Visualization Techniques
Multidimensional Visualization

Data Models

- Foundational topics for Multidimensional, graph and tree etc..
- Data types
- Data representations
- Data models
- Tables

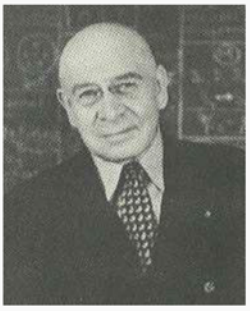
Data

- An abstraction of a real phenomenon
- Models objects we are interesting
- Data Visualization
  - Visualization is only as good as the data
  - Visualizations can misleading
  - Good data is important!
- Map–territory relation

Map–territory relation

- Map–territory relation
  - describes the relationship between an object and a representation of that object.
- "The map is not the territory "
  - an abstraction derived from something, or a reaction to it, is not the thing itself.

Alfred Korzybski

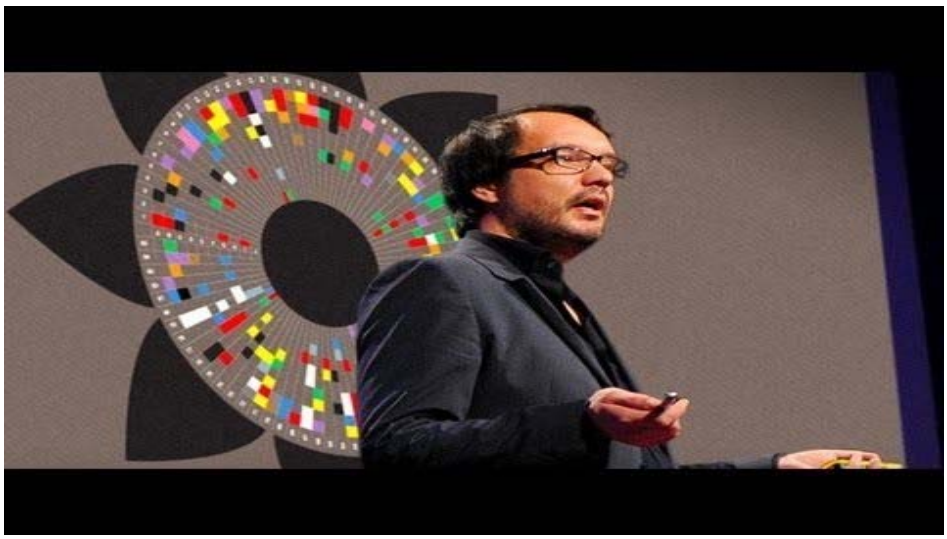


Born	July 3, 1879 Warsaw, Vistula Country, Russian Empire
Died	March 1, 1950 (aged 70) Lakeville, Connecticut, USA
Occupation	Engineer, philosopher, mathematician

http://en.wikipedia.org/wiki/Alfred_Korzybski

Hans Rosling

The beauty of data visualization
David McCandless (TED 2010)



Digitized Data

- 5 - 10% structured data
- 90-95% unstructured
  - Images
  - Video
  - Sound
  - Log files
  - Text
  - Web pages

Data Models

- Three types of entities for structured data generation
  - Objects
    - Actual items of interest
    - Different types possible
    - Example: people in a social network
  - Attributes
    - Characteristics of objects
    - Example: age, gender, email, IM, blog, etc..
  - Relations
    - Connections between objects
    - Examples: friends, chats, blog replies.

Relational Data Model

- Records in a data table
- Structured from amenable to analysis and visualization
- Fixed-length tuples (attributes)
- Each column (attribute) has a domain (type)

Data Dimensions

- Common dimensions: 1, 2, 3, (4?)
- 1D – univariate
  - Mass, distance, temperature, potential, energy
- 2D – bivariate
  - Positions on a map
- 3 dimensions – trivariate
  - Positions in space, velocity, acceleration, color in RGB
- More than 3 dimensions
  - Multivariate
  - Hypervariate

US Census Data

- People: # of people in group
- Year: 1850 – 2000 (every decade)
- Age: 0 – 90+
- Sex: Male, Female
- Marital Status: Single, Married, Divorced, …

- http://factfinder.census.gov/

- Data is there, what's next?

