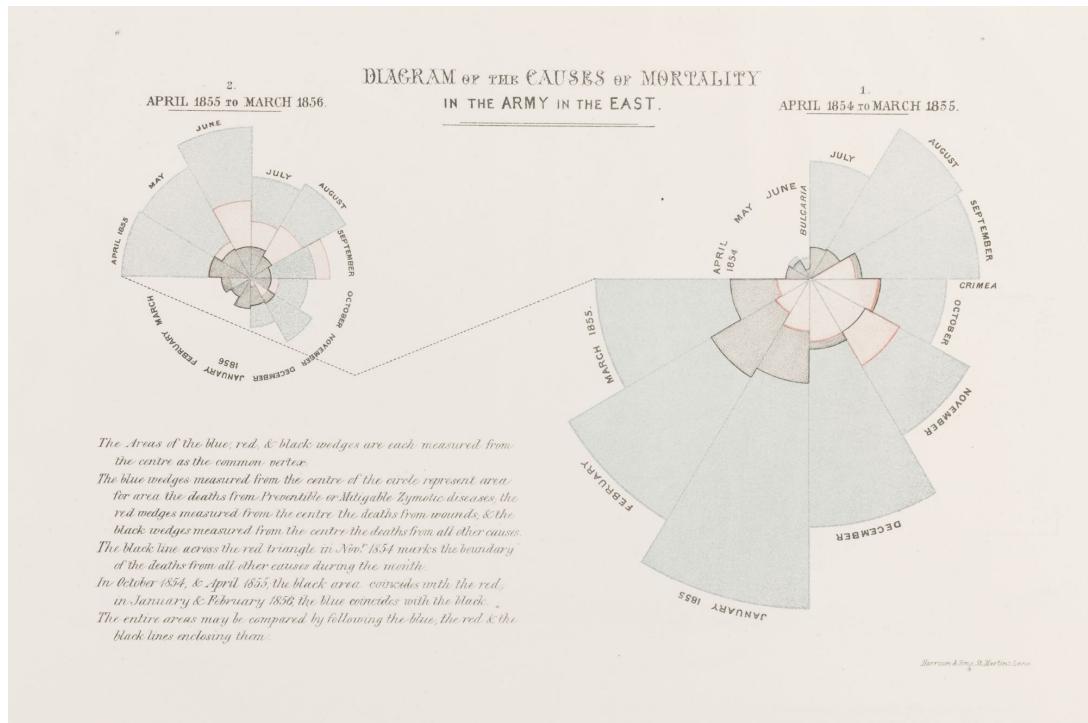


Figure 3.8: Florence Nightingale's original wedge diagram. [Image from the Wellcome Library, London. Used under the terms of Creative Commons CC BY-NC 2.0 UK.]

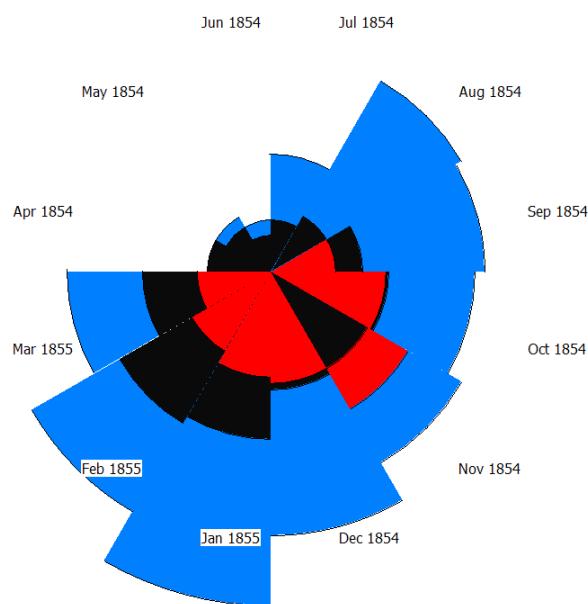


Figure 3.9: Modern wedge diagram.

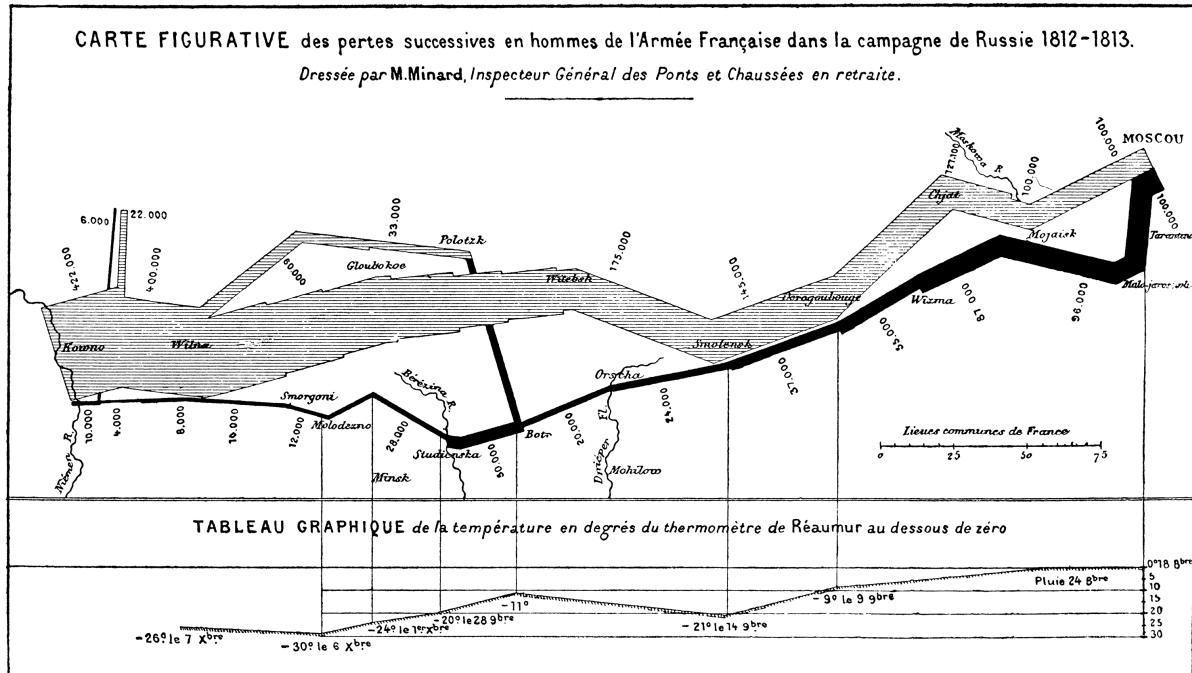


Figure 3.10: Minard's Map

3.6 Charles Minard

Diagram of Napoleon's Russian Campaign (1861)

- Charles Joseph Minard, 1861.

3.7 Fletcher Hewes and Henry Gannett

Fletcher Hewes and Henry Gannett produced the 1883 edition of Scribner's Statistical Atlas of the United States [Hewes and Gannett 1883]:

- Plate 151 of the Atlas is shown in Figure 3.11.
- It shows a ranking of the then 47 states, according to ten dimensions.
- Each state appears once in each ranking and its instances are connected by a line, an early form of parallel coordinates plot.
- The darker blue boxes indicate the position of the United States as a whole.

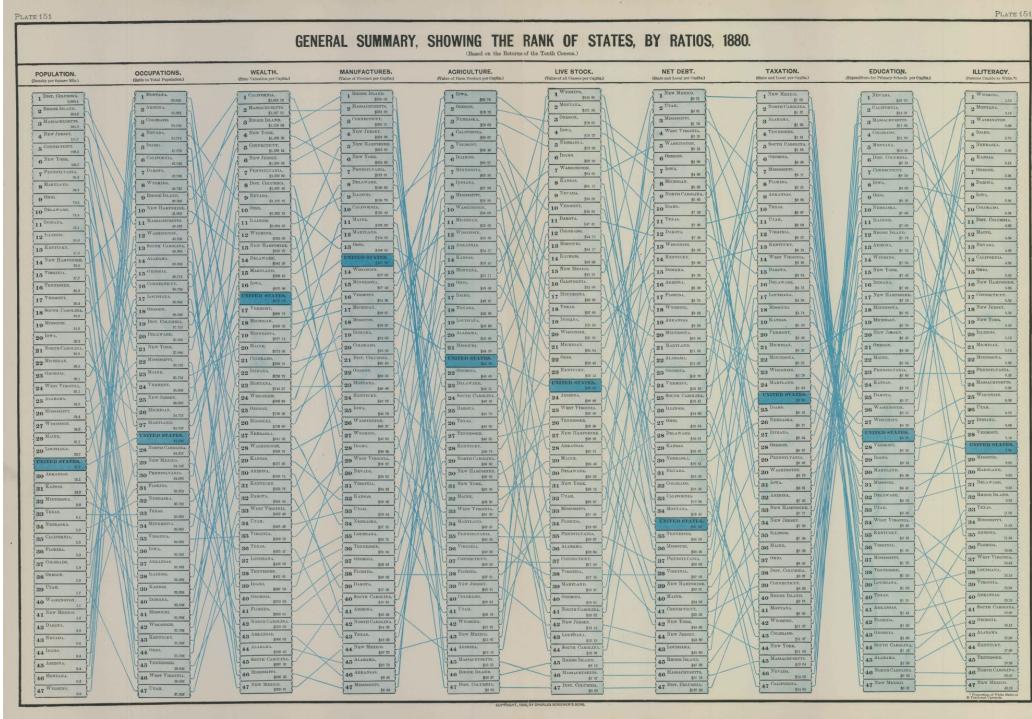


Figure 3.11: Hewes' and Gannett's parallel coordinates from [Image kindly provided by the Library of Congress, Geography and Map Division.]

3.8 Marey and Ibry (1878)

In his 1878 book [Marey 1878], Entienne Jules Marey published a graphic train schedule:

- The schedule is shown in Figure 3.12, which is taken from the 2nd Edition of the book [Marey 1885, page 20].
- He attributes the graphic to a Mr. Ibry, who is reported to have been deputy chief operating officer of the railway from Paris to Rouen [Wainer et al. 2013, page 56].
- Ibry had apparently been using this kind of display since at least 1846.
- As Wainer et al. [2013] describe, similar graphic train schedules had also been published in Russia in 1854.

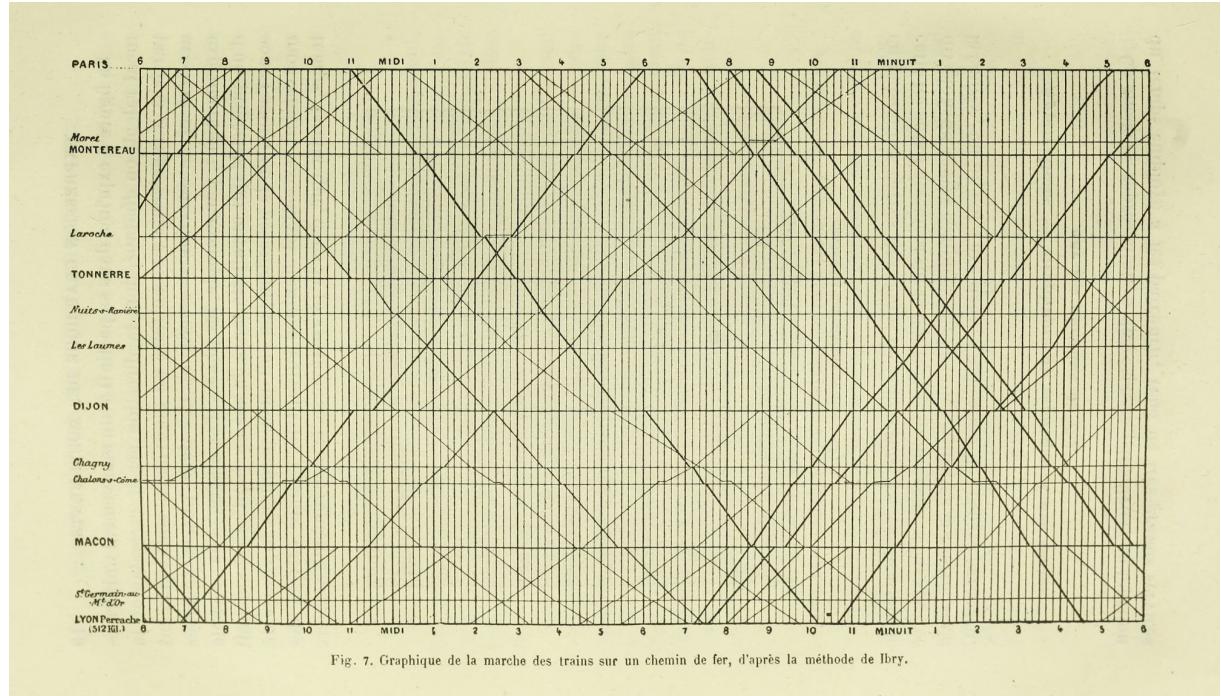


Fig. 7. Graphique de la marche des trains sur un chemin de fer, d'après la méthode de Ibry.

Figure 3.12: Marey's graphic train schedule, which he attributes to Ibry. [Image from the Internet Archive, in the public domain.]

3.9 Paul Otlet

Radial tree visualisation(s).

3.10 Jaques Bertin

Reorderable Matrix

- Jaques Bertin created a physical device for reordering matrices called Domino, see Figure 3.13.
- It is described in more detail by Henry [2008, page 78].

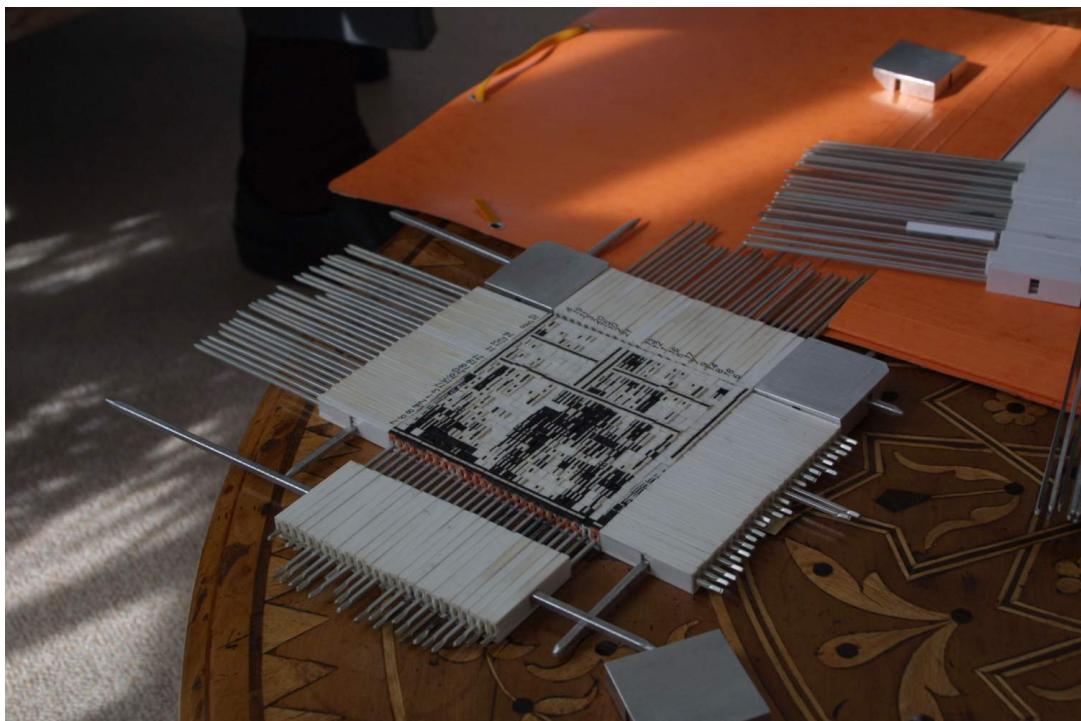


Figure 3.13: Bertin's reorderable matrix. [Photograph used with kind permission of Jean-Daniel Fekete.]

Chapter 4

Visualising Linear Structures

Linearly structured information:

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

4.1 Bifocal Display

- Invented by Robert Spence and Mark Apperley in 1980 [Spence and Apperley 2018; Apperley et al. 1982]
- Separate focus and context areas. See Figure 4.1.

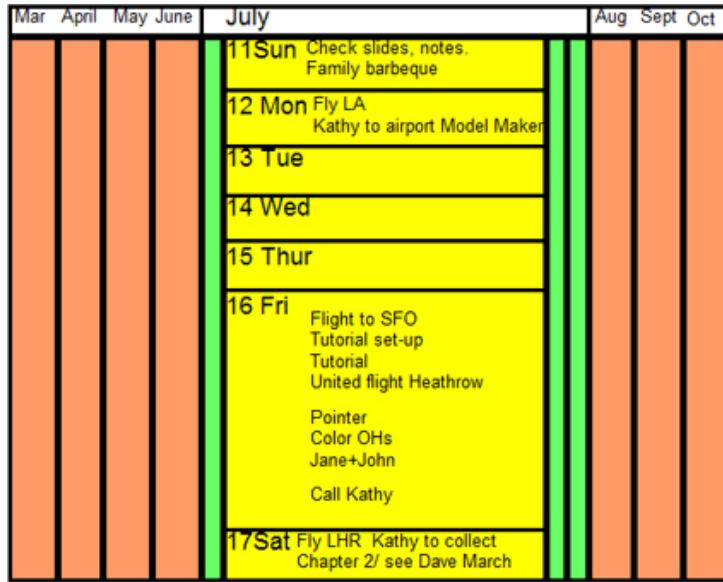


Figure 4.1: The bifocal calendar has a focus area in the middle and context areas to the left and right. [Courtesy of Bob Spence, placed under a Creative Commons Attribution-NoDerivs 3.0 Unported (CC-Att-ND-3) licence.]

4.2 Perspective Wall

- Xerox PARC, 1990.
- 3d perspective technique for linear information.
- Focus on the front panel and context in the side panels. See Figure 4.2.
- CHI'91 paper [Mackinlay et al. 1991] and video [Robertson et al. 1991b]. <https://youtu.be/hYUZbrWtCZg>
- US Patent 5339390 [Robertson et al. 1994b].

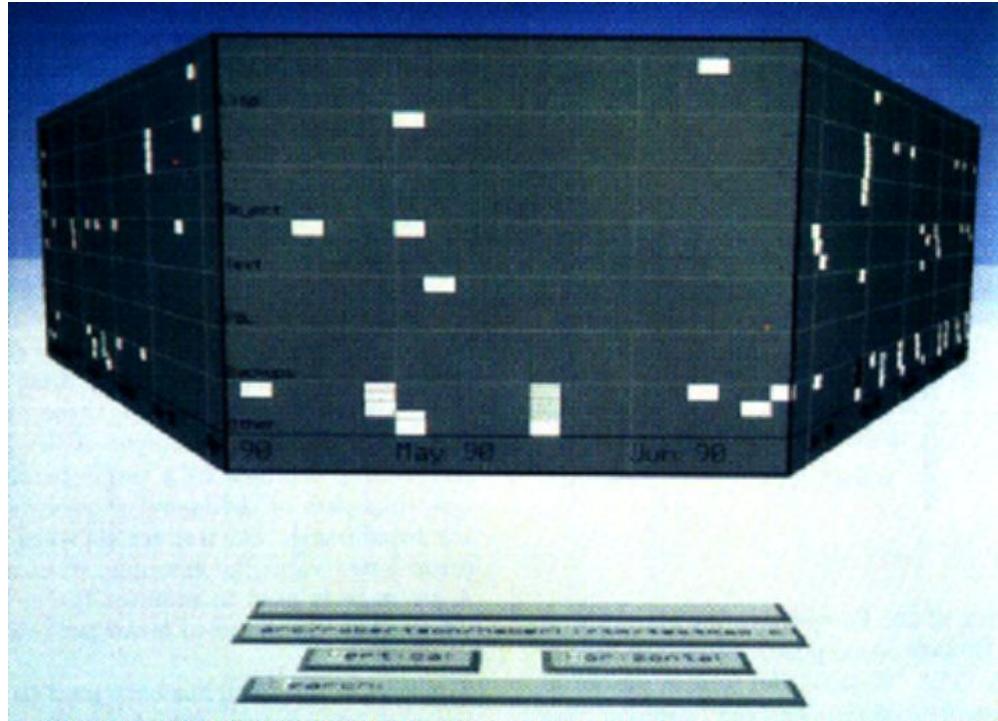


Figure 4.2: The perspective wall spreads linearly structured information across a wall from left to right. 3d perspective provides focus on the central segment of interest. [Copyright © by the Association for Computing Machinery, Inc.]

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 4.3.
- Like hanging program listings on a wall several metres away.
- Zooming window supports several levels of zoom, from overview to lines of code.
- Articles [Eick et al. 1992; Ball and Eick 1996] and InterCHI'93 video [Steffen and Eick 1993].
- US Patent 5644692 [Eick 1997].

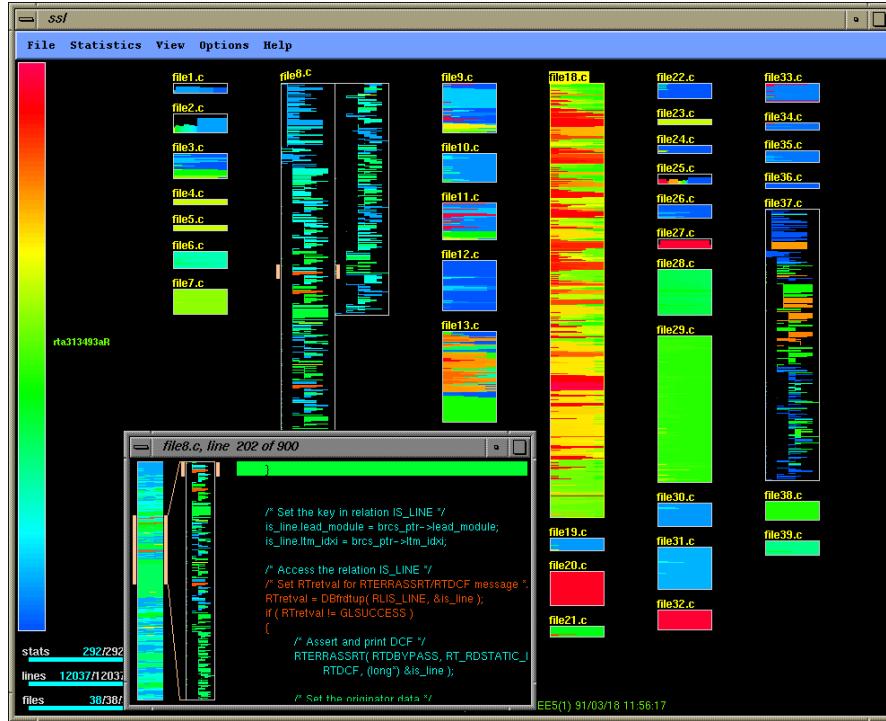


Figure 4.3: Seesoft visualising software consisting of 38 files comprising 12037 lines of code. The newest lines are shown in red, the oldest in blue, with a rainbow colour scale in between.
[Image used with kind permission of Steve Eick, Visual Insights.]