Total New Passenger Car Sales (in thousands)

	Total	Domestic	Imports	Japan	Germany	Other
1970	8,400	7,119	1,280	313	750	217
1975	8,624	7,053	1,572	808	493	271
1980	8,949	6,580	2,369	1,894	292	184
1985	10,979	8,205	2,775	2,171	408	196
1990	9,303	6,919	2,384	1,719	263	402
1991	8,189	6,162	2,028	1,505	193	330
1992	8,213	6,286	1,927	1,452	201	275
1993	8,518	6,742	1,776	1,328	186	262
1994	8,991	7,255	1,735	1,239	192	303
1995	8,635	7,129	1,506	982	207	317
1996	8,526	7,255	1,271	726	237	308
1997	8,272	6,917	1,355	726	297	332
1998	8,142	6,762	1,380	691	367	322
1999	8,698	6,979	1,719	758	467	494
2000	8,847	6,831	2,016	863	517	637
2001	8,423	6,325	2,098	837	523	738
2002	8,103	5,878	2,226	930	547	749
2003	7,610	5,527	2,083	830	544	709
2004	7,545	5,396	2,149	810	542	797
2005	7,720	5,533	2,187	923	534	729
2006	7,821	5,476	2,345	1,154	561	630
2007	7,618	5,253	2,365	1,183	567	615
2008	6,813	4,535	2,278	1,142	507	630

http://www.bts.gov/

Can you get some conclusions from the table?

Yes. Table is a great way for data visualization.

Relational Data Model

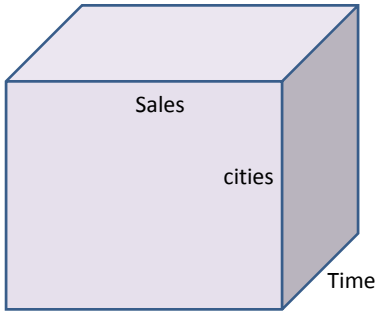
- Relational data model manipulation:
  Standard Query Language
  - Selection (SELECT)
  - Projection (WHERE)
  - Sorting (ORDER BY)
  - Aggregation (GROUP BY, SUM, MIN, …)
  - Set operations (UNION, …)
  - Join (INNER JOIN)

OLAP

- OLAP -- Online analytical processing
  - Swiftly answer multi-dimensional analytical queries.
  - Borrow aspects of navigational databases and hierarchical databases that are faster than relational databases.
- Key concept: OLAP Cube

OLAP Cube

- An OLAP cube is a data structure that allows fast analysis of data
- The cube metadata (structure) may be created from tables in a relational database.

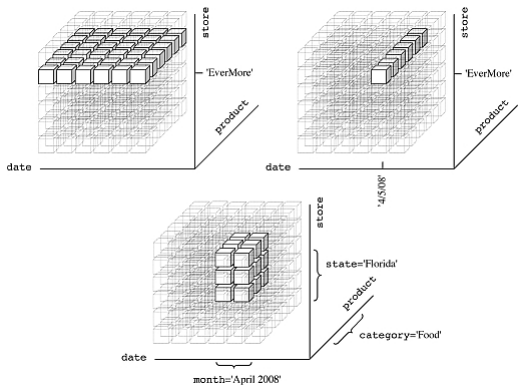


OLAP Query Languages

- MDX -- Multidimensional Expressions
  - a query language for OLAP databases
  - Same role as SQL for relational databases.
  - a calculation language, with syntax similar to spreadsheet formulas.
- XMLA -- XML for Analysis (Microsoft 2001)
  - based on other industry standards such as XML, SOAP and HTTP
  - MDX statements can be enclosed in XMLA

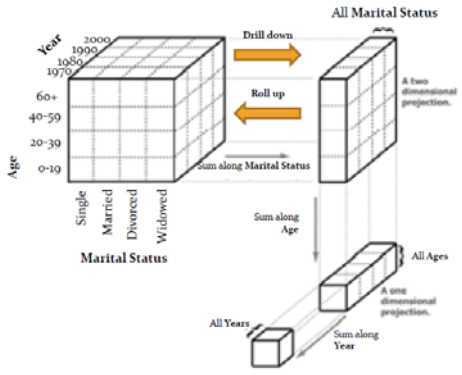
OLAP Cube

- Sales data



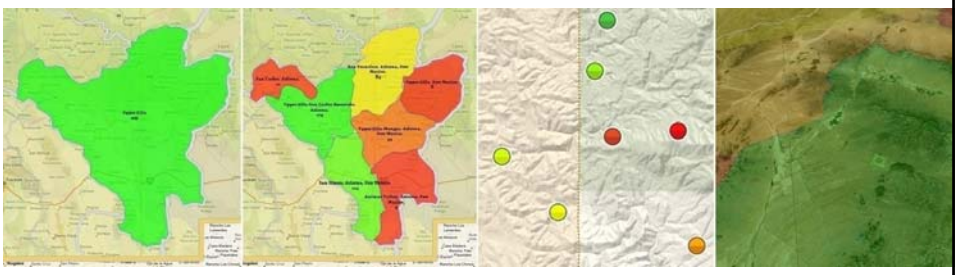
OLAP Cube

- OLAP cube for US census data



OLAP

- SOLAP – Spatial Online Analytical Processing
  - incorporates OLAP technology with mapping capabilities
- SOLAP with Virtual Earth (Polygons, Points on 2D and 3D maps)



Tables vs Graphs

- Table -- Simple way to “visualize” data
- When to use tables?
  - look up individual values
  - Need precise data
- When to use graphs?
  - Need to know shapes and trends of values
  - Find relationships

- *“For small data sets, usually a simple table shows the data more effectively than a graph, let alone a chartjunk graph.” – E. R. Tufte, 2003*

Multidimensional Visualization

- How to effectively present more than 3 dimensions of information in a visual display with 2 (to 3) dimensions?
- How to effectively visualize "inherently abstract" data?
- How to effectively visualize very large, often complex data sets?
- How to effectively display results – when you don't know what those results will be?

From James Reffell

Multidimensional Visualization

Goals of multidimensional visualization:

- Without loss of information
- With:
  - Minimal complexity
  - Any number of dimensions
  - Variables treated uniformly
  - Objects remain recognizable across transformations
  - Easy / intuitive conveyance of information
  - Mathematically / algorithmically rigorous

(Adapted from Inselberg)

Multidimensional Visualization

Purposes and applications

- Find clusters of similar data
- Find "hot spots" (exceptional items in otherwise homogeneous regions)
- Show relationships between multiple variables
- Similarity retrieval rather than boolean matching, show near misses

"Searching for patterns in the big picture and fluidly investigating interesting details without losing framing context" (Rao & Card)

Multidimensional Visualization

Visualization methods

- Geometric techniques
  - Scatter plot matrices, parallel coordinates, landscapes, Dust & Magnet …
- Icon-based techniques
  - glyphs, shape-coding, color icons, …
- Hierarchical techniques
  - Dimensional stacking, worlds-within-worlds, …

Multidimensional Visualization

Visualization methods

- Pixel-oriented techniques
  - Recursive pattern, circle segments, spiral, axes techniques,…
- Table-based techniques
  - HeatMap, tableLens

Multidimensional Visualization

- Complex problems → more dimensions
- Closer to real world situations → more dimensions

- Example: purchase a car
  - Price, model, company, new/used, finance, dealer
  - Use visualization to help decision making?

Parallel Coordinates

Case: Iris

- Iris is a genus of 260 species of flowering plants with showy flowers.

- Scientists measured sepal length, sepal width petal length, petal width of many Iris species.