4.4 Lifestrands

- 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].

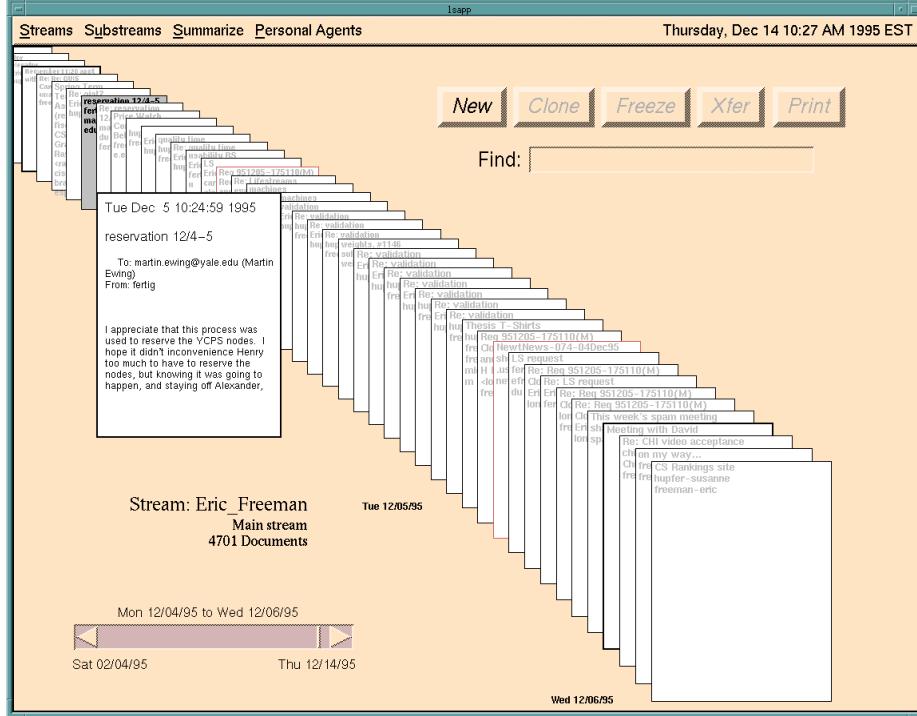


Figure 4.4: Lifestreams orders streams of item chronologically. It is possible to filter items into substreams. [Copyright © by the Association for Computing Machinery, Inc.]

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

JUCS Spiral of Authors

- Journal of Universal Computer Science (JUCS), Graz University of Technology, 2009.
- High-profile authors in a sub-field of computer science are visualised in a spiral (in decreasing order of number of publications in that sub-field). See Figure 4.6.
- FIT 2009 paper [Afzal et al. 2009].

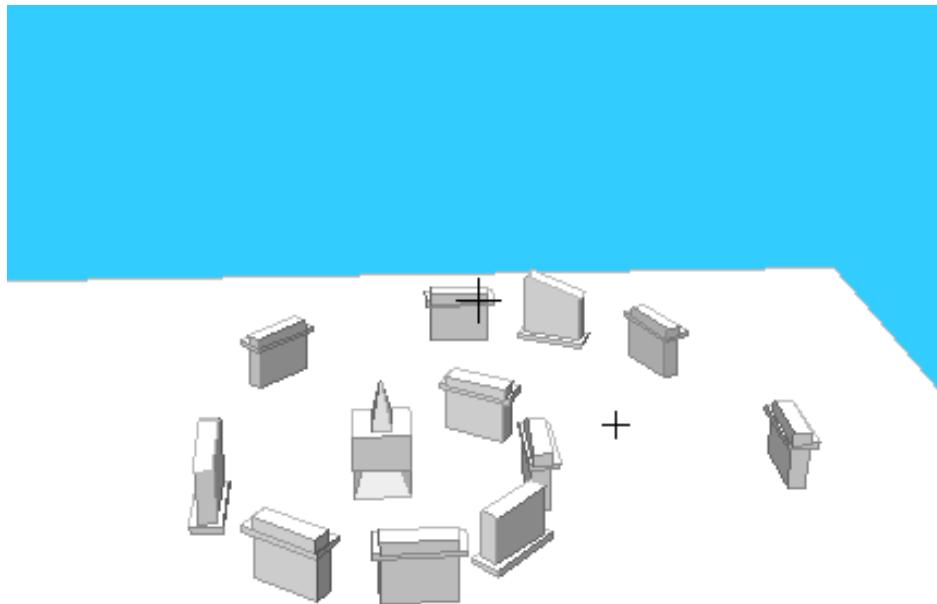


Figure 4.5: GopherVR spiral of search results. [Image used with kind permission of Tom Erickson]

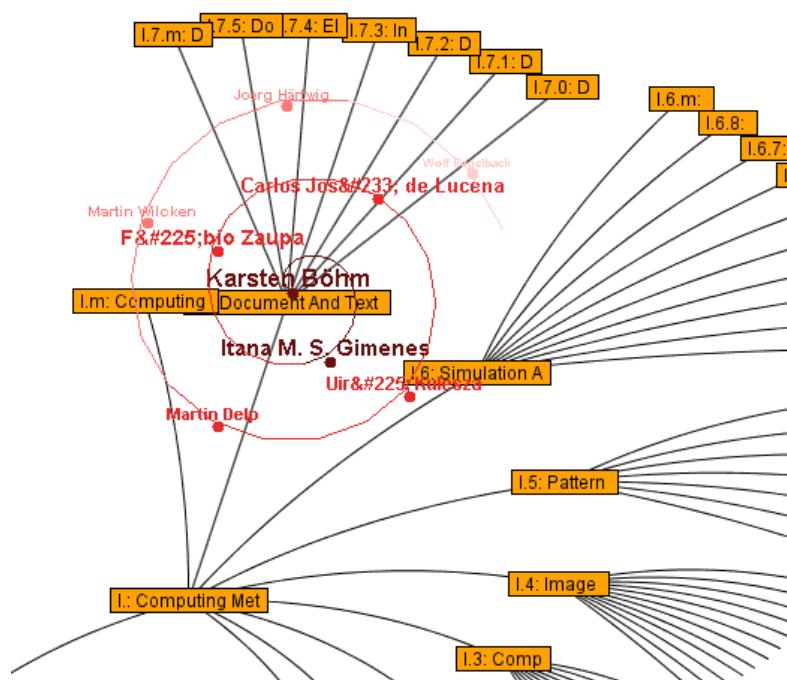


Figure 4.6: JUCS spiral of authors.

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; *treevis.net: A Tree Visualization Reference*; IEEE Computer Graphics and Applications, Vol. 31, No. 6, 2011. [Schulz 2011]
- ++ Hans-Jörg Schulz et al; *The Design Space of Implicit Hierarchy Visualization: A Survey*; IEEE Transactions on Visualization and Computer Graphics, Vol. 17, No. 4, 2011. [Schulz et al. 2011]
- + Manuel Lima; *The Book of Trees*; Princeton Architectural Press, 08 Apr 2014. ISBN 1616892188 (com, uk) [Lima 2014]
- + Jürgensmann and Schulz; *A Visual Survey of Tree Visualization*; Best poster at IEEE InfoVis 2010. [Jürgensmann and Schulz 2010]

Online Resources

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

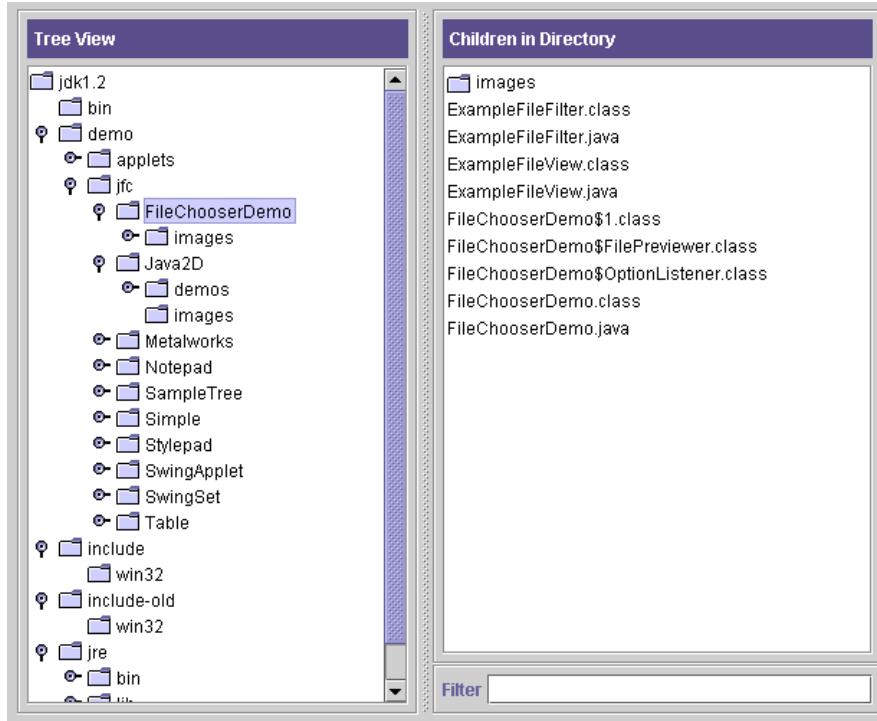


Figure 5.1: The Java Swing JTree tree view component. A view of directories on the left and their contents on the right.

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.
- 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.

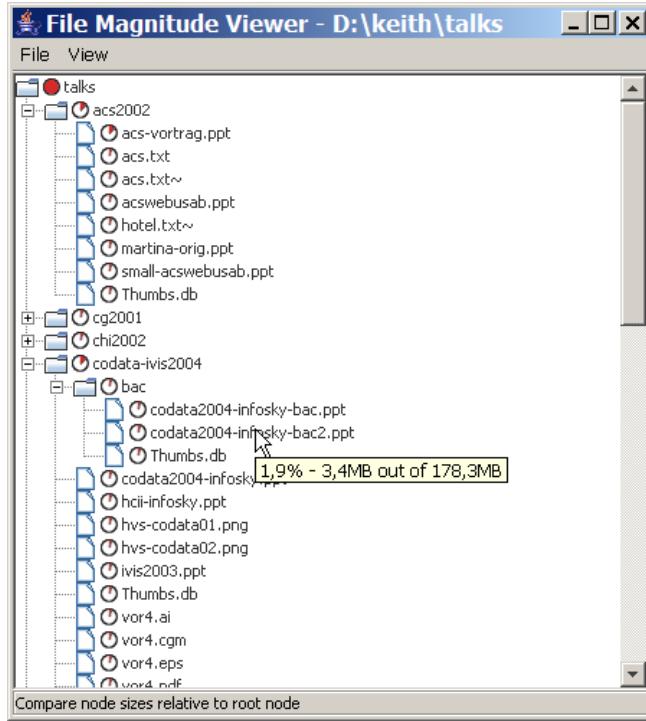


Figure 5.2: MagTree showing part of a file system hierarchy. Here, the sizes are all relative to the root.

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.
- 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].

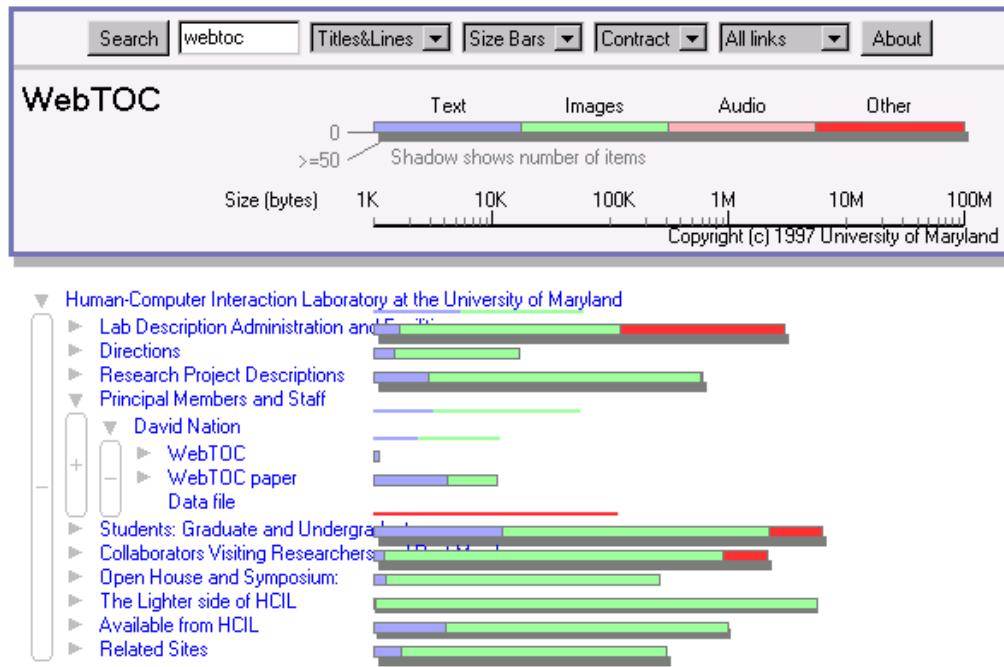


Figure 5.3: A WebTOC table of contents for the University of Maryland's HCI Lab web site.

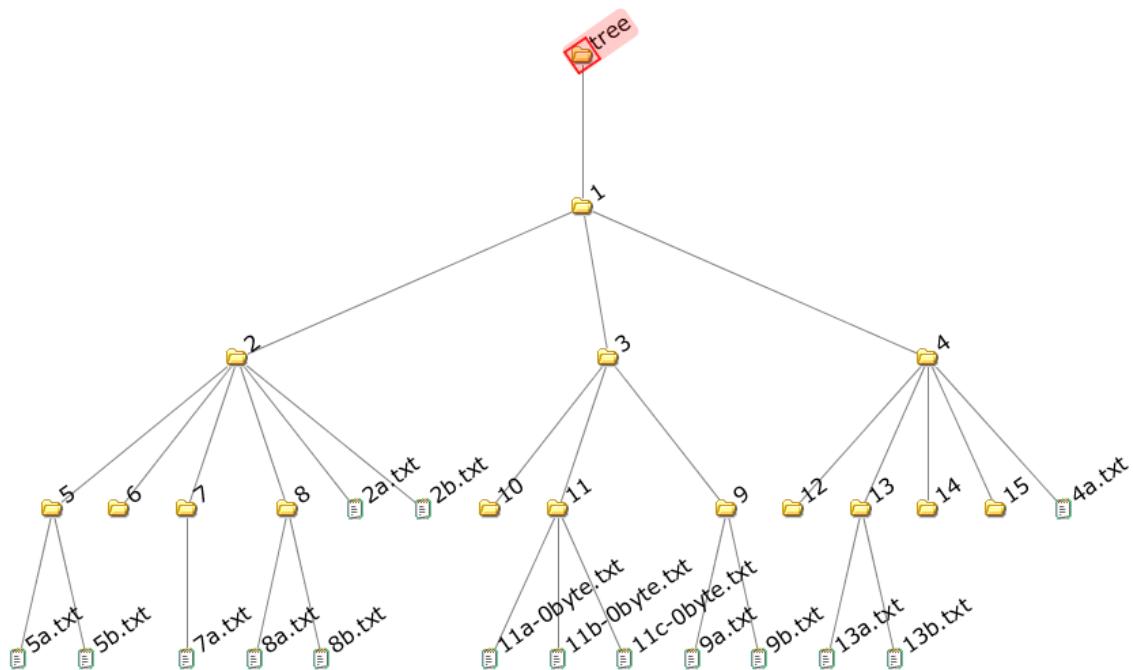
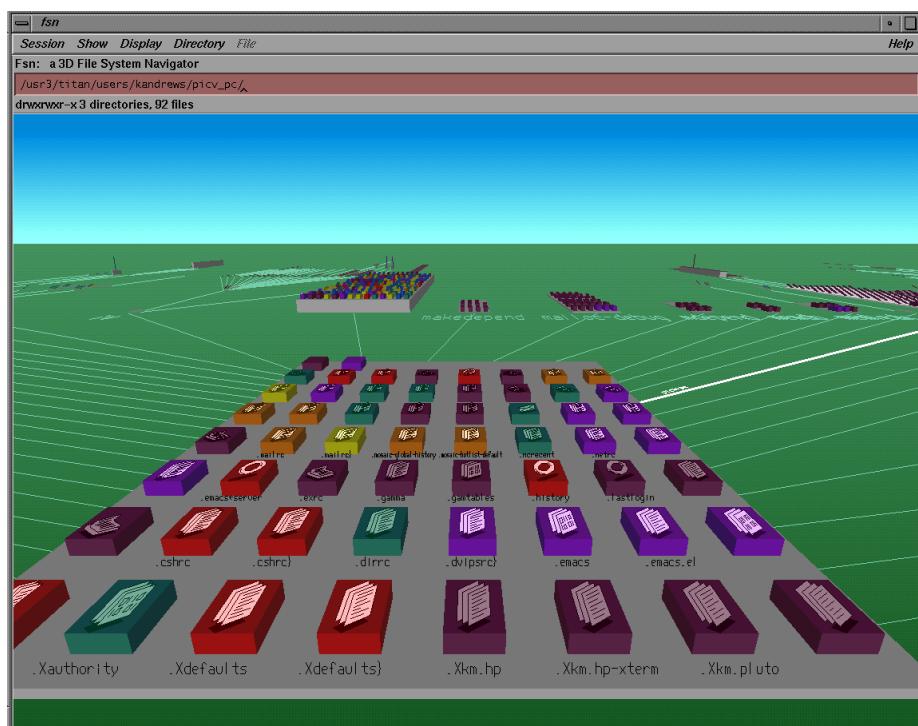
5.2 Layered Node-Link Tree Browsers

5.2.1 Walker Layout

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

**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.

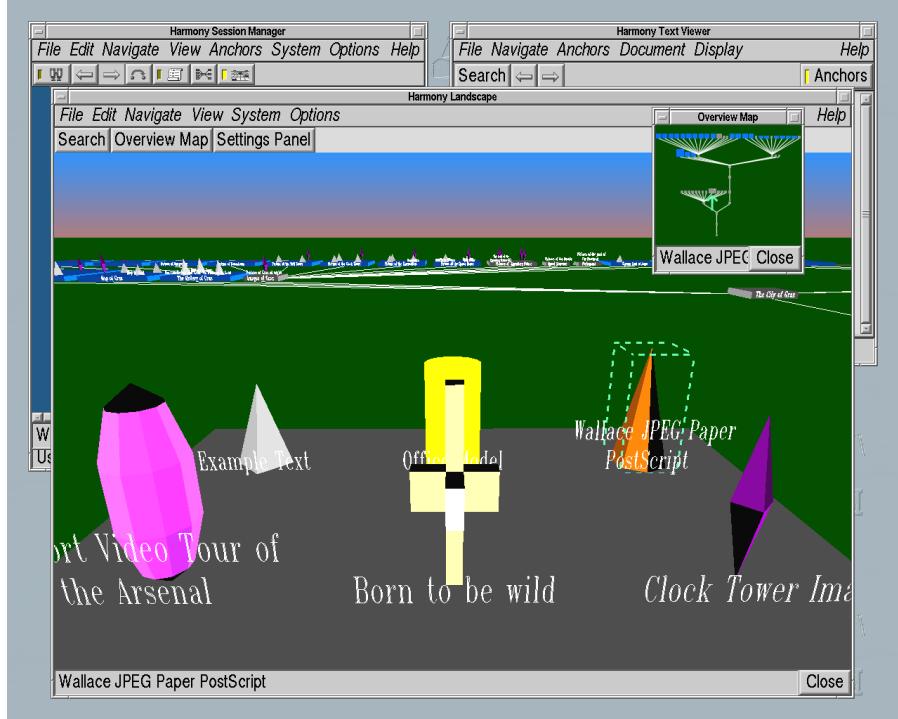


Figure 5.6: The Harmony Information Landscape visualises Hyperwave collection structures.

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 [Card et al. 1999]), [Andrews 1996].

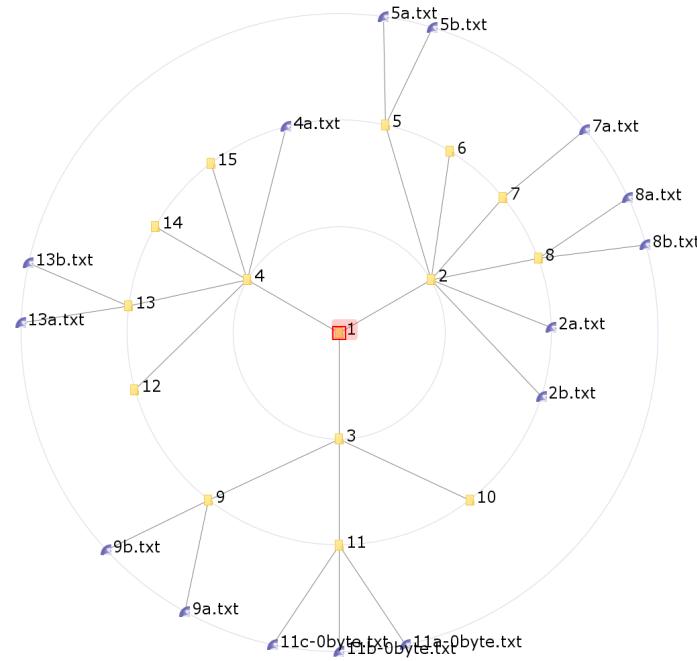


Figure 5.7: A radial tree from HVS.