	Classes	sepal-length	sepal-width	petal-length	petal-width
1	Iris-virginica	6.7	3	5.2	2.3
2	Iris-virginica	6	2.2	5	1.5
3	Iris-virginica	6.2	2.8	4.8	1.8
4	Iris-virginica	7.7	3.8	6.7	2.2
5	Iris-virginica	7.2	3	5.8	1.6
6	Iris-versicolor	5.5	2.4	3.8	1.1
7	Iris-versicolor	6	2.7	5.1	1.6
8	Iris-versicolor	5.5	2.5	4	1.3
9	Iris-versicolor	5.6	2.9	3.6	1.3
10	Iris-versicolor	5.7	2.9	4.2	1.3
11	Iris-setosa	5	3.2	1.2	0.2
12	Iris-setosa	4.9	3.1	1.5	0.1
13	Iris-setosa	5.3	3.7	1.5	0.2
14	Iris-setosa	4.8	3.1	1.6	0.2
...	...	...	...	...	...

Data source: ManyEyes

Question: How to visualize it?

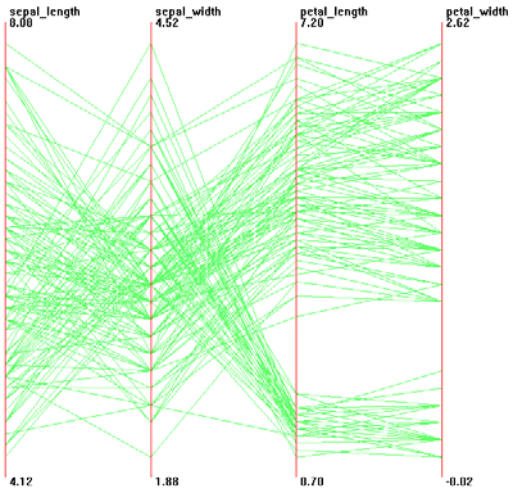
Parallel Coordinates

- Parallel coordinates were invented by Maurice d'Ocagne in 1885 and were independently re-discovered and popularized by Al Inselberg in 1959 and systematically developed as a coordinate system starting from 1977.

http://en.wikipedia.org/wiki/Parallel_coordinates

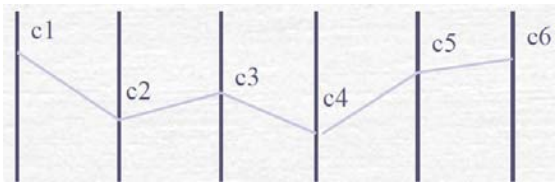
Parallel Coordinates

	Classes	sepal-length	sepal-width	petal-length	petal-width
1	Iris-virginica	6.7	3	5.2	2.3
2	Iris-virginica	6	2.2	5	1.5
3	Iris-virginica	6.2	2.8	4.8	1.8
4	Iris-virginica	7.7	3.8	6.7	2.2
5	Iris-virginica	7.2	3	5.8	1.6
6	Iris-versicolor	5.5	2.4	3.8	1.1
7	Iris-versicolor	6	2.7	5.1	1.6
8	Iris-versicolor	5.5	2.5	4	1.3
9	Iris-versicolor	5.6	2.9	3.6	1.3
10	Iris-versicolor	5.7	2.9	4.2	1.3
11	Iris-setosa	5	3.2	1.2	0.2
12	Iris-setosa	4.9	3.1	1.5	0.1
13	Iris-setosa	5.3	3.7	1.5	0.2
14	Iris-setosa	4.8	3.1	1.6	0.2
...	...	...	...	...	...

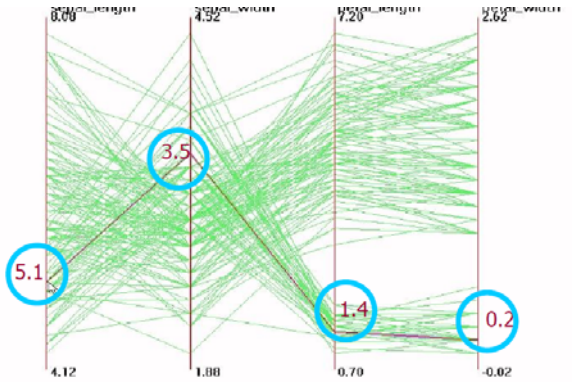


Parallel Coordinates

- To represent N dimensional data
- Set N vertical axes in parallel
- Put data to intersects on corresponding axes
- Connect intersects
- Example: (c1, c2, c3, c4, c5, c6)