5.3 Radial Node-Link Tree Browsers

5.3.1 Radial Tree

- Classic tree layout technique.
- The root is in the centre of a circle, surrounded by its descendants on concentric circles based on their depth.
- In fixed-wedge layouts, each branch of the tree is constrained within a wedge of the circle (“annulus wedge”) [di Battista et al. 1999, pages 52–53].
- In flexible-wedge layouts, children are allowed to make use of free space in neighbouring wedges.
- Figure 5.7 shows the radial tree implemented in HVS [Andrews et al. 2007; Fuchs 2015].

5.3.2 The Brain

- Harlan Hugh, 1996.
- Conceived as a mind-mapping tools, but also used for web site mapping. See Figure 5.8.
- Web site thebrain.com
- Patented under [Hugh 2000a; Hugh 2000b].

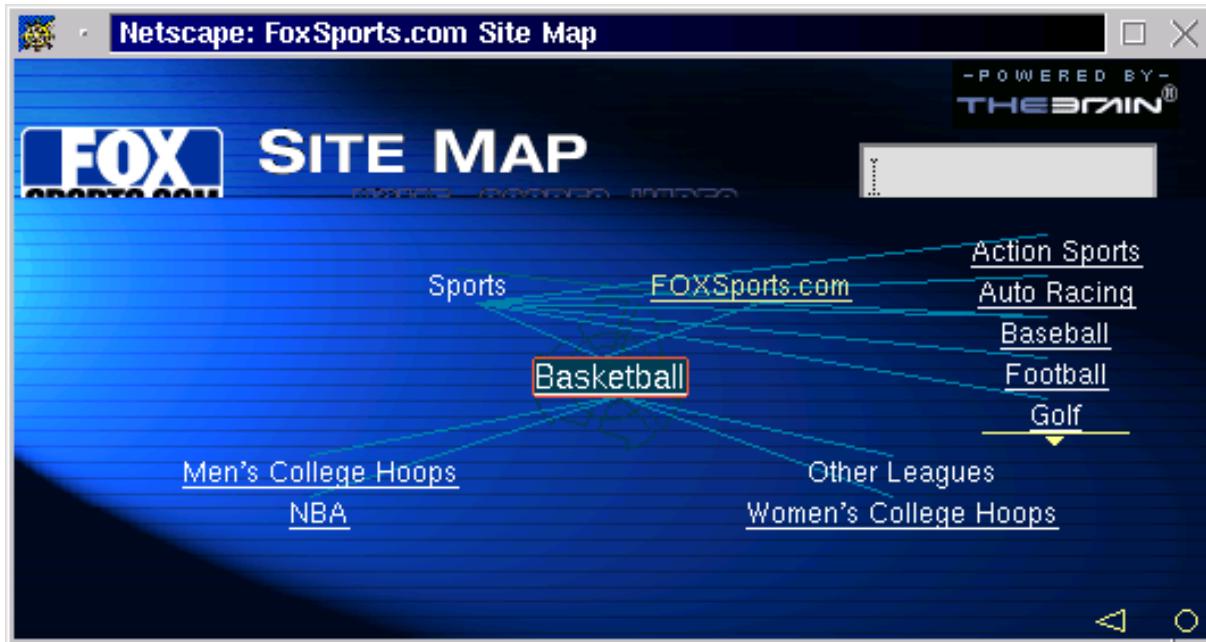


Figure 5.8: The Brain used as a site map for the Fox Sports web site in 2002.

5.3.3 Hyperbolic Browser

- Xerox PARC, 1994–1995.
- Focus+context technique, always displaying the entire hierarchy. See Figure 5.9.
- 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, acquired by Business Objects, now owned by SAP.
- Papers at UIST'94 and CHI'95 [J. Lamping and R. Rao 1994; J. Lamping et al. 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!

5.3.4 3D Hyperbolic Browser

- Tamara Munzner, University of Minnesota and Stanford University.
- 3D hyperbolic browser. See Figure 5.10.
- 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].

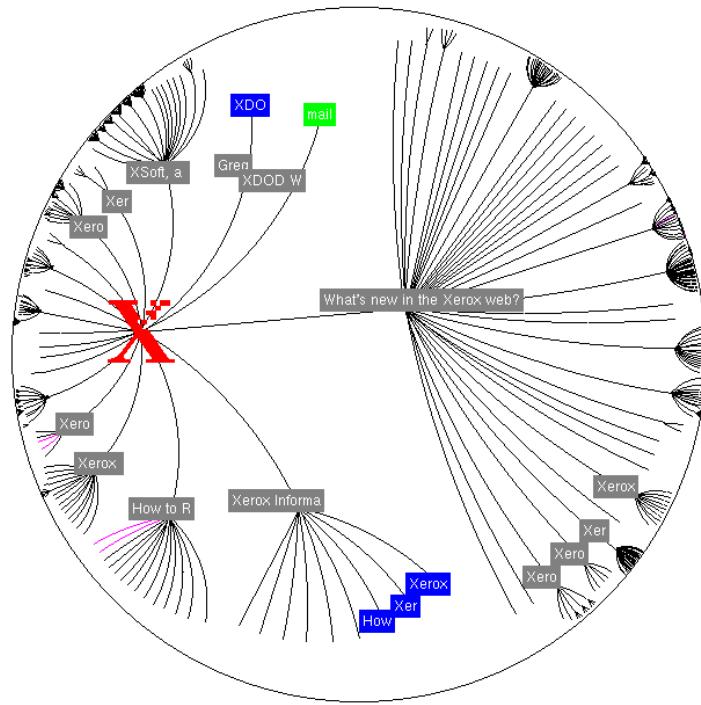


Figure 5.9: The original hyperbolic browser from Xerox. The hyperbolic browser always displays the entire hierarchy. However, subtrees around the edge of the disk become so small they are invisible. [Image used with kind permission of Ramana Rao, Xerox PARC].

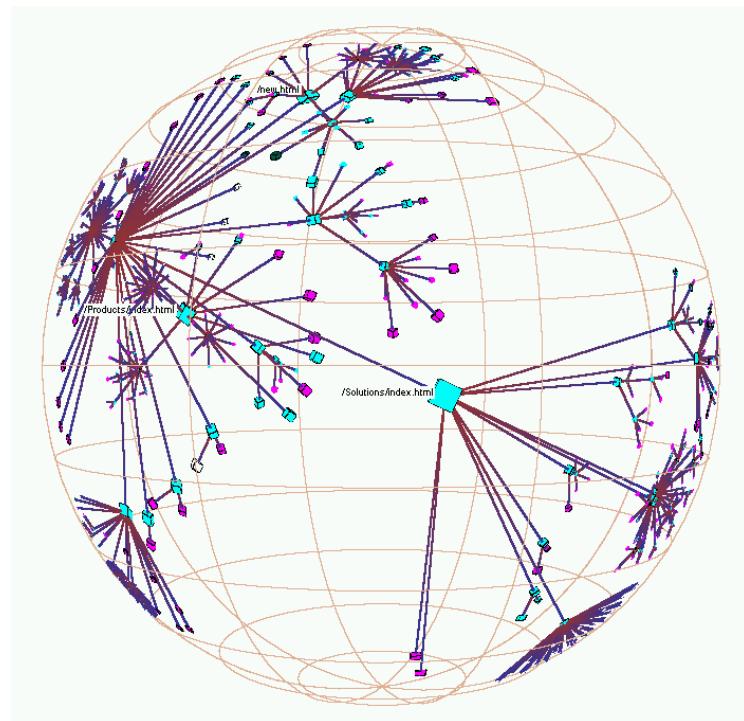


Figure 5.10: The H3 3d hyperbolic browser.

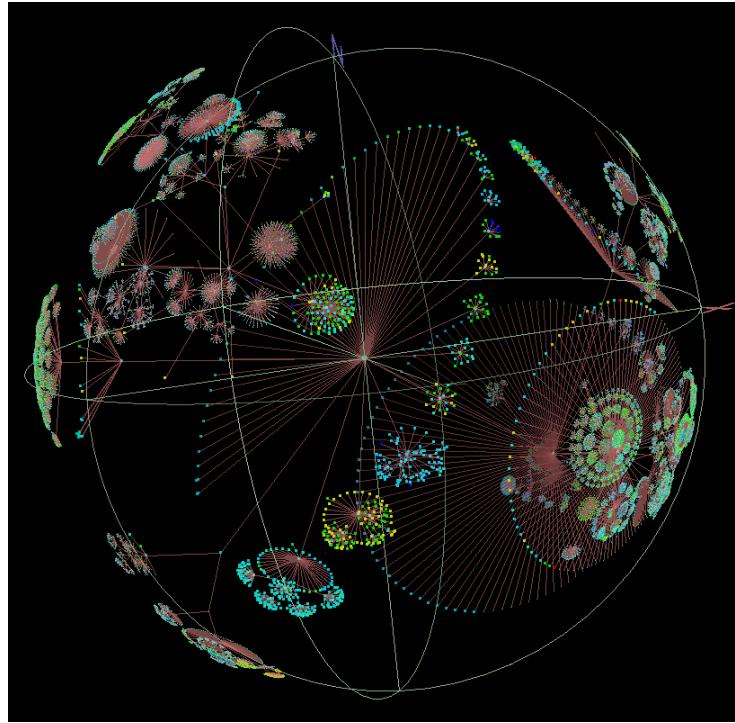


Figure 5.11: The Walrus 3d hyperbolic browser displaying a directory tree. [Image used with kind permission of Young Hyun, CAIDA.]

5.3.5 Walrus

- Young Hyun, CAIDA, 2002.
- 3D hyperbolic browser, homegrown implementation of Tamara Munzner's algorithms. See Figure 5.11.
- Paper in BMC Bioinformatics Journal 2004 [Hughes et al. 2004], web site [Hyun 2005].

5.3.6 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 5.12.
- 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].

5.3.7 Cone Tree

- Xerox PARC, 1990.

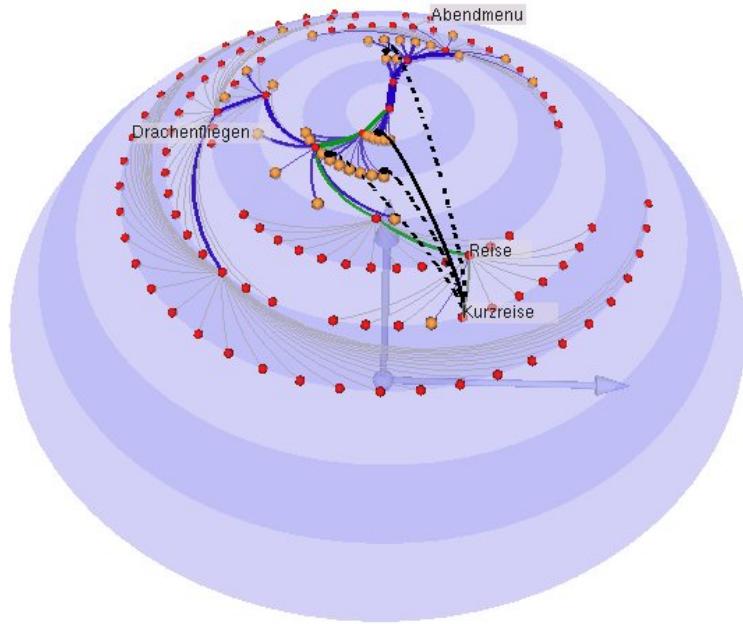


Figure 5.12: The SInVis Magic Eye View. [Image used with kind permission of Matthias Kreuseler, University of Rostock.]

- 3d conical representation of tree. See Figure 5.13.
- A horizontal layout (cam tree) allows better labeling of nodes.
- CHI'91 paper [Robertson et al. 1991a] and video [Robertson et al. 1991b]. <https://youtu.be/RbcQT80zyI>
- Patented under [Robertson et al. 1994a].

5.3.8 Botanical Visualisation

- Eindhoven University of Technology, 2001.
- An abstract tree is converted into a geometric model of branches and leaves and then rendered.
- For better aesthetics, continuing branches are emphasised, long branches are contracted, and leaves are shown as fruit.
- Paper at InfoVis 2001 [Kleiberg et al. 2001]. https://youtu.be/mTipHD_MBZk?t=08m35s

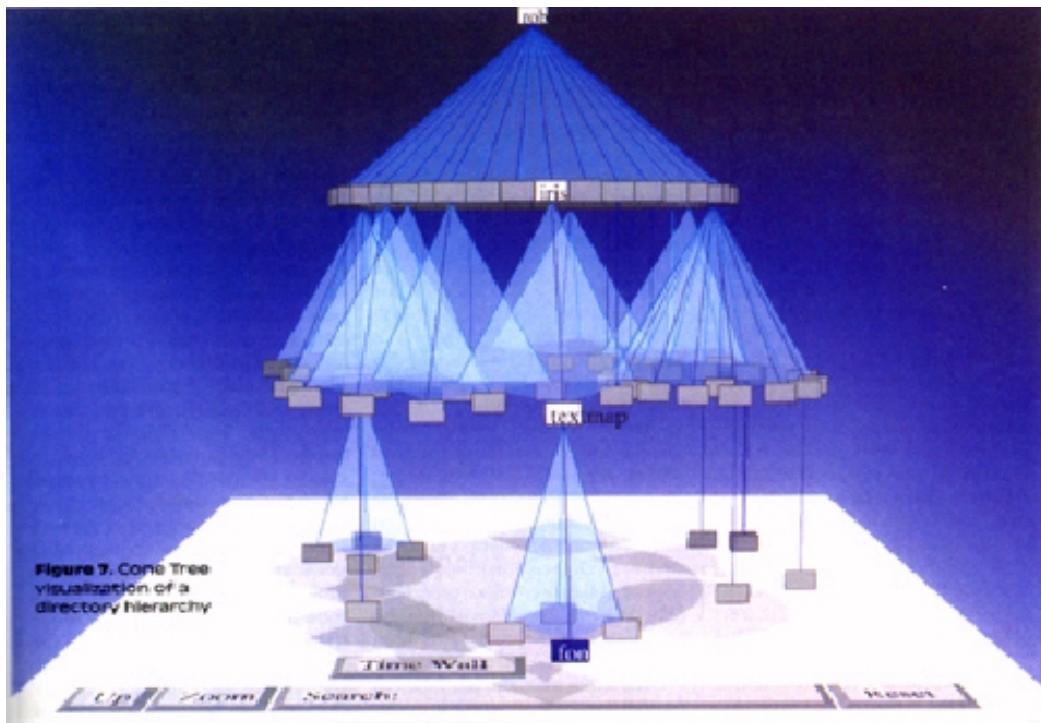


Figure 5.13: The cone tree is a 3d conical representation of a hierarchy. [Copyright © by the Association for Computing Machinery, Inc.]

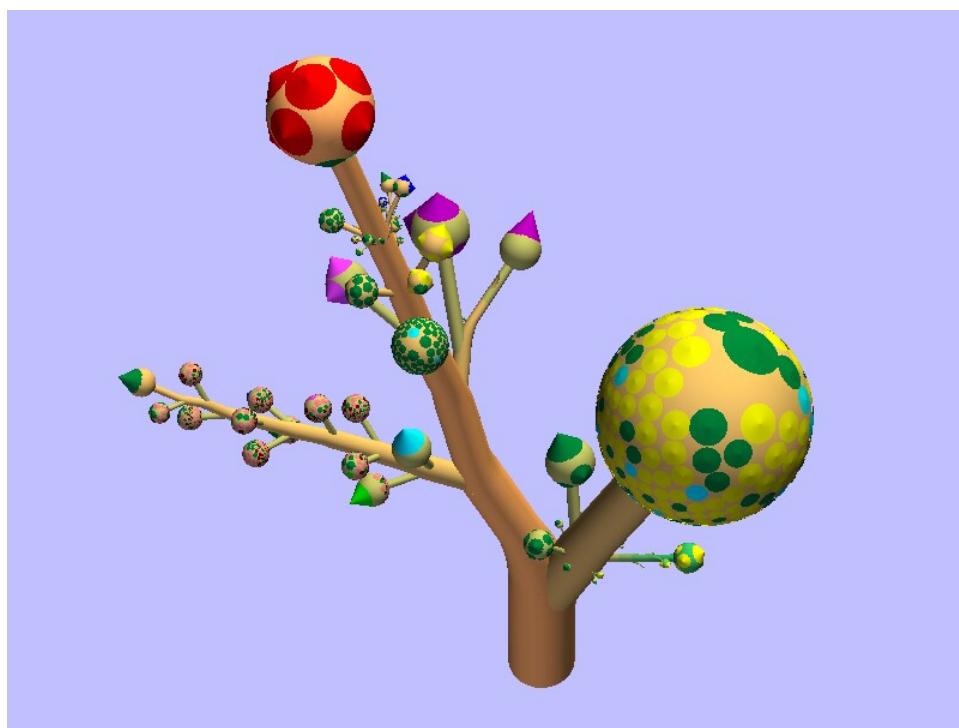


Figure 5.14: Botanical visualisation of a hierarchy. [Image used with kind permission of Jack van Wijk, Eindhoven University of Technology.]

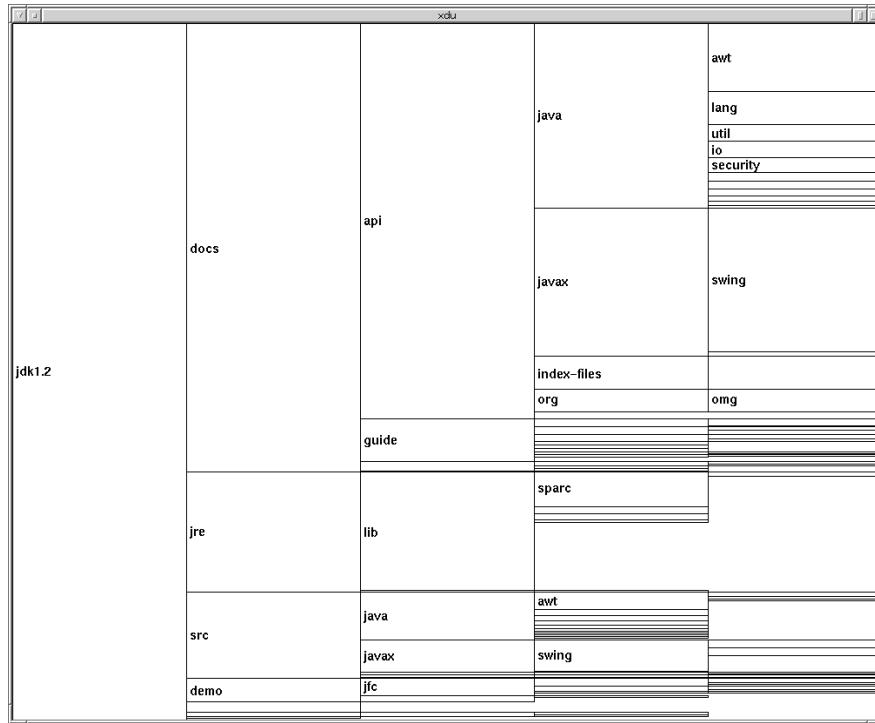


Figure 5.15: An xdu visualisation of the Java JDK 1.2 distribution.

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].

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 5.16.
- The number of levels displayed on each disc can be changed interactively, 4 or 5 works well.
- The area of each segment is proportional to the total size of its contents.
- Clicking on a directory in the left disc fans out its contents in the right disc, allowing rapid exploration of large hierarchies.

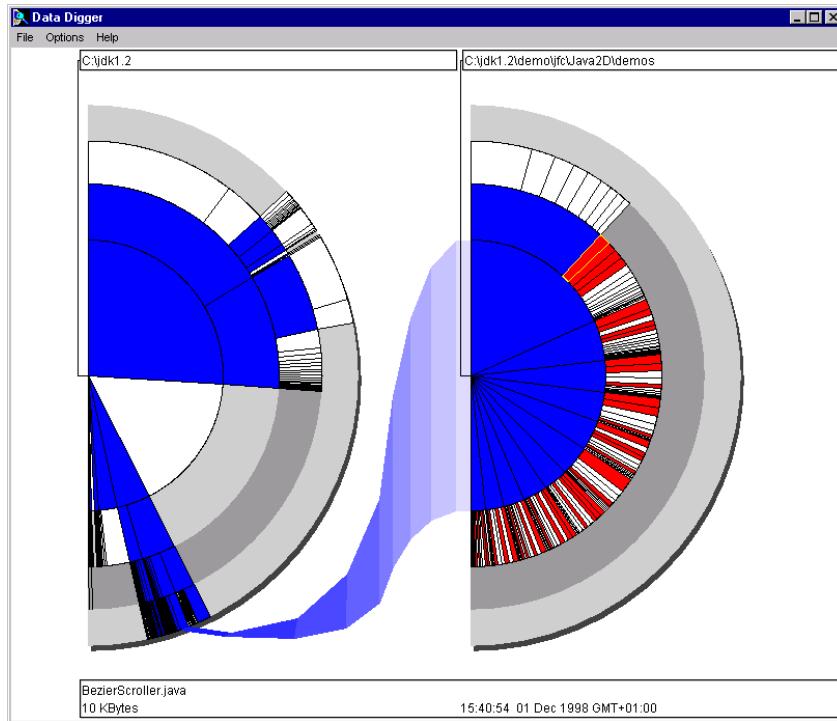


Figure 5.16: An Information Slices visualisation of the JDK 1.2 tree. For deeper hierarchies discs are stacked up in the left margin.

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

5.5.2 SunBurst

- John Stasko et al, GVU, Georgia Tech, 1999-2000.
- Much more advanced version of InfoSlices. See Figure 5.17.
- 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 et al. 2000].
- Video at InfoVis 2000 [Stasko and E. Zhang 2000b]. <https://youtu.be/YaMmDU6GIpo>

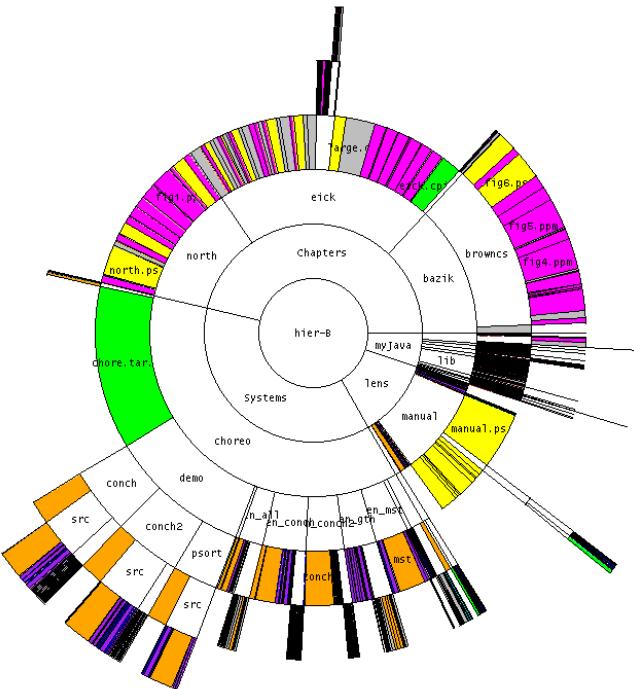


Figure 5.17: The SunBurst directory visualiser. [Image used with kind permission of John Stasko, Georgia Tech.]