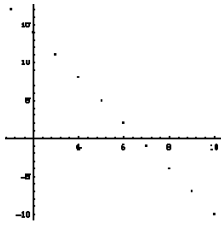
Parallel Coordinates



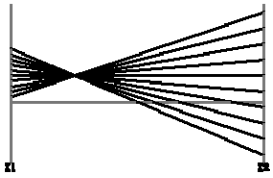
Parallel Coordinates

(Inselberg)

Like a normal graph, but different views



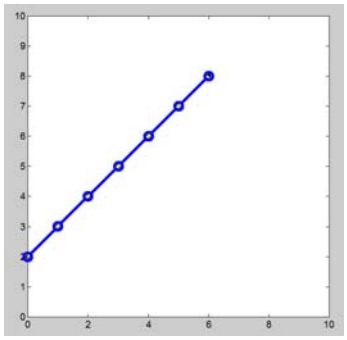
Dataset in a Cartesian graph



Same dataset in parallel coordinates

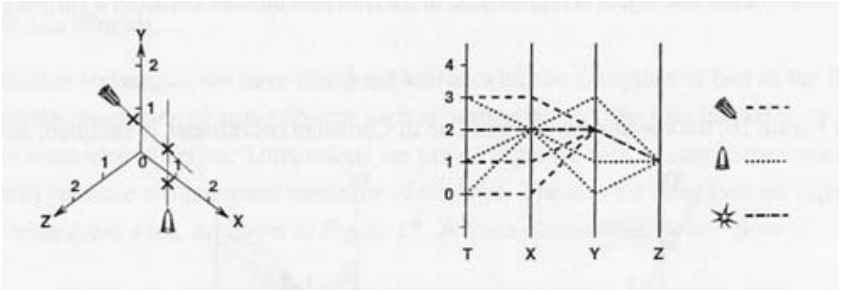
Parallel Coordinates

Question: sketch the following graph in parallel coordinates?



Parallel Coordinates

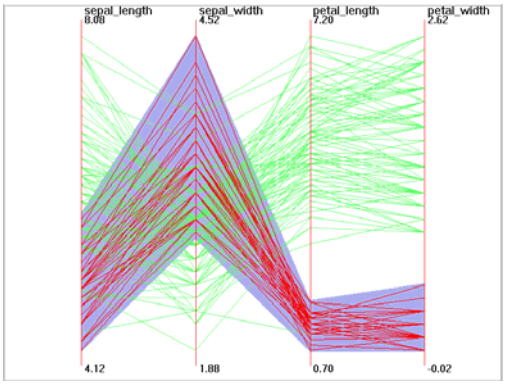
- Applications: View aircraft collisions



Pak Wong, 1997

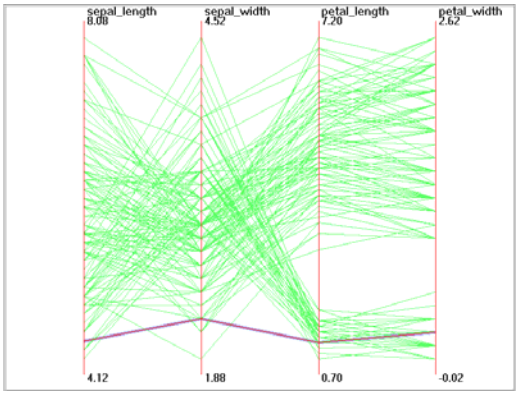
Parallel Coordinates

- Cluster: A group of data items that are similar in all dimensions.



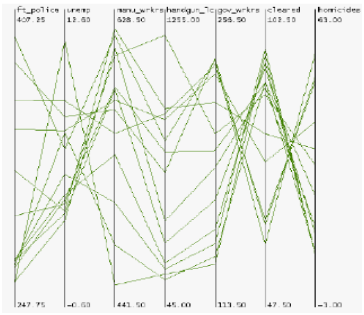
Parallel Coordinates

- Outlier: A data item that is similar to few or no other data items.