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” treemap layout), as shown in Figure 5.18.
 - 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 <https://cs.umd.edu/hcil/treemap/>.

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 5.19.
 - Uses a heuristic to slice up each rectangle into more evenly proportioned sub-rectangles (“Squarified” treemap layout) by placing the largest child first.



Figure 5.18: A tree map of the Dewey Decimal classification hierarchy widely used in libraries.

Copyright ©University of Maryland 1984-1994, all rights reserved.

- 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 5.20.
- Explicit borders are no longer necessary, freeing up pixels for the data.
- Software package called SequoiaView produces disk usage maps using squarified cushion treemaps [SequoiaView 2005].
- Many clones of SequoiaView have been built for various platforms: KDirStat for Unix/X11 [Hundhammer 2010], WinDirStat for Windows [Seifert and Schneider 2018], and Disc Inventory X for Mac [Derlien 2010].
- InfoVis'99 paper [van Wijk and van de Wetering 1999], VisSym 2000 paper [Bruls et al. 2000].
https://youtu.be/mTipHD_MBZk?t=07m09s

5.6.4 Information Pyramids

- IICM, 1997–2001.

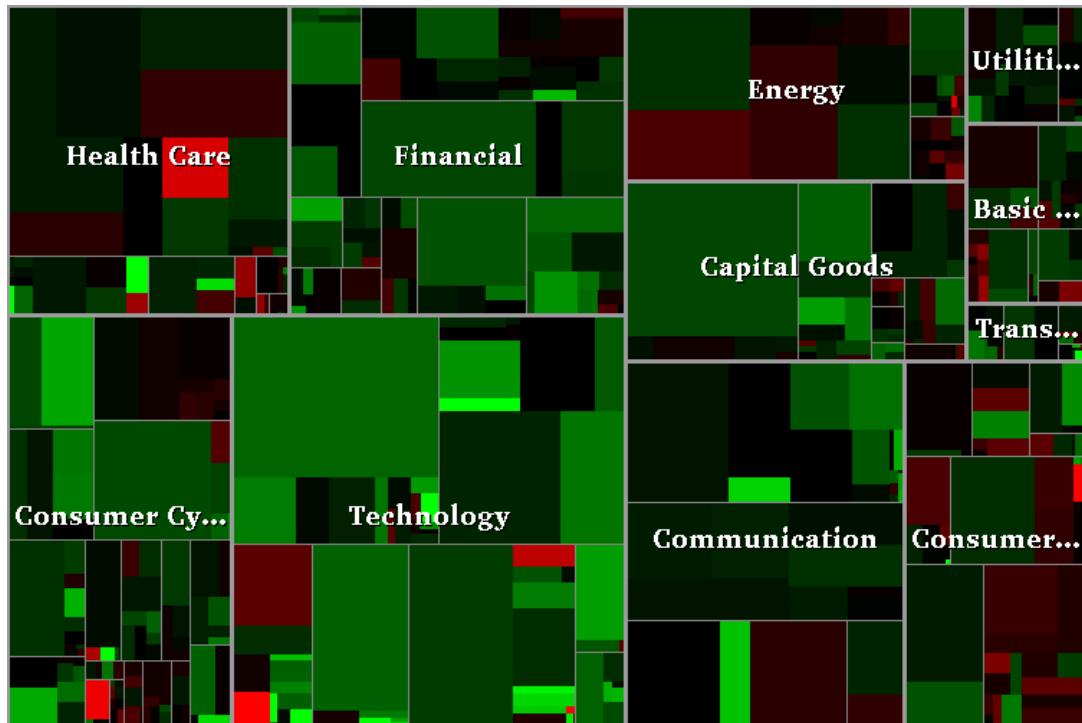


Figure 5.19: A market map of US stocks generated on 17th September 1999.

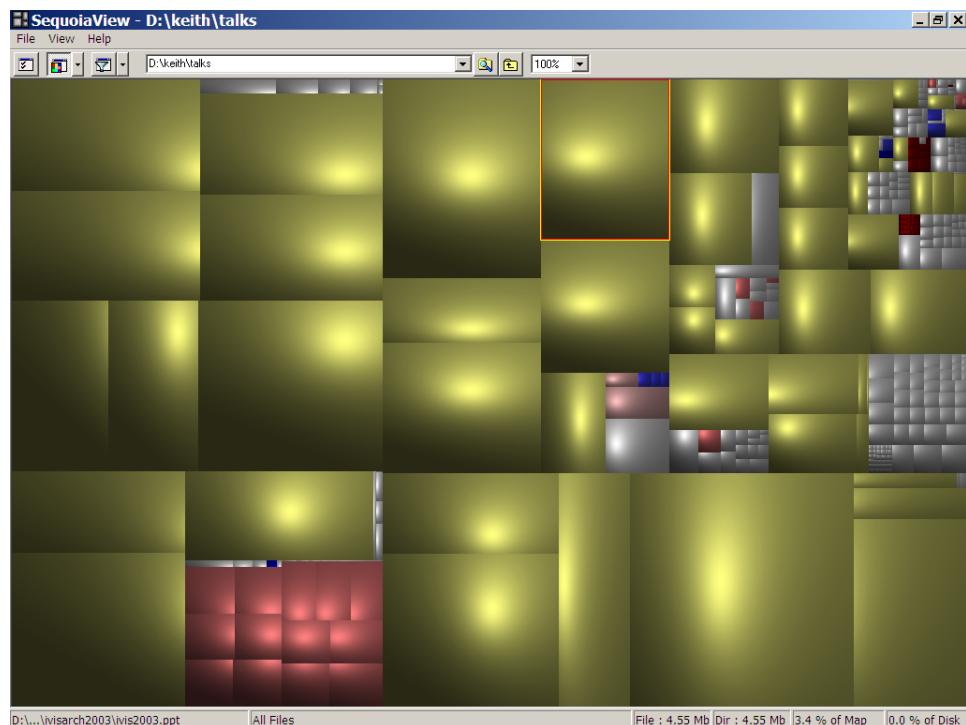


Figure 5.20: SequoiaView produces disk usage maps using squarified cushion treemaps.

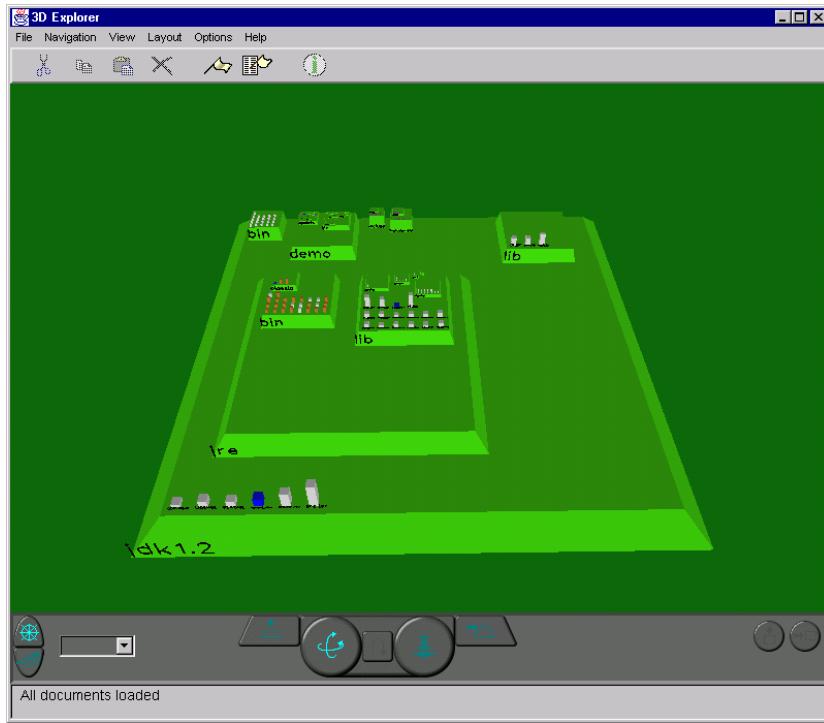


Figure 5.21: An Information Pyramids visualisation of the JDK 1.2 tree. The view from above gives a graphical disk usage. The dashboard provides user navigation. This version uses OpenGL for 3d output.

- A plateau represents the root of the tree. Other, smaller plateaus arranged on top of it represent its subtrees. See Figure 5.21.
- 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 5.22.
- Late Breaking Hot Topics Proc., IEEE Visualization'97 [Andrews et al. 1997] and IEEE CG&A July/Aug. 1998 [Andrews 1998], IV'02 [Andrews 2002a].

5.6.5 InfoSky Cobweb Browser

- First example of recursive Voronoi subdivision for hierarchy visualisation.
- Each parent polygon is subdivided into Voronoi polygons, one for each child, whose area is proportional to its size. See Figures 5.23 and 5.24.
- Paper in journal [Andrews et al. 2002] and at InfoVis 2004 [Granitzer et al. 2004]. <https://youtu.be/fnyKj8r0CN4?t=0m45s>

5.6.6 Voronoi Treemap

- Three years after InfoSky Cobweb.

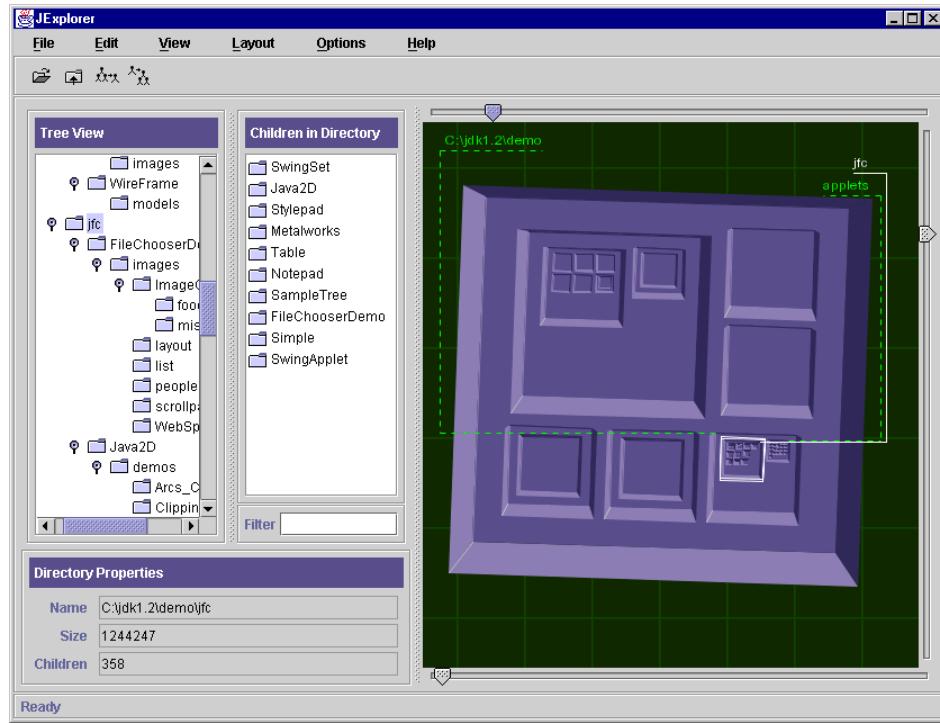


Figure 5.22: The JExplorer combines a Java tree viewer with a synchronised Information Pyramids display.

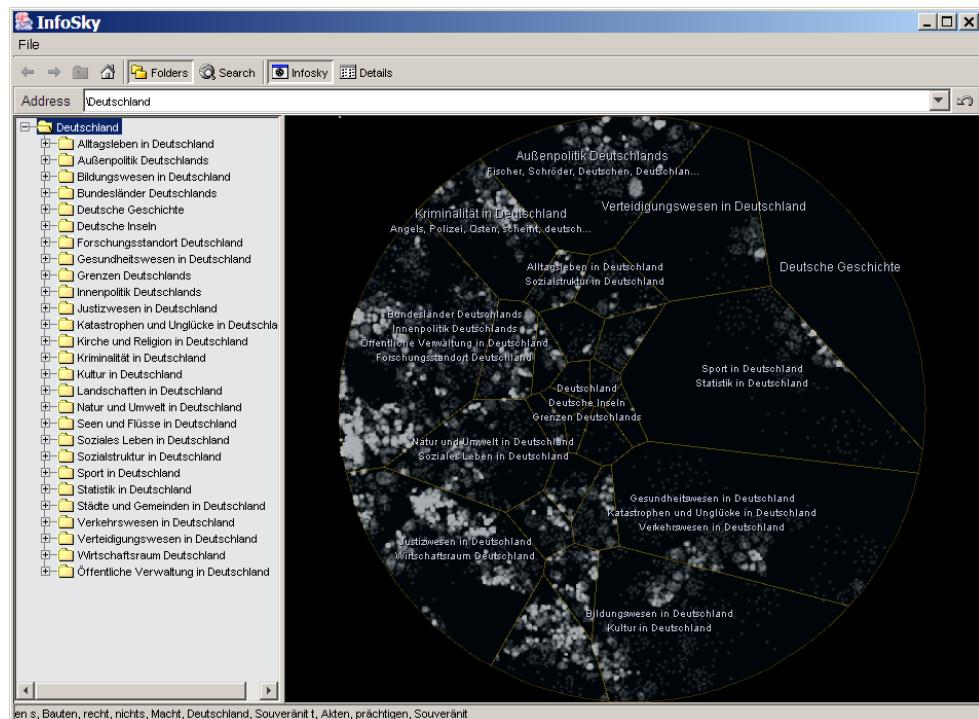


Figure 5.23: The InfoSky Cobweb hierarchy browser.

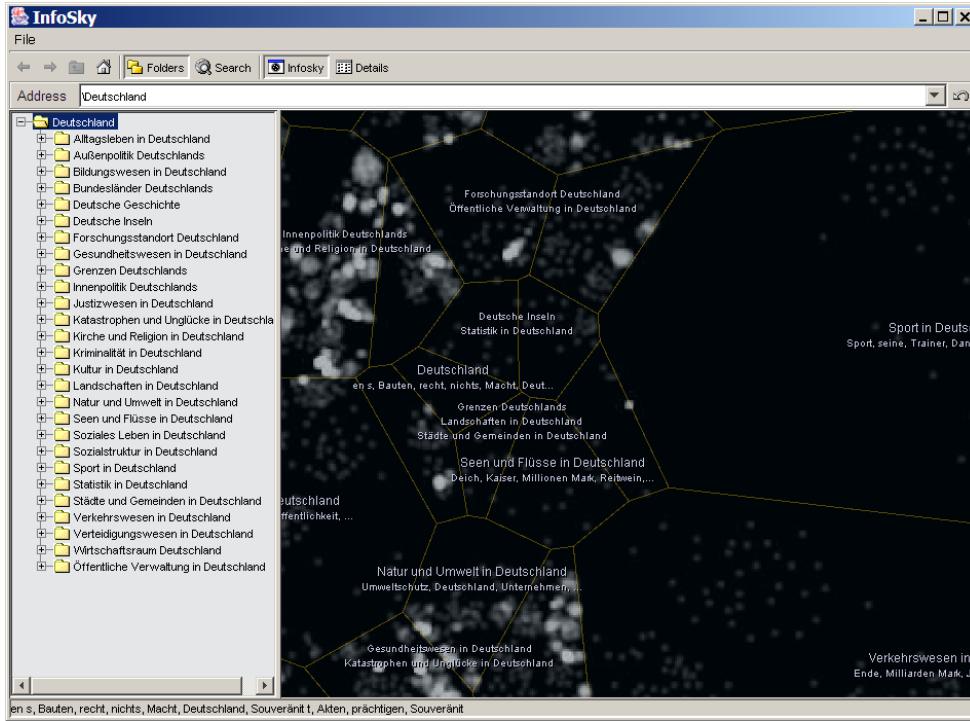


Figure 5.24: The InfoSky Cobweb hierarchy browser, zoomed in for a closer look.

- Also uses space-filling, recursive voronoi subdivision to allocate available space to child polygons. See Figure 5.25.
- Papers at SoftVis 2005 [Balzer et al. 2005] and InfoVis 2005 [Balzer and Deussen 2005a].
- Video at [Balzer and Deussen 2005b]. <https://youtu.be/3Qd56UBDKQE>

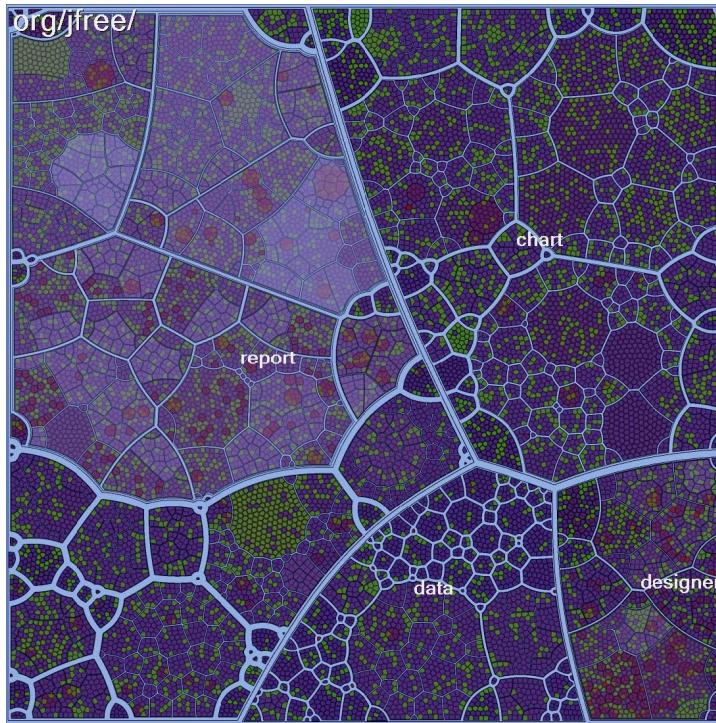


Figure 5.25: The Voronoi Treemap also uses recursive voronoi subdivision. [Image extracted from [Balzer et al. 2005], Copyright © by the Association for Computing Machinery, Inc.]

5.7 Overlapping Space-Filling Tree Browsers

5.7.1 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 5.26.
- Paper at Visualization'96 [Beaudoin et al. 1996].
- Software (Java classes) at CRIM [2002].

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 5.27 and 5.28.
- InfoVis 2002 paper [van Ham and van Wijk 2002].

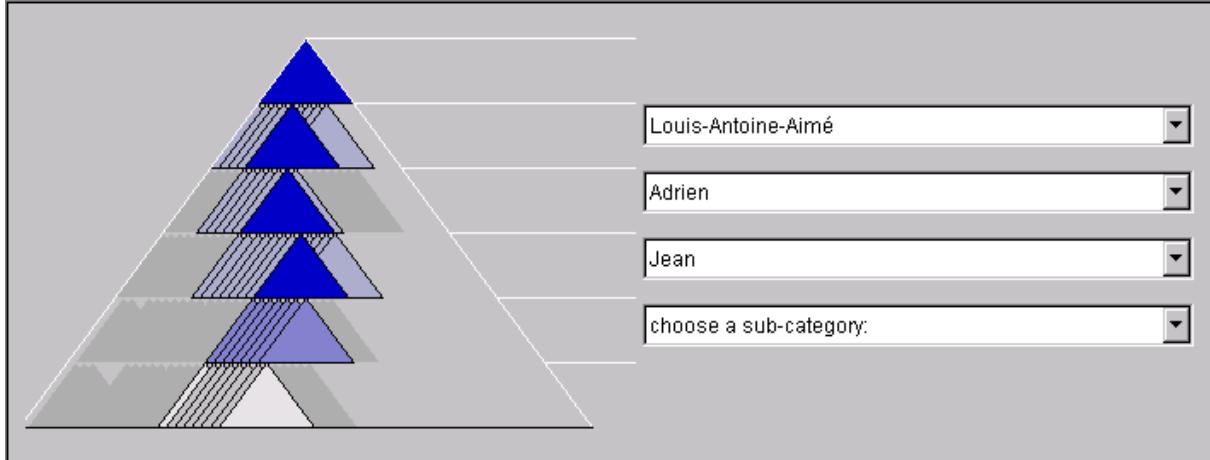


Figure 5.26: Cheops uses stacked triangles to compactly display a hierarchy.

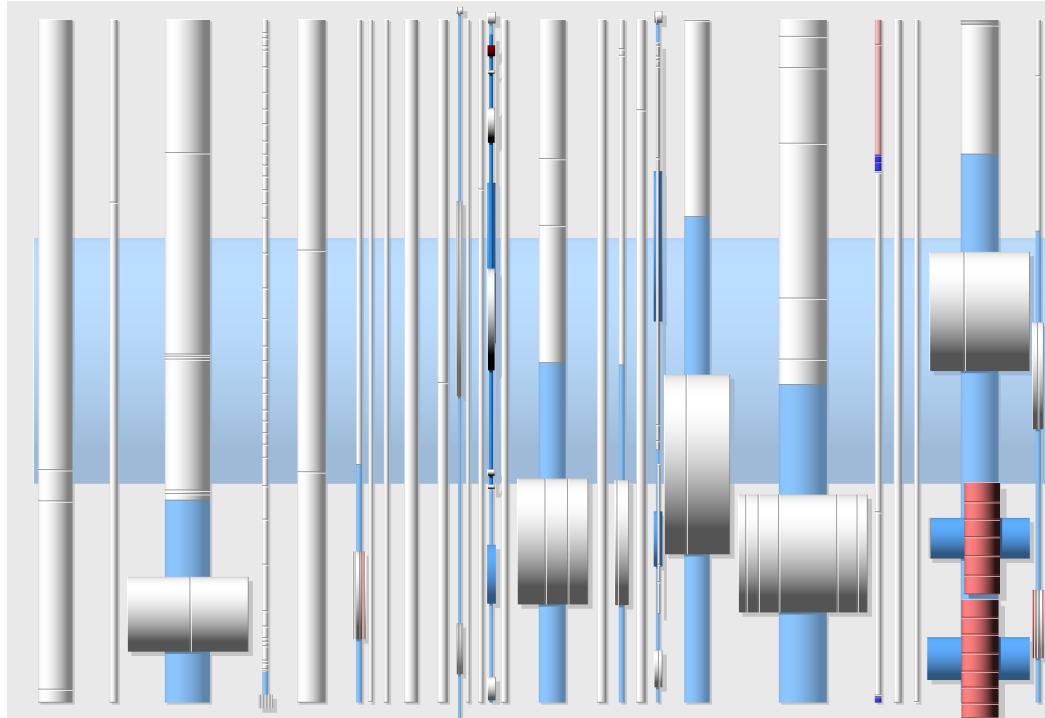


Figure 5.27: BeamTrees are a variation on treemaps using overlapping beams. Directories are coloured blue, files are other colours. The root directory is at the back, other directories are overlaid upon it.

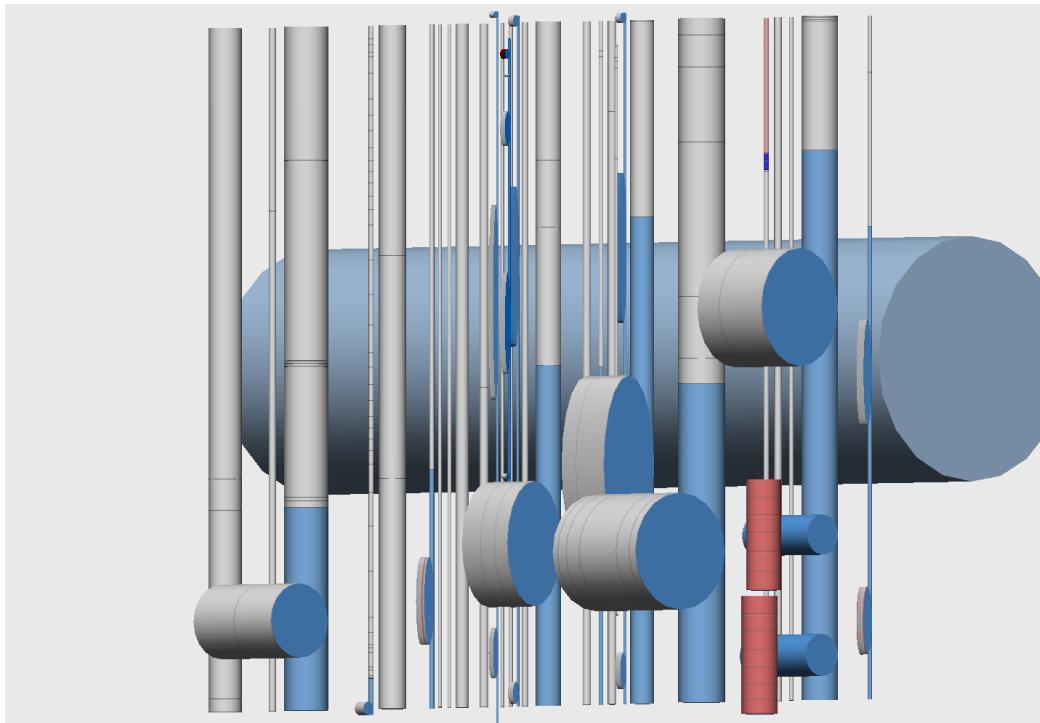


Figure 5.28: The directory structure is only really recognisable when a 3D rendering is used.

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.
- Cute physical simulation of shaking when landing, can jump up and look around.
- Papers [McCahill and Erickson 1995; Iacovou and McCahill 1995]. <https://youtu.be/mljHFaNHzhc>

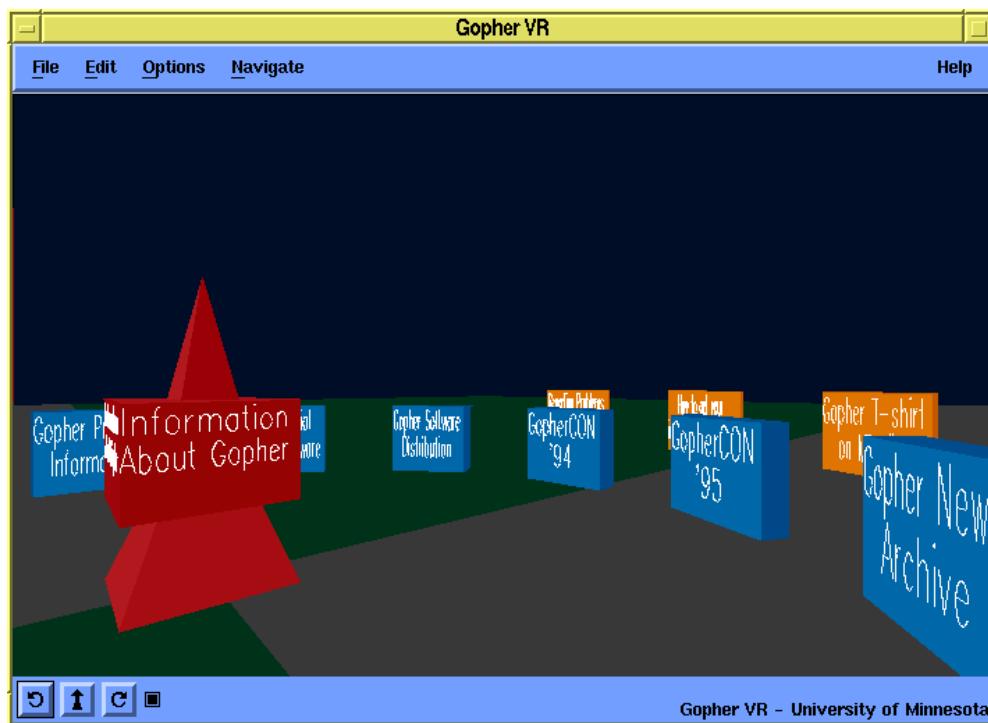


Figure 5.29: GopherVR visualises one level of a Gopher hierarchy at a time. The central pyramid bears the name of the current level, clicking on it returns the user to the next higher level.

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.

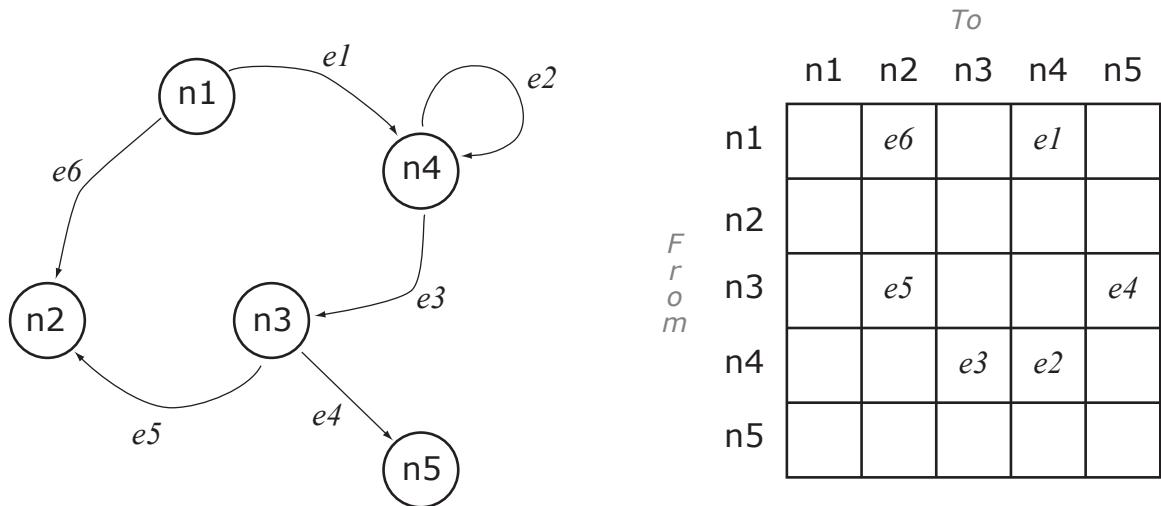


Figure 6.1: A graph with five nodes and six directed edges. The drawing on the left is hand-drawn. The representation on the right shows the same graph in the form of an adjacency matrix.



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.

6.2 Predetermined Position

The nodes of a graph are laid out in predetermined positions (linear, circular, grid, geographical) and the edges are routed and encoded 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 Circular

Also called ring-based layouts or chord diagrams.

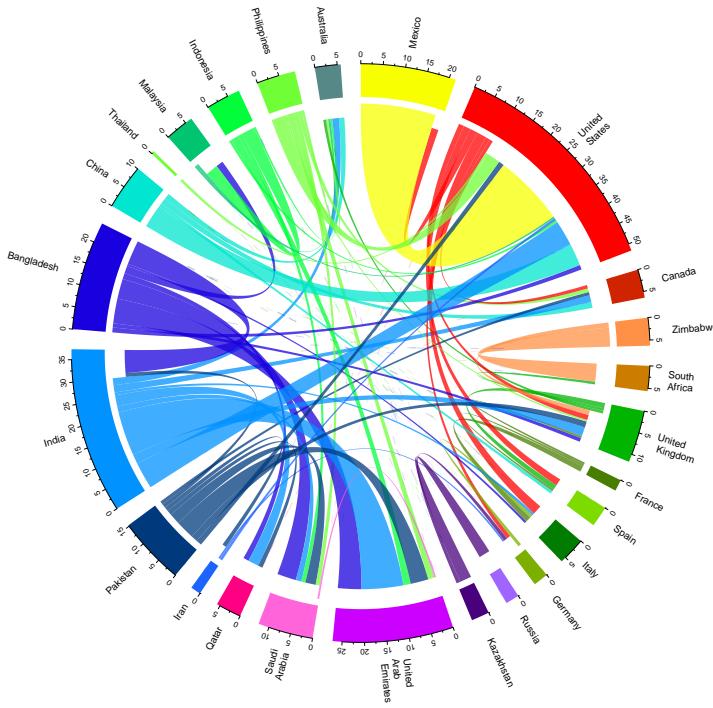


Figure 6.3: A circular plot of migration flows between the world’s top 25 sending and receiving countries between 2005 and 2010. A large gap at the outer segment indicates destination, a small gap indicates origin. The tick marks show the numbers of migrants in millions [Image created by Keith Andrews using data and R code kindly provided by G. Abel [2014]] .

Migration Flows

- Guy Abel and Nikola Sander, at Vienna Institute of Demography, produce circular plots of migration data [G. J. Abel and Sander 2014; G. Abel 2014].
- Figure 6.3 shows a circular plot of migration flows between the world’s top 25 sending and receiving countries between 2005 and 2010.

Flare Dependency Graph

- The Flare Dependency Graph is a circular layout showing dependencies among classes within the Flare library [Heer 2010].
- Each class is placed around the edge of a circle. 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 6.4.

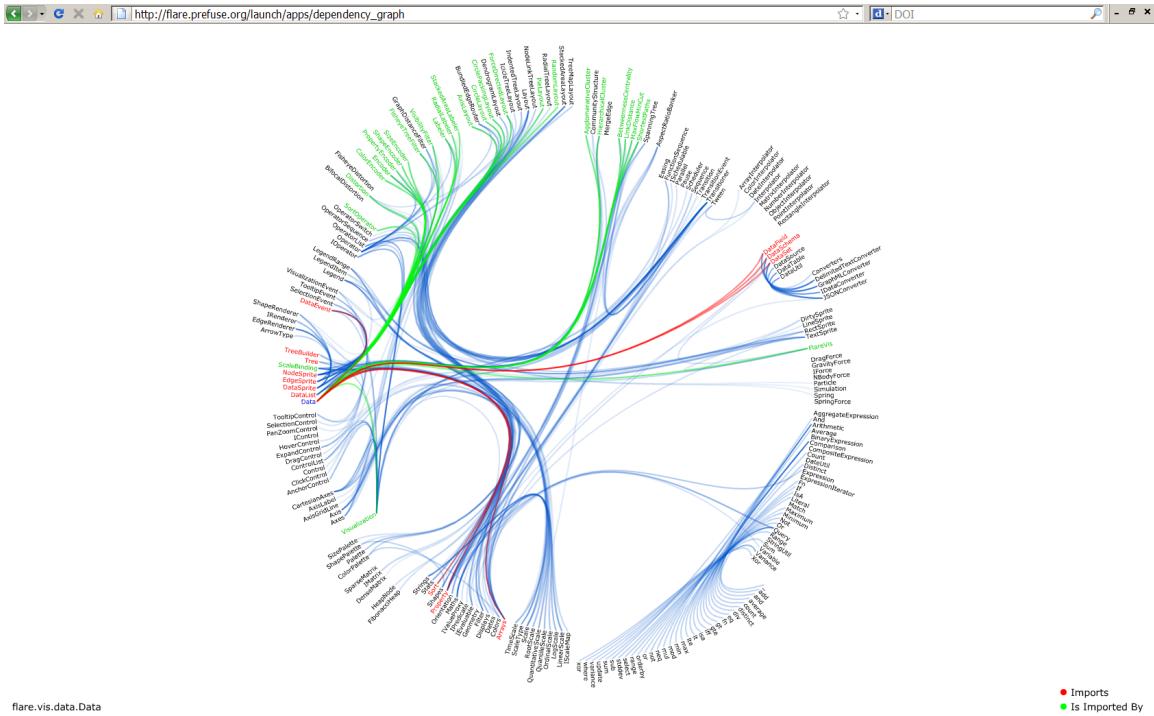


Figure 6.4: The Flare Dependency Graph is a circular layout showing the dependencies between classes in the Flare library. Here the class Data has been selected.

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 6.5.

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 et al. 2005].
 - See Figure 6.6 shows migration to California using US Census data from 2000.

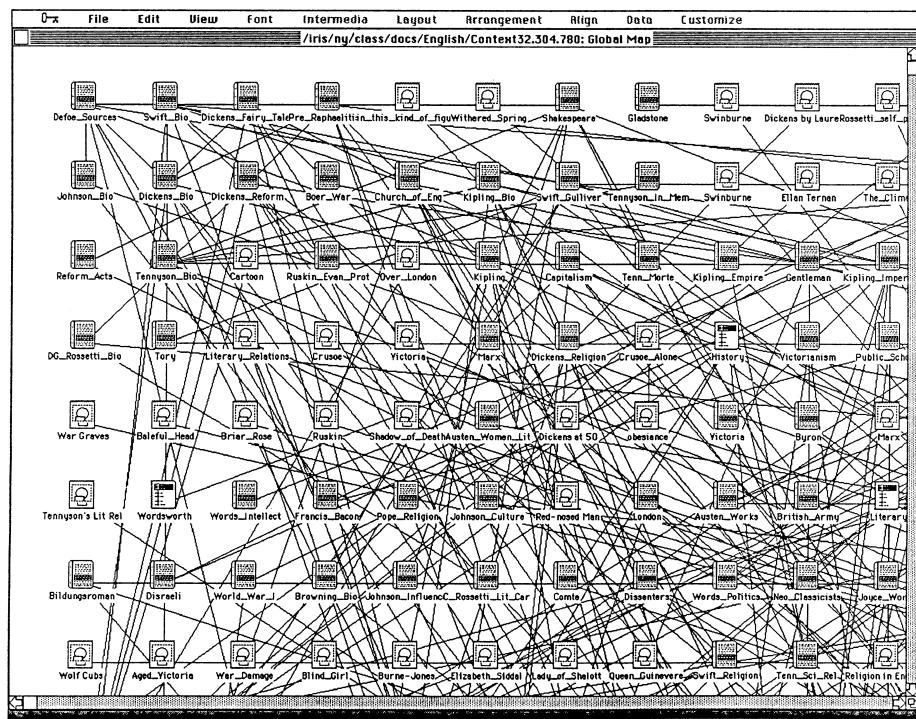


Figure 6.5: The Intermedia Global Map. Hypermedia nodes (documents) are placed on a regular grid and links are drawn between them. [Image extracted from Conklin [1987]. Copyright ©1987 IEEE. Used with permission.]

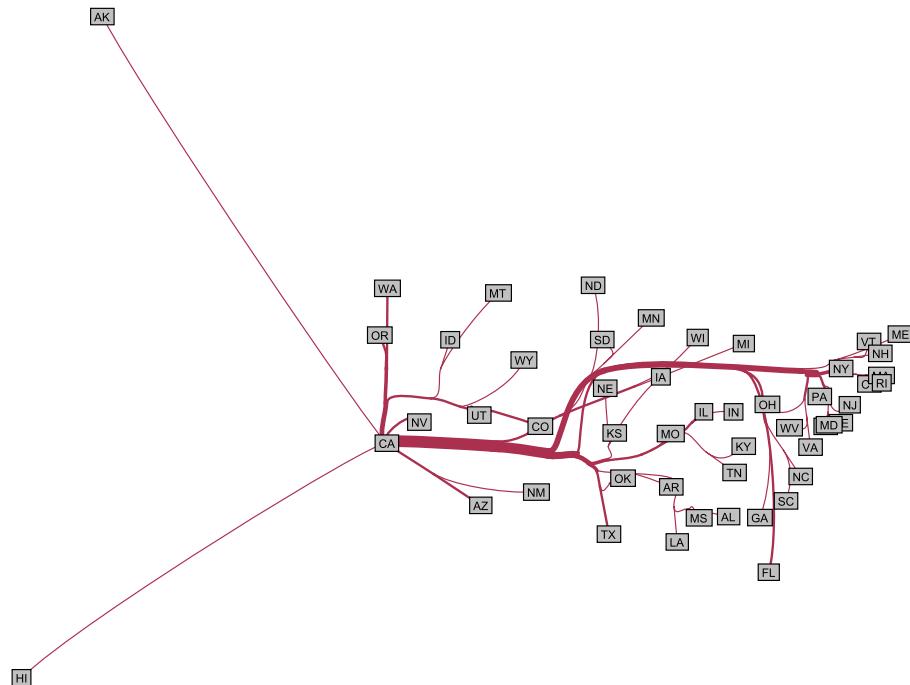


Figure 6.6: A flow map showing migration to California from other US states, using data from the US Census 2000. [Image created by Keith Andrews using the software available from Phan et al. [2006]]

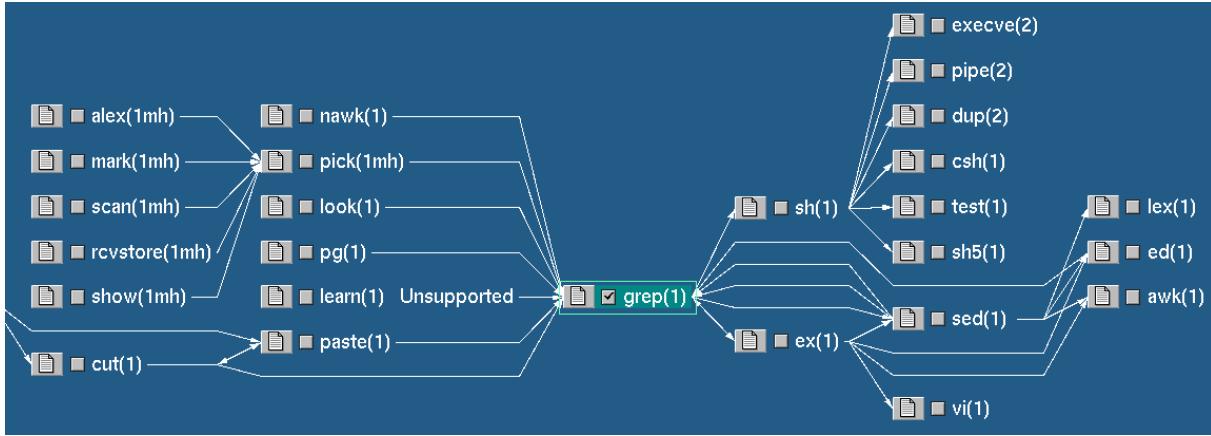


Figure 6.7: The Harmony Local Map uses graph drawing algorithms to lay out a map of the link environment of hypermedia documents. In this example, Unix manual pages one and two links away from the grep manual page are visualised.

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).

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 6.8.
- Description in Chapter 8 of [Andrews 1996].

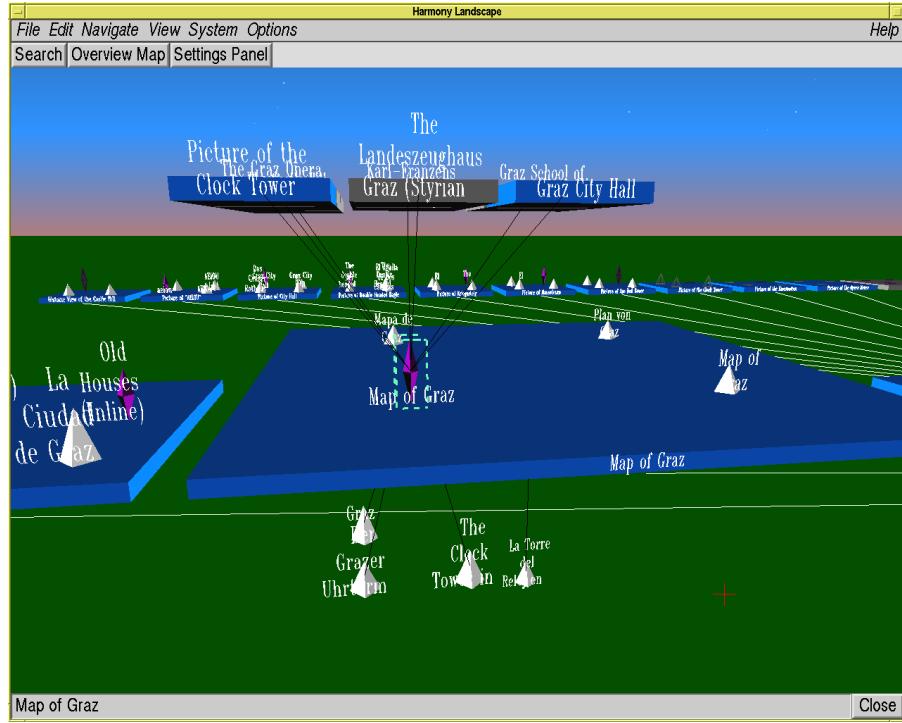


Figure 6.8: The Harmony Local Map 3D display hierarchical structure on the horizontal plane and superimposes hyperlink connections in the vertical plane.