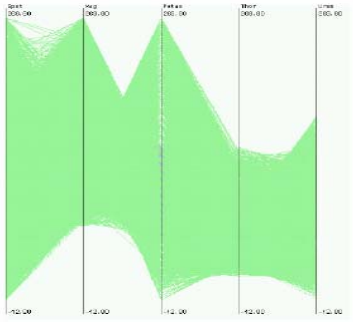


Parallel Coordinates

Good visualization

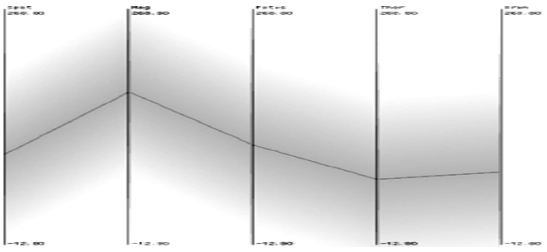


Bad visualization



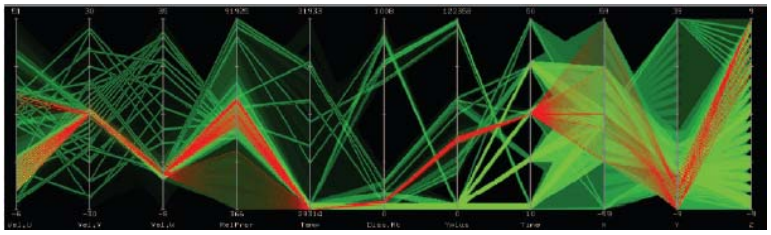
Parallel Coordinates

- Simple statistical view



Average

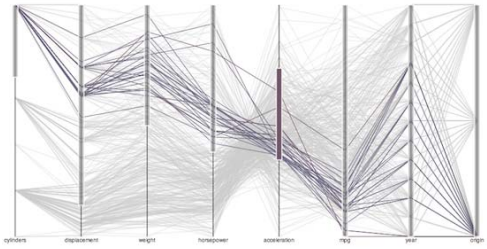
Parallel Coordinates



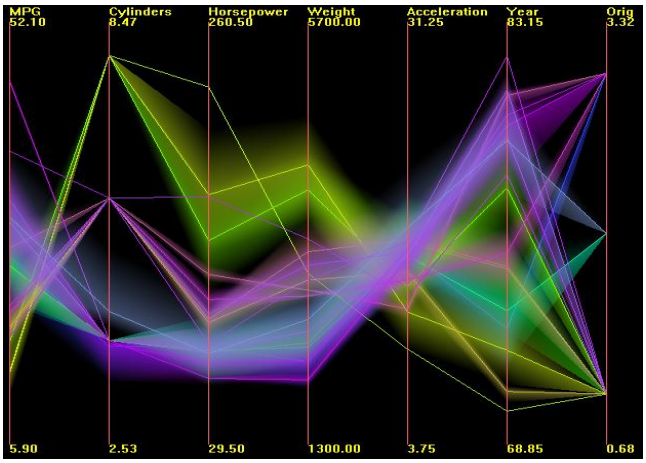
InfoVis 2006 “Outlier-preserving Focus+Context Visualization in Parallel Coordinates”
by Matej Noveotny, Helwig Hauser