6.4 Force-Based Layouts

6.4.1 SemNet

- Fairchild, Poltrack, Furnas, MCC, 1988.
- The first 3d information visualisation.
- 3d spatial layout of a semantic network. See Figure 6.9.
- Article [K. M. Fairchild et al. 1988].
- Video at CHI '87 [K. Fairchild 1987]. <https://youtu.be/wAu75r77Qko?t=03m00s>
- Patented under [Wexelblat and K. M. Fairchild 1991].

6.4.2 HyperSpace (Narcissus)

- University of Birmingham, 1995.
- Self-organising structure based forces and springs. See Figure 6.10.
- The number of links between documents provides the attractive force.
- Narcissus [Hendley et al. 1995], later renamed HyperSpace [Wood et al. 1995].

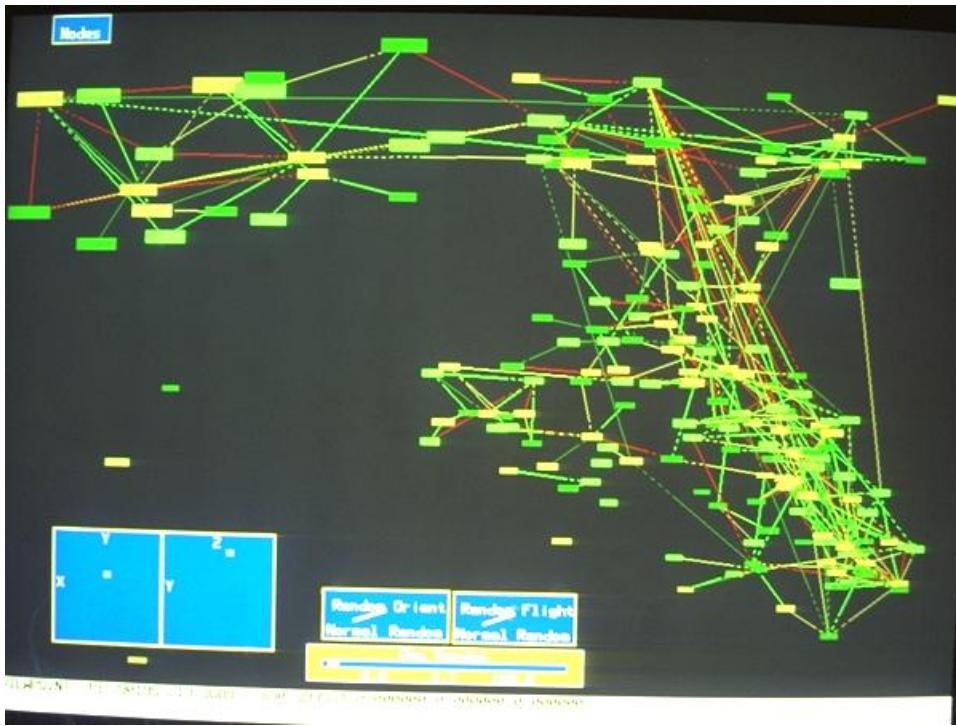


Figure 6.9: SemNet visualised a semantic network in 3d. [Image used with kind permission of Kim Fairchild.]

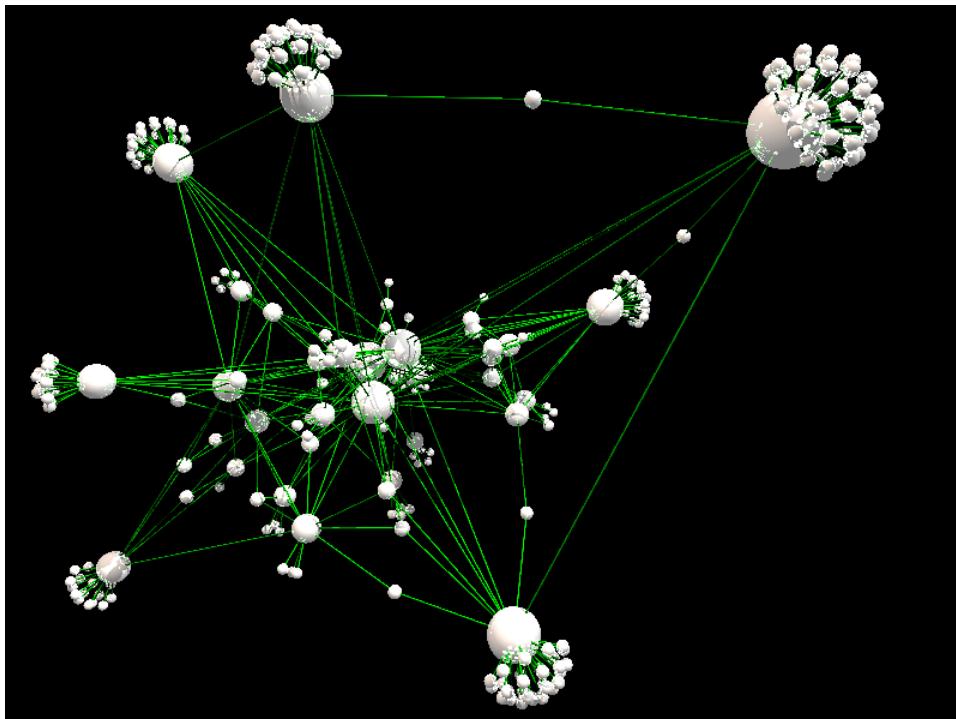


Figure 6.10: HyperSpace showing the structure of a website. White spheres represent web pages. Green lines represent links between pages. The size of a sphere is proportional to the total number of incoming and outgoing links. [Image used with kind permission of Andy Wood.]

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 Card 1994] and CHI’95 video [R. Rao and Card 1995]. <https://youtu.be/ZDY9CYv7z8?t=49s>
- US Patent 5632009 [R. B. Rao and Card 1997].

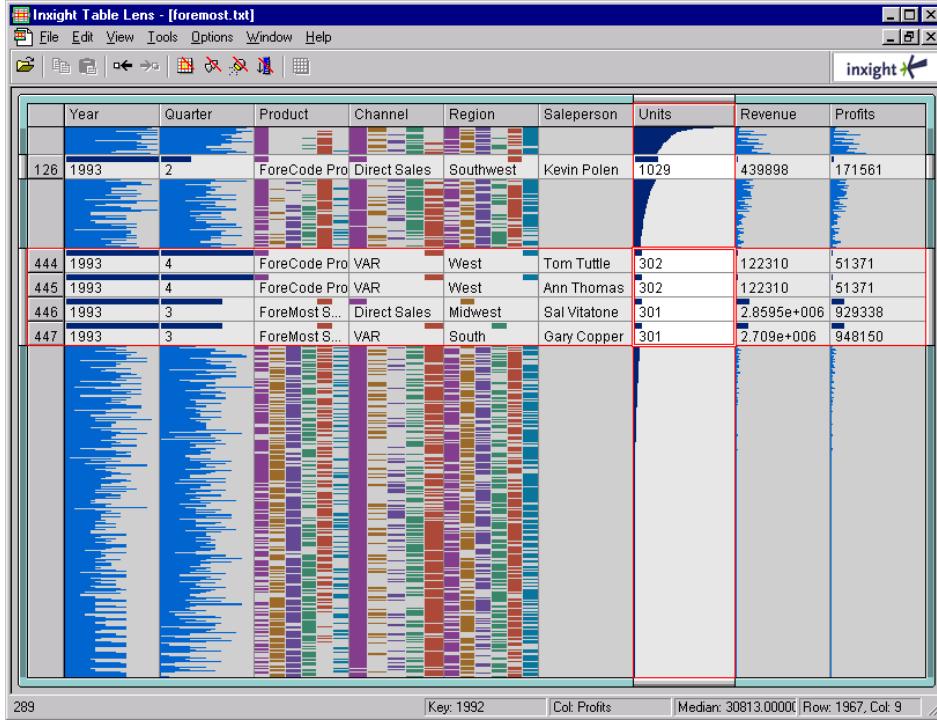


Figure 7.1: The Table Lens represents rows of a table as rows of pixels. The user can focus and stretch out rows or columns to see the data, whilst maintaining surrounding context.
[Screenshot made by Keith Andrews from Inxight Eureka 30-day free trial.]

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 et al. 1992] and video [Shneiderman et al. 1992], CHI’94 paper [Ahlberg and Shneiderman 1994b] and video [Ahlberg and Shneiderman 1994a]. <https://youtu.be/usLM4ncvhjk?t=04m33s>
- Commercialised as part of the Spotfire toolkit [Spotfire 2000].

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 et al. 1996] and CHI’97 online abstracts [Nowell et al. 1997].

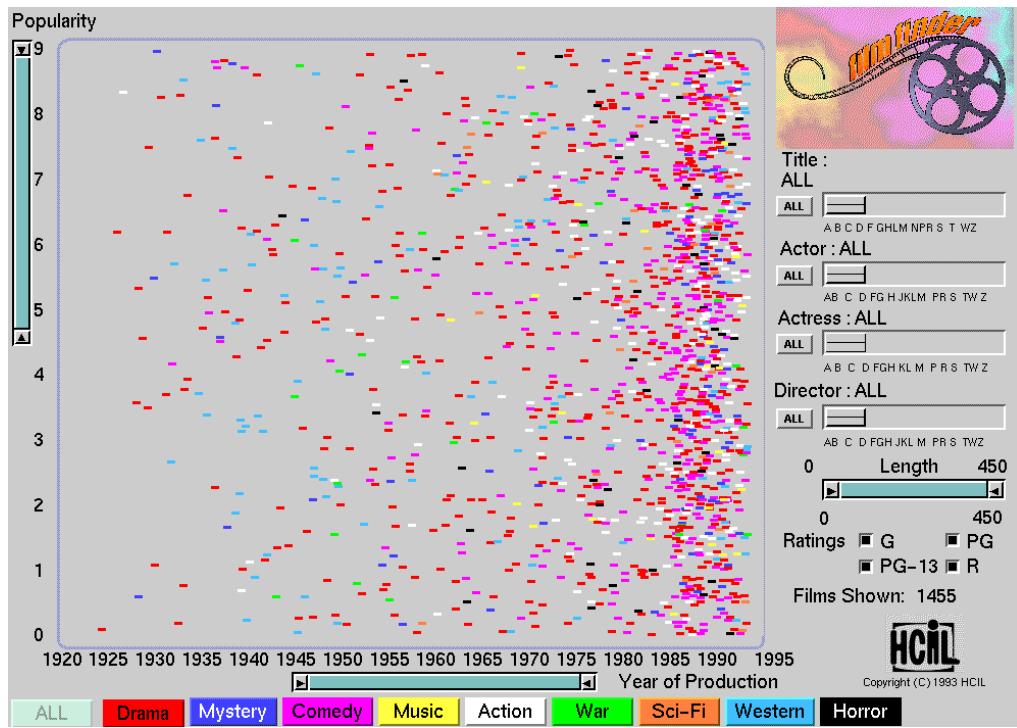


Figure 7.2: The FilmFinder, a starfield display combined with dynamic queries for rapid filtering.
[Copyright ©University of Maryland 1984-1994.]

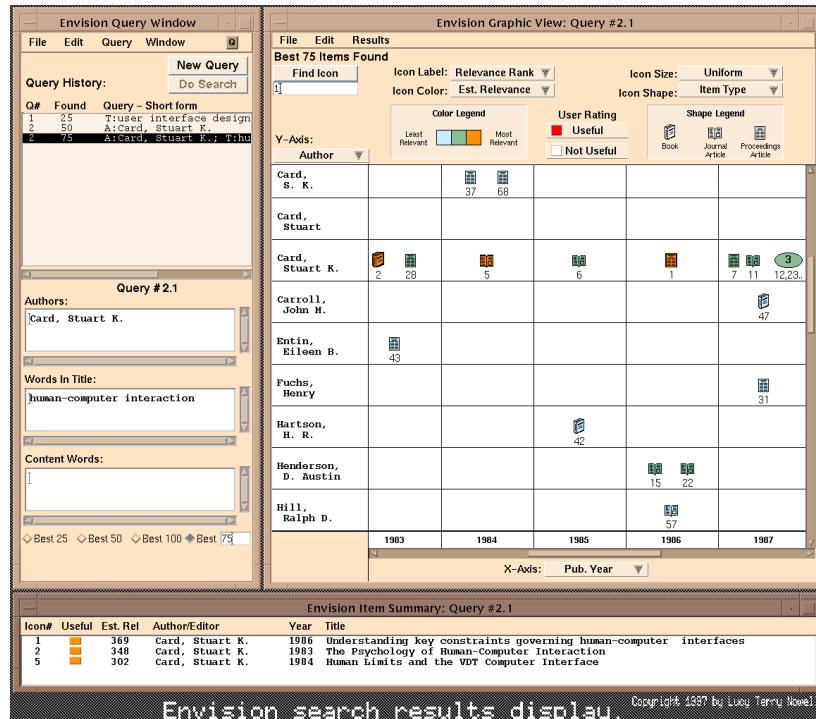


Figure 7.3: Envision visualises a set of search results, by mapping document attributes along two axes. Where too many documents would occupy a cell, an ellipse is used as a container object. Another problem is where to place documents matching multiple categories.
[Copyright © by the Association for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

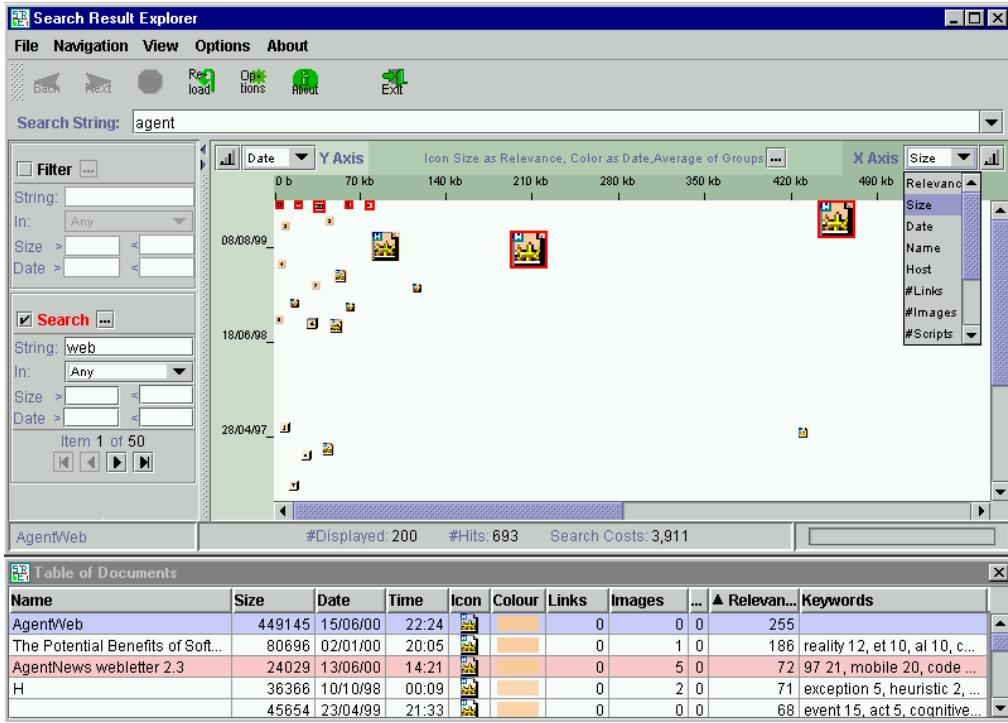


Figure 7.4: Search Result Explorer.

7.2.3 Search Result Explorer

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

7.3 Multidimensional Glyphs

Chernoff Faces

- Invented by Herman Chernoff in 1973 [Chernoff 1973].
- Dimensions (variables) are mapped to characteristics of cartoon-like human faces, such as the curvature of the mouth and the slant of the eyes.
- Figure 7.5 shows Chernoff faces for R's built-in mtcars dataset.

Name	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
Mazda RX4	21.0	6	160.0	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6	160.0	110	3.90	2.875	17.02	0	1	4	4
Datsun 710	22.8	4	108.0	93	3.85	2.320	18.61	1	1	4	1
Hornet 4 Drive	21.4	6	258.0	110	3.08	3.215	19.44	1	0	3	1
Hornet Sportabout	18.7	8	360.0	175	3.15	3.440	17.02	0	0	3	2
Valiant	18.1	6	225.0	105	2.76	3.460	20.22	1	0	3	1
Duster 360	14.3	8	360.0	245	3.21	3.570	15.84	0	0	3	4
Merc 240D	24.4	4	146.7	62	3.69	3.190	20.00	1	0	4	2
Merc 230	22.8	4	140.8	95	3.92	3.150	22.90	1	0	4	2
Merc 280	19.2	6	167.6	123	3.92	3.440	18.30	1	0	4	4
Merc 280C	17.8	6	167.6	123	3.92	3.440	18.90	1	0	4	4
Merc 450SE	16.4	8	275.8	180	3.07	4.070	17.40	0	0	3	3
Merc 450SL	17.3	8	275.8	180	3.07	3.730	17.60	0	0	3	3
Merc 450SLC	15.2	8	275.8	180	3.07	3.780	18.00	0	0	3	3
Cadillac Fleetwood	10.4	8	472.0	205	2.93	5.250	17.98	0	0	3	4
Lincoln Continental	10.4	8	460.0	215	3.00	5.424	17.82	0	0	3	4
Chrysler Imperial	14.7	8	440.0	230	3.23	5.345	17.42	0	0	3	4
Fiat 128	32.4	4	78.7	66	4.08	2.200	19.47	1	1	4	1
Honda Civic	30.4	4	75.7	52	4.93	1.615	18.52	1	1	4	2
Toyota Corolla	33.9	4	71.1	65	4.22	1.835	19.90	1	1	4	1
Toyota Corona	21.5	4	120.1	97	3.70	2.465	20.01	1	0	3	1
Dodge Challenger	15.5	8	318.0	150	2.76	3.520	16.87	0	0	3	2
AMC Javelin	15.2	8	304.0	150	3.15	3.435	17.30	0	0	3	2
Camaro Z28	13.3	8	350.0	245	3.73	3.840	15.41	0	0	3	4
Pontiac Firebird	19.2	8	400.0	175	3.08	3.845	17.05	0	0	3	2
Fiat X1-9	27.3	4	79.0	66	4.08	1.935	18.90	1	1	4	1
Porsche 914-2	26.0	4	120.3	91	4.43	2.140	16.70	0	1	5	2
Lotus Europa	30.4	4	95.1	113	3.77	1.513	16.90	1	1	5	2
Ford Pantera L	15.8	8	351.0	264	4.22	3.170	14.50	0	1	5	4
Ferrari Dino	19.7	6	145.0	175	3.62	2.770	15.50	0	1	5	6
Maserati Bora	15.0	8	301.0	335	3.54	3.570	14.60	0	1	5	8
Volvo 142E	21.4	4	121.0	109	4.11	2.780	18.60	1	1	4	2

Table 7.1: R's mtcars dataset.

Variable	Characteristic
mpg	height of face
cyl	width of face
disp	structure of face
hp	height of mouth
drat	width of mouth
wt	smiling
qsec	height of eyes
vs	width of eyes
am	height of hair
gear	width of hair
carb	style of hair
mpg	height of nose
cyl	width of nose
disp	width of ear
hp	height of ear

Table 7.2: The mapping of variables in the mtcars dataset to facial characteristics.

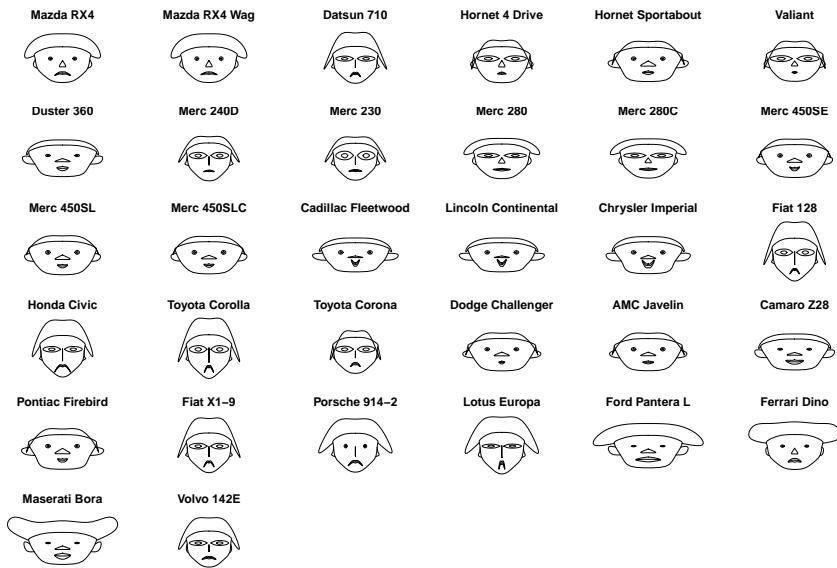


Figure 7.5: Chernoff faces for R’s built-in mtcars dataset.

7.4 Parallel Coordinates

Parallel Coordinates Plot

- 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 7.6 shows plot of 11 data points (students) on six dimensions (FirstName, Quiz1, Quiz2, Homework1, Homework2, Final).
- Figure 7.7 shows InfoScope [Brodbeck and Girardin 2003; Girardin and Brodbeck 2001; MacroFocus 2015], which combines a parallel coordinates view with a geographic map and a similarity map for exploration of multidimensional data about 73 cities. <https://youtu.be/fnyKj8r0CN4?t=03m27s>

History of Parallel Coordinates

- The first known use was by Henry Gannett in 1883 [Hewes and Gannett 1883, Plate 151] used to visualise 10 attributes for each the (then 47) states of the USA. [It is shown in Figure 3.11.]
- Maurice d’Ocagne discussed the theoretical foundations of parallel coordinates in his book in 1885 [d’Ocagne 1885].
- The technique was independently re-invented by Alfred Inselberg in 1959 [Inselberg 2004]

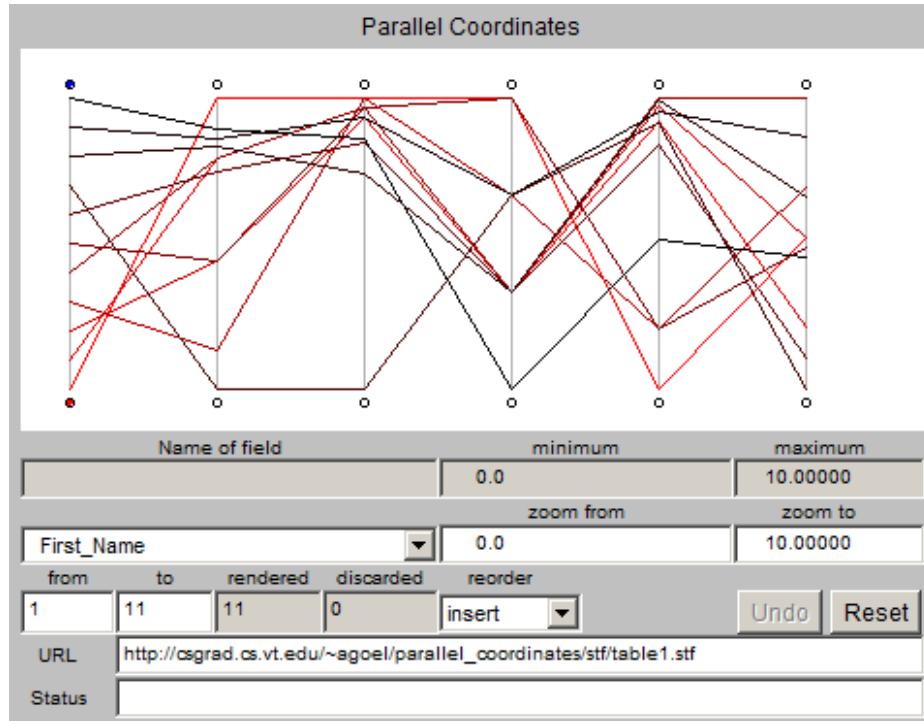


Figure 7.6: Parallel Coordinates. The six vertical lines represent (from left to right) the name and marks of students in five exams. The eleven polylines represent the data from eleven students. Polylines which mirror one another closely from vertical lines 2 to 6 indicate students achieving very similar marks.

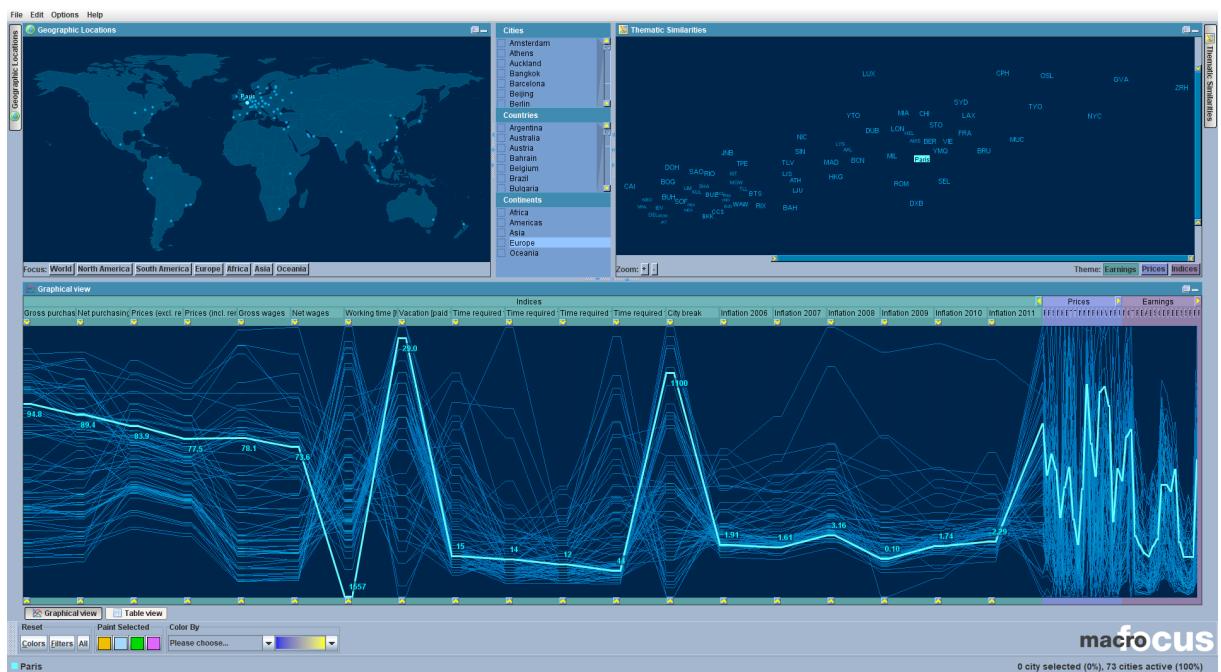


Figure 7.7: InfoScope [Brodbeck and Girardin 2003] allows users to explore multidimensional data about 73 cities. The parallel coordinates view at the bottom is complemented with geographic map and a similarity map. [Screenshot made by Keith Andrews with the InfoScope software [MacroFocus 2015].]

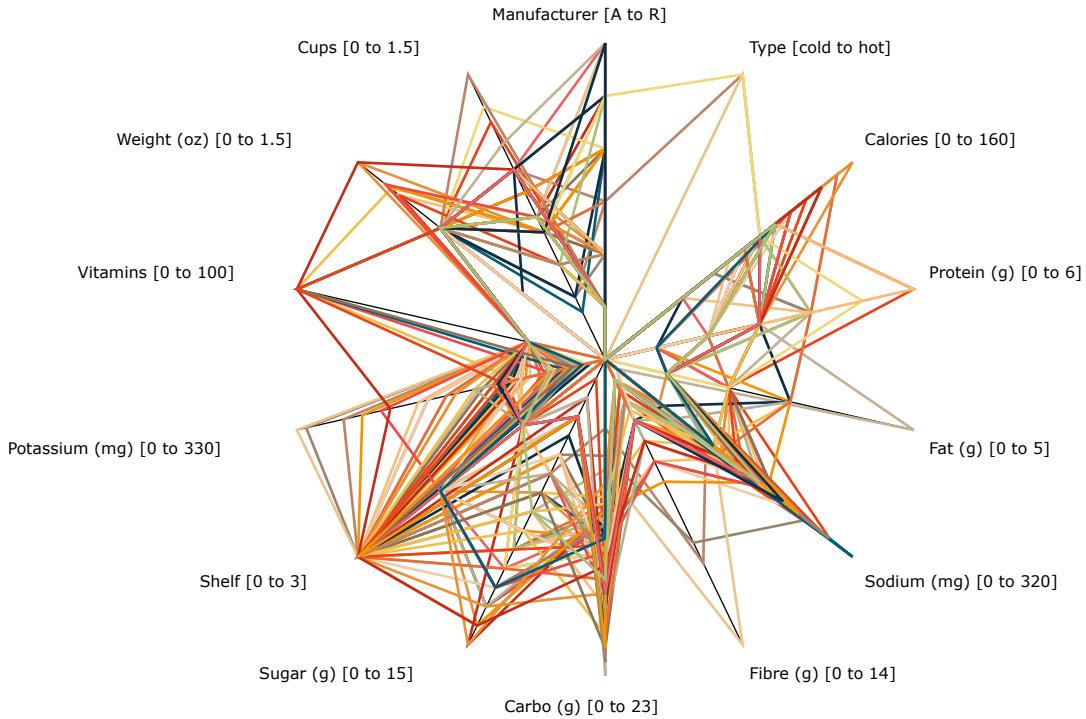


Figure 7.8: A star plot of the classic cereals dataset. [Image created by Keith Andrews using Liquid Diagrams.]

- Inselberg published a comprehensive overview paper in the journal *The Visual Computer* in 1985 [Inselberg 1985] and has published widely on parallel coordinates since.
- Inselberg published his definitive book on the subject in 2009 [Inselberg 2009].

References

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- ++ Maurice d'Ocagne; *Coordonnées Parallèles et Axiales*; Gauthier-Villars, Paris, 1885. [d'Ocagne 1885]

7.5 Star Plot

- Also known as star chart, radar chart, spider plot, wheel chart, and polar chart.
- Dimensions are laid out radially.
- Each record is represented as an irregular polygon.
- The visual image is highly dependent on the chosen ordering of dimensions.
- Sometimes lines are drawn on top of one another (occlusion).

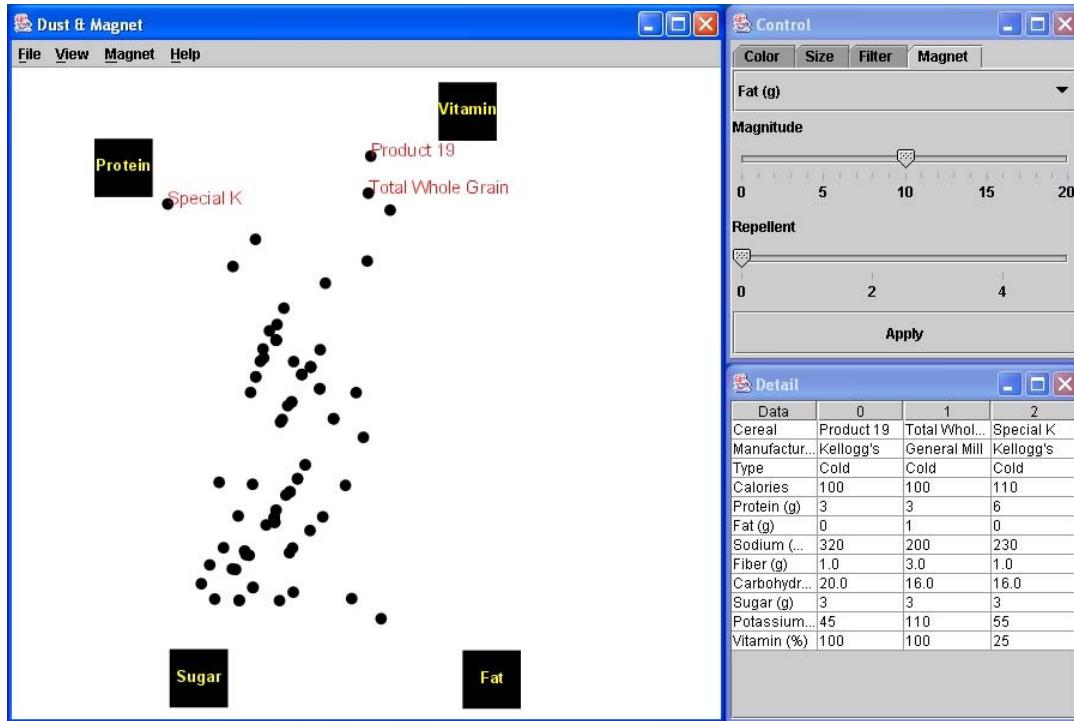


Figure 7.9: Dust and Magnet. Small circles (dust) represent items, square blocks (magnets) represent dimensions (variables). A higher value along a dimension causes an item to be attracted more strongly. [Image used with kind permission of Ji Soo Yi.]

7.6 Interactive Attraction

7.6.1 Dust and Magnet

- Ji Soo Yi, John Stasko, et al, Georgia Tech, 2005.
- Metaphor of dust particles attracted to magnets, as shown in Figure 7.9.
- Magnets can be added and removed, and their strength increased or decreased.
- Paper in IV journal 2005 [Yi et al. 2005b].
- Video from 2005 [Yi et al. 2005a]. <https://youtu.be/wLXwL38xek0?t=28s>
- More recently re-implemented for touch interface. <https://www.cc.gatech.edu/gvu/ii/dnm/dustnmagnet-16Hub.mp4>

7.7 Interactive Histograms

7.7.1 Attribute Explorer

- Imperial College, 1993.
- Direct manipulation of coupled views of histograms, as shown in Figure 7.10.
- CHI'94 video [Tweedie et al. 1994]. <https://open-video.org/details.php?videoid=8162>

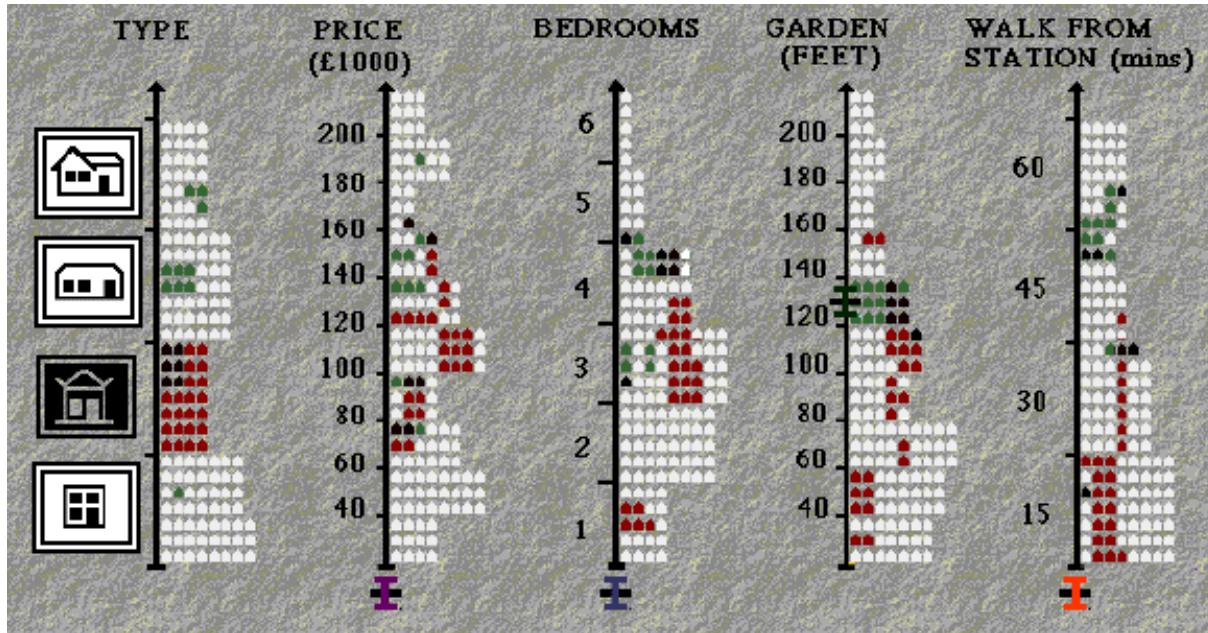


Figure 7.10: The Attribute Explorer. Each attribute is assigned to a scale with histograms showing the population spread running up one side. Initially these display each item in the total population. The user can interact with the scales: using sliders for continuous attributes (e.g. price) and buttons 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.]

7.8 Circular Histograms

Daisy Chart

- Daisy Analysis, UK, 2003 [Daisy 2003].
- Attributes and (ranges of) their values are arranged around the perimeter of a circle. A polygon of connecting lines represents an individual item. See Figure 7.11.

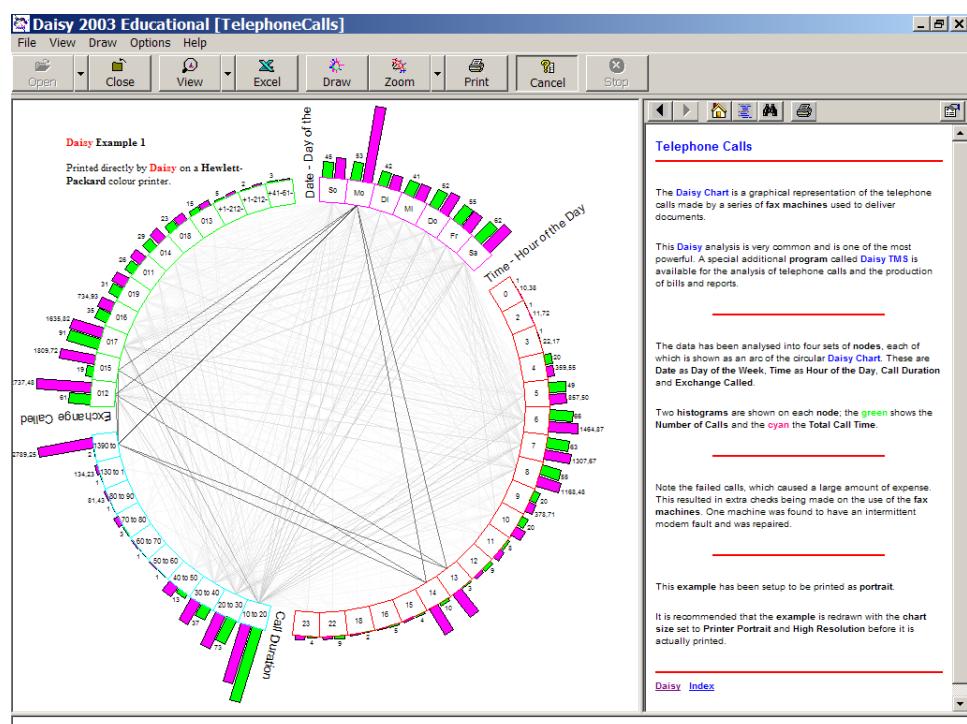


Figure 7.11: The Daisy Chart maps attributes and ranges of their values to positions on the circumference of a circle. Items are represented by polygons connecting attribute values.

Chapter 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 et al. 2007].
- Distances are often normalised to values between 0 and 1.
- Results in a symmetric matrix of distance values.

Multidimensional Projection

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

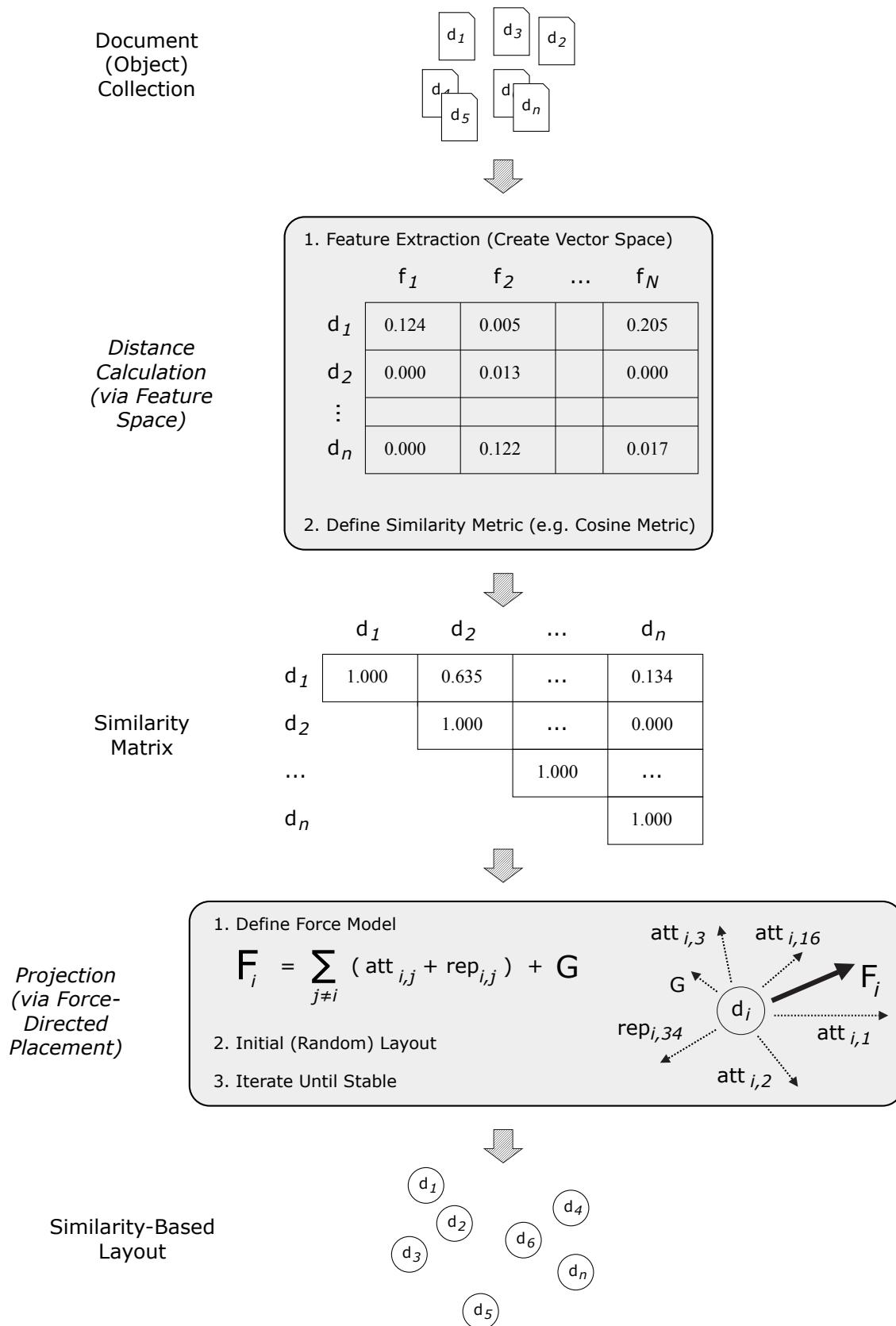


Figure 8.1: The visualisation pipeline for distance-based projection. Here, the vector space model has been chosen as the distance calculation algorithm and force-directed placement has been chosen as the projection algorithm.

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 et al. 2003].
- Least Squares Projection (LSP) [Paulovich et al. 2008].

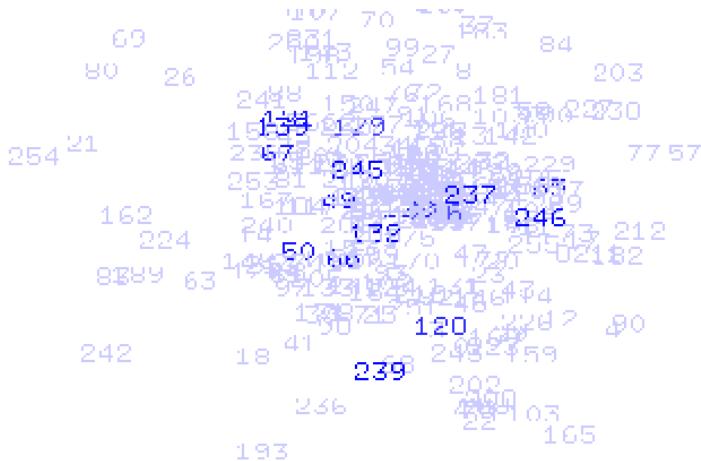


Figure 8.2: Part of the Bead visualisation of 301 entries from the HCI Bibliography. The objects represent articles from the field of HCI. Documents containing similar keywords are placed near each other in the 3d point cloud. A search has been done on the keywords “information retrieval” and the results 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 et al. 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 et al. 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.