Parallel Coordinates

- Protovis Example: Select cars

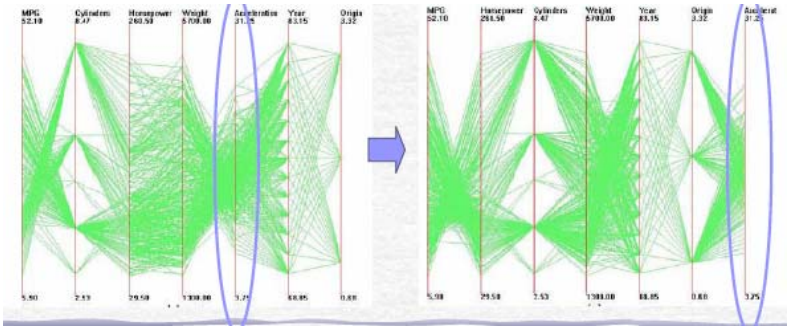


http://vis.stanford.edu/protovis/ex/cars.html

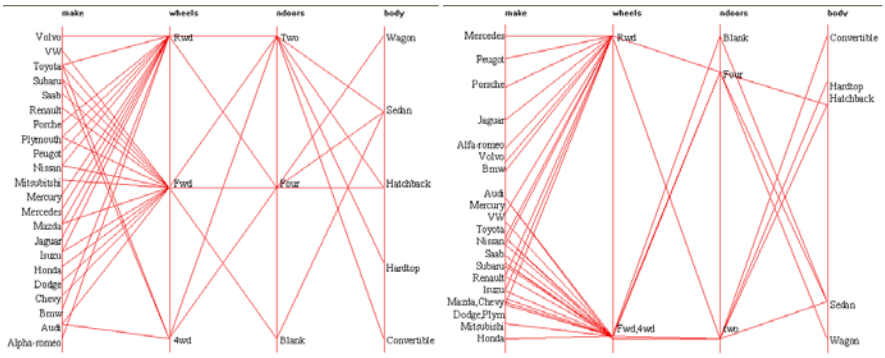


Parallel Coordinates

- Coordinate reordering



Parallel Coordinates



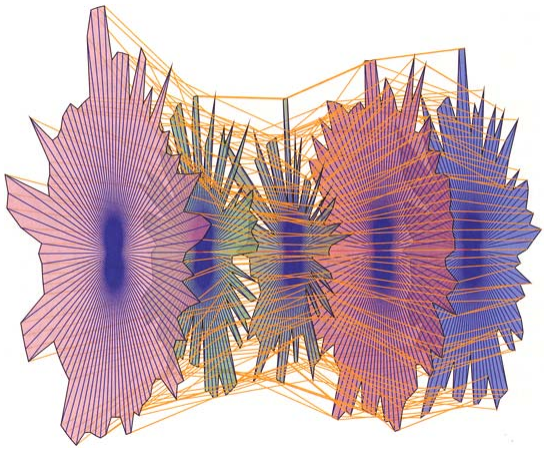
Original Assignment

Assignment after Correspondence Analysis

M. Wade

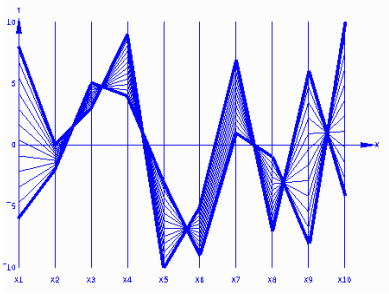
Parallel Coordinates

- 3D?



Parallel Coordinates

- Useful for recognizing patterns between the axes
  - Example: adding or removing parts of the data to see general patterns or more closely examine particular interactions.
- Articles offer suggestions on how to most effectively use this system.



Parallel Coordinates

Advantages, Strengths:

- Works for any dimensional
- Clearly displays data characteristics of the data
  - No explanation needed
- Easy to adjust or focus displays/ queries
- Can be used in decision support
  - Adjusting one parameter effects others

Disadvantages, Weaknesses

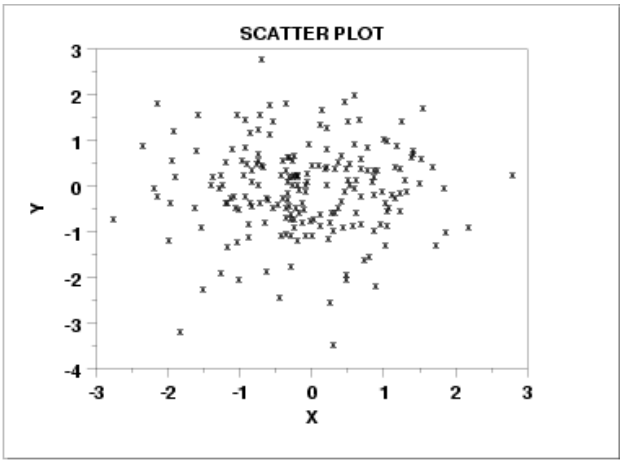
- Formation of complex queries can be tricky
- Results can be hard to interpret

Scatter Plot Matrix

Scatter Plot

- Scatter Plot

Plot (X,Y)

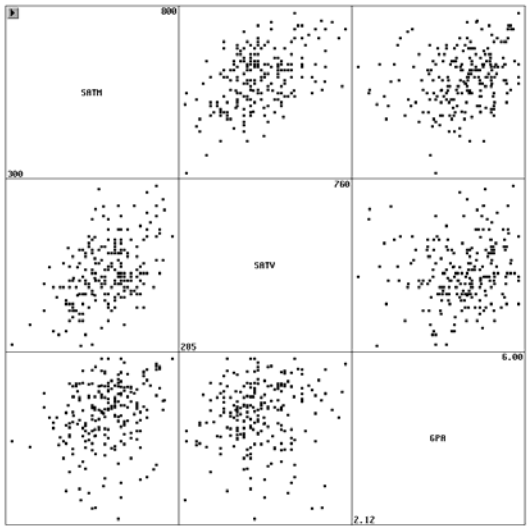


Scatter Plot Matrix

224	7	Int GPA	Int HSM	Int HSS	Int HSE	Int SATM	Int SATV	Nom SEX
■	20	4.57	9	10	10	417	518	Male
■	21	5.80	10	9	8	560	530	Male
■	22	4.88	9	7	6	690	460	Female
■	23	4.28	8	10	10	600	600	Male
■	24	5.06	8	6	5	540	400	Female
■	25	5.21	8	8	7	600	400	Female
■	26	3.60	4	7	7	460	460	Male
■	27	5.47	10	10	9	720	680	Male
■	28	4.00	3	7	6	460	530	Female
■	29	5.18	9	10	8	670	450	Female
■	30	4.77	6	5	9	590	440	Female
■	31	4.38	9	9	10	650	570	Male

Scatter Plot Matrix

224	7	Int GPA	Int HSM	Int HSS	Int HSE	Int SATM	Int SATV	Nom SEX
■	20	4.57	9	10	10	417	518	Male
■	21	5.80	10	9	8	560	530	Male
■	22	4.88	9	7	6	690	460	Female
■	23	4.28	8	10	10	600	600	Male
■	24	5.06	8	6	5	540	400	Female
■	25	5.21	8	8	7	600	400	Female
■	26	3.60	4	7	7	460	460	Male
■	27	5.47	10	10	9	720	680	Male
■	28	4.00	3	7	6	460	530	Female
■	29	5.18	9	10	8	670	450	Female
■	30	4.77	6	5	9	590	440	Female
■	31	4.38	9	9	10	650	570	Male

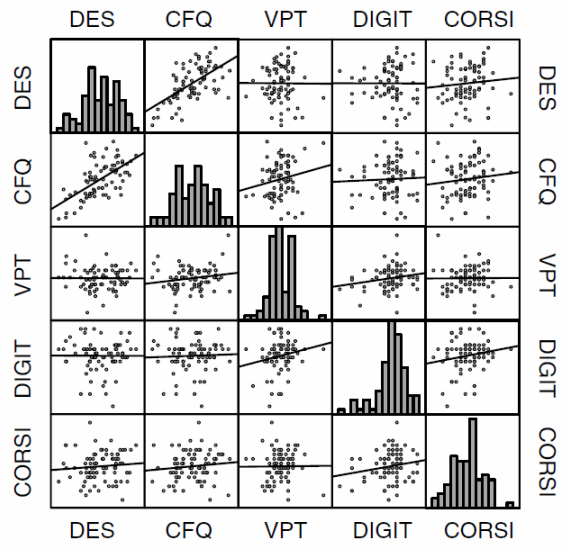