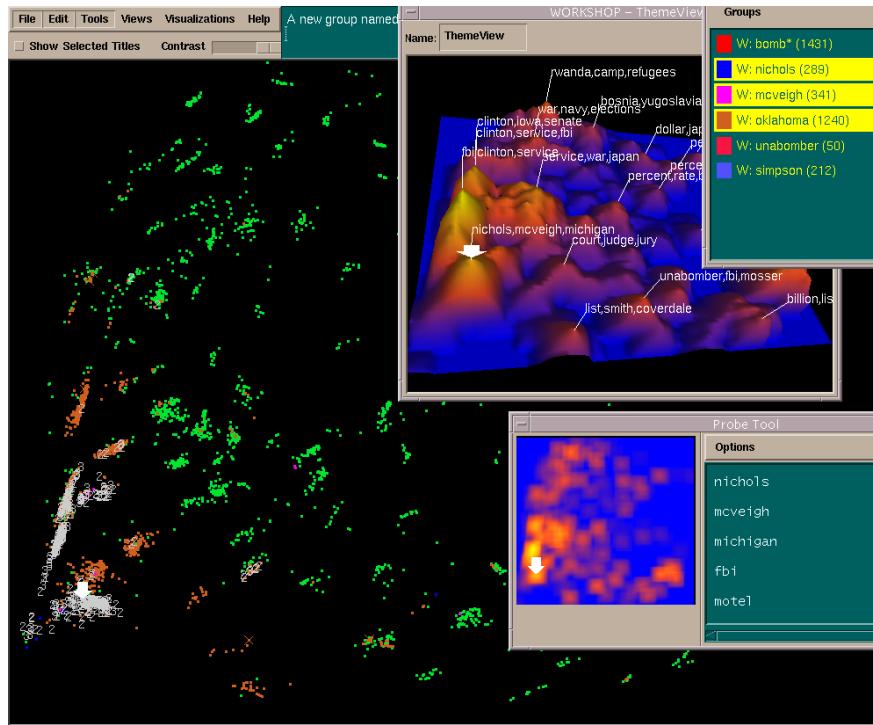


Figure 8.3: SPIRE showing the Galaxy View (below), Themescape (upper right) and Probe Tool. [Image used with kind permission of Pacific Northwest National Laboratory.]

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].
 - Video at InfoVis 2004 Contest <http://www.cs.umd.edu/hcil/InfovisRepository/contest-2004/>
 - Tutorial video <https://youtu.be/YONTBZaxz8g>.

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.

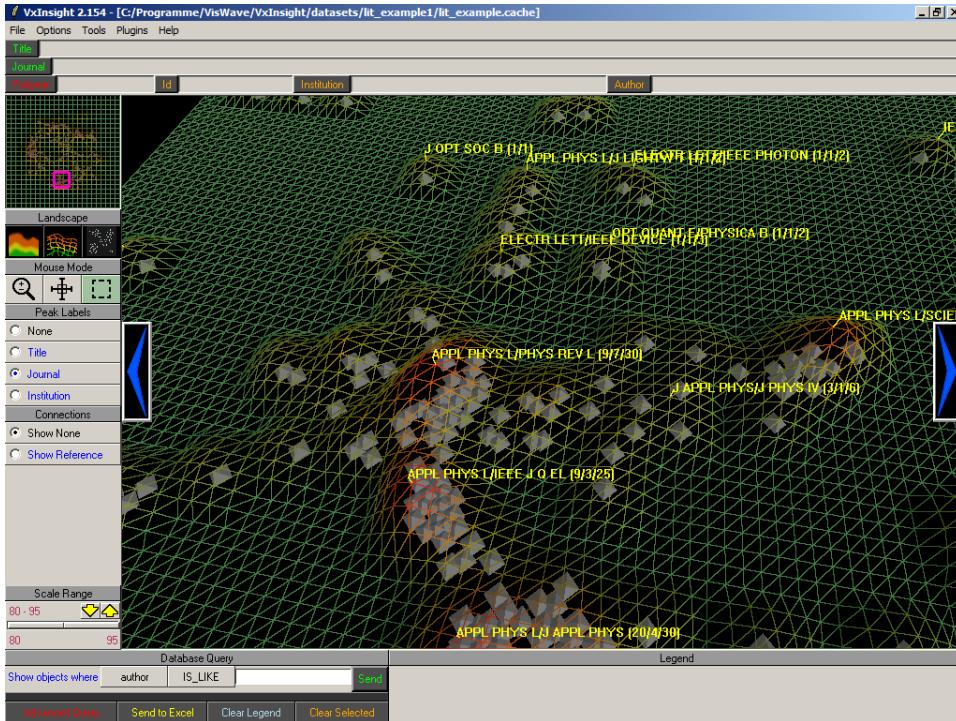


Figure 8.4: VxInsight showing some of 1,231 bibliographic records extracted from the physical sciences portion of the Science Citation Index Expanded. The layout uses similarities based on direct and cocitation links between articles. [Thanks to Brian Wylie, Sandia National Laboratories, for providing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

8.3.4 VisIslands

- IICM, 2001 [Andrews 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 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.

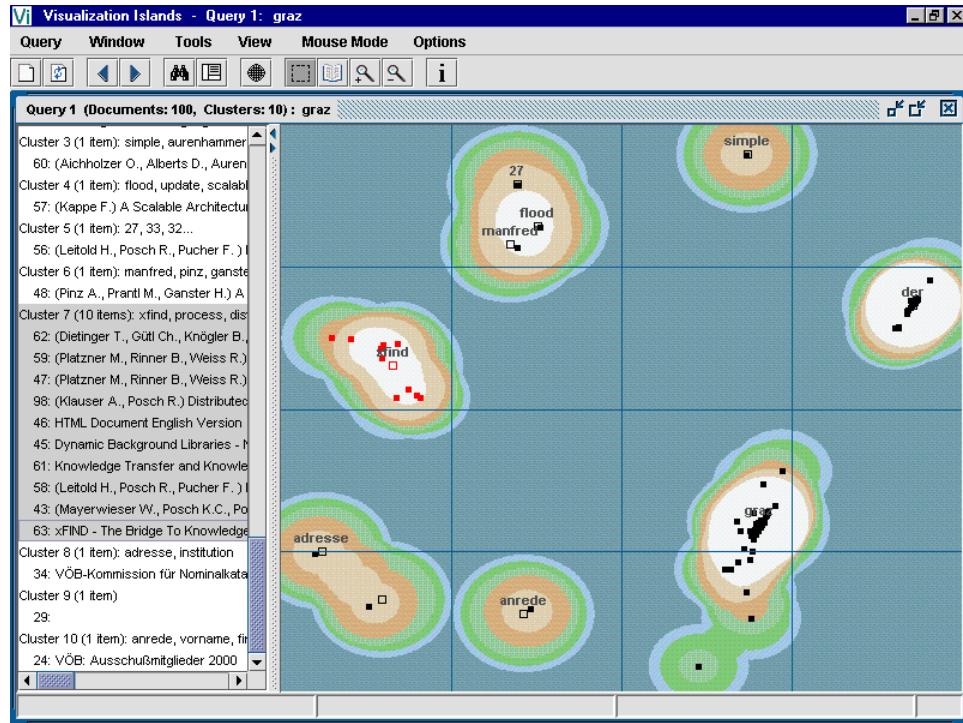


Figure 8.5: VisIslands forms visual clusters of search result sets.

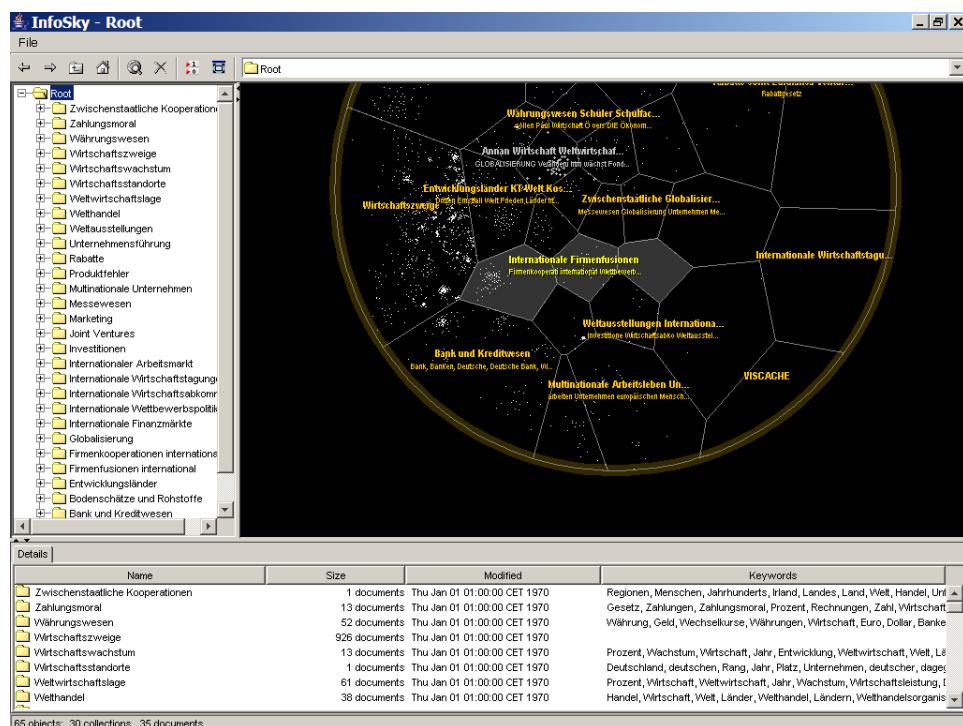


Figure 8.6: InfoSky showing a collection of newspaper articles from the German newspaper Süddeutsche Zeitung. The articles have previously been manually placed within a topical hierarchy by the newspaper editors.

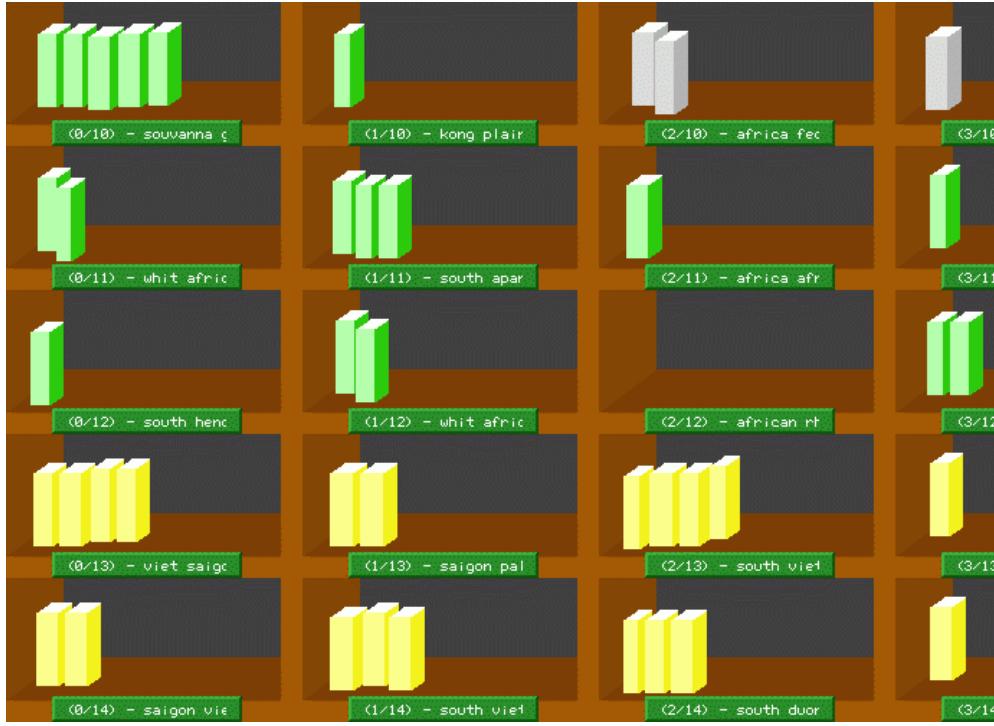


Figure 8.7: The SOMLib system with the libViewer interface. Documents are assigned to sections of a bookshelf (or post boxes) according to their content. [Image used with kind permission of Andreas Rauber.]

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].

8.4.2 WEBSOM

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

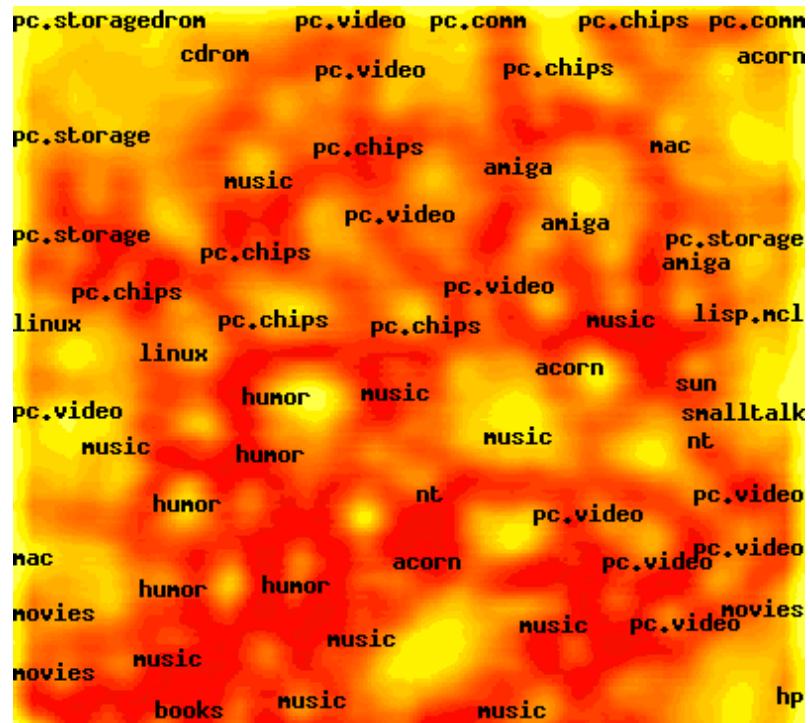


Figure 8.8: WEBSOM.

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

Chapter 9

Other Kinds of Visualisation

9.1 Visualising Query Spaces

9.1.1 InfoCrystal

- Anselm Spoerri, MIT, 1993.
- Builds upon the idea of a Venn diagram to indicate which sets of items match each permutation of a boolean query, as shown in Figure 9.1.
- n boolean query terms are placed at the corners of an n -sided regular polygon.
- Icons representing items matching each permutation of a boolean query are positioned within the polygon.
- Figure 9.2 shows an InfoCrystal with four query terms.
- Papers at Vis'93 [Spoerri 1993a], CIKM'93 [Spoerri 1993b], and VL'93 [Spoerri 1993c], as well as PhD thesis [Spoerri 1995].

9.1.2 MetaCrystal

- Application of InfoCrystal idea to search results from multiple search engines [Spoerri 2004a; Spoerri 2004b].
- See Figure 9.3.

9.1.3 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].

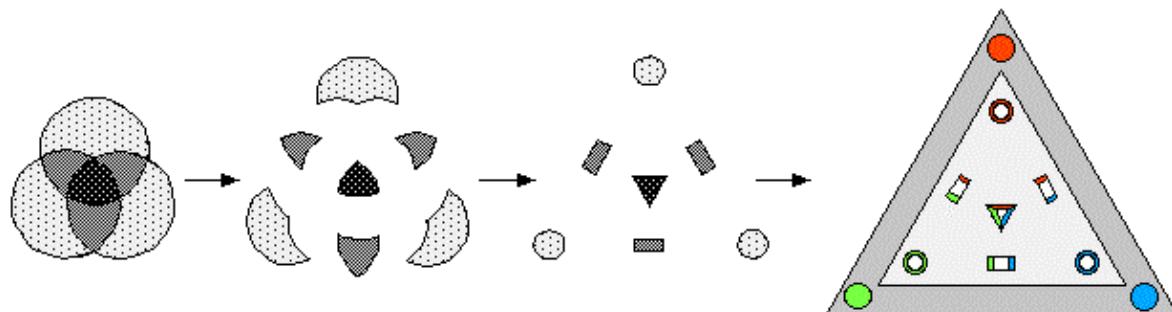


Figure 9.1: InfoCrystal builds upon the idea of a Venn diagram to indicate which sets of items match each permutation of a boolean query. [Image used with kind permission of Anselm Spoerri.]

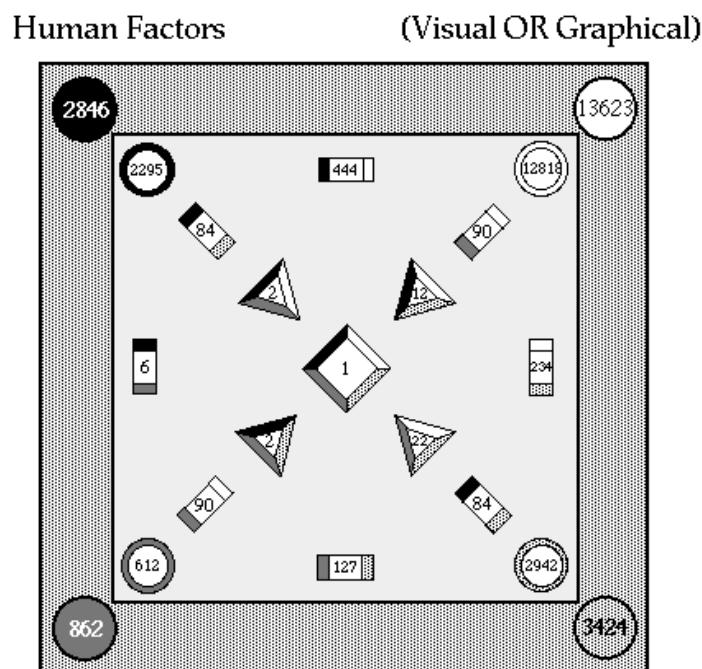


Figure 9.2: InfoCrystal with four query terms. The numbers indicate how many document match the corresponding boolean query. [Image used with kind permission of Anselm Spoerri.]

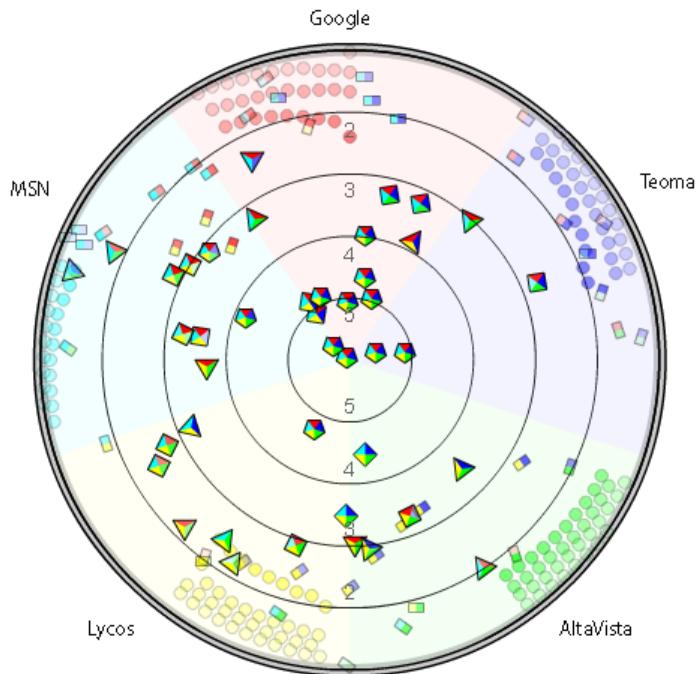


Figure 9.3: MetaCrystal combines the results from multiple search engines in response to the same query. [Image used with kind permission of Anselm Spoerri.]

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 9.4.
- Paper at CHI'95 [Hearst 1995], video at CHI'96 [Hearst and Pedersen 1996].

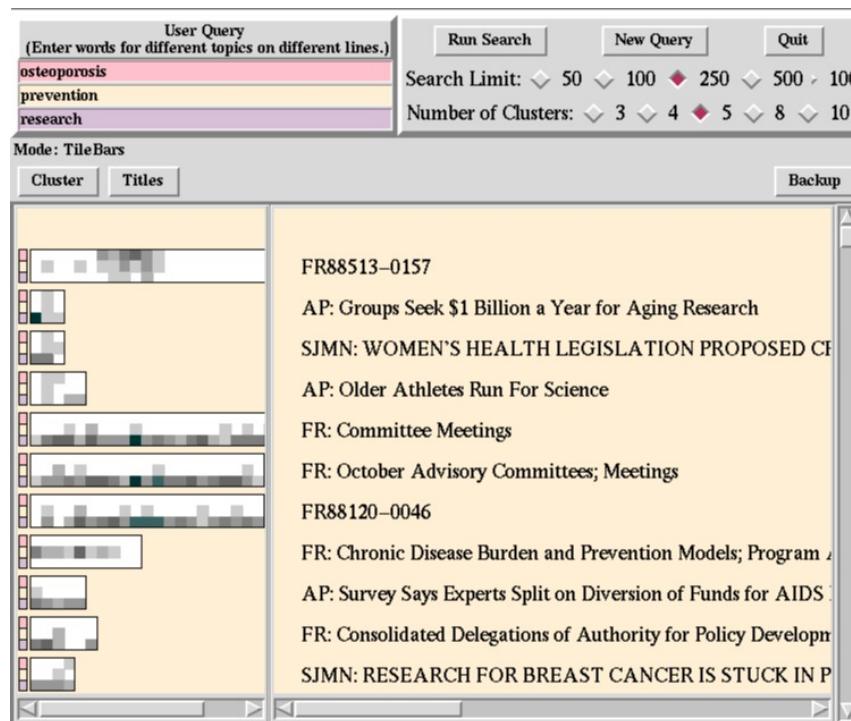


Figure 9.4: TileBars visualisation of the distribution of three search terms “osteoporosis”, “prevention”, and “research” within matching documents. The top-ranked document has some discussion of all three terms in the middle of the document. The fifth, sixth, and seventh matching documents all discuss research but have no mention of osteoporosis. [Image used with kind permission of Marti Hearst.]

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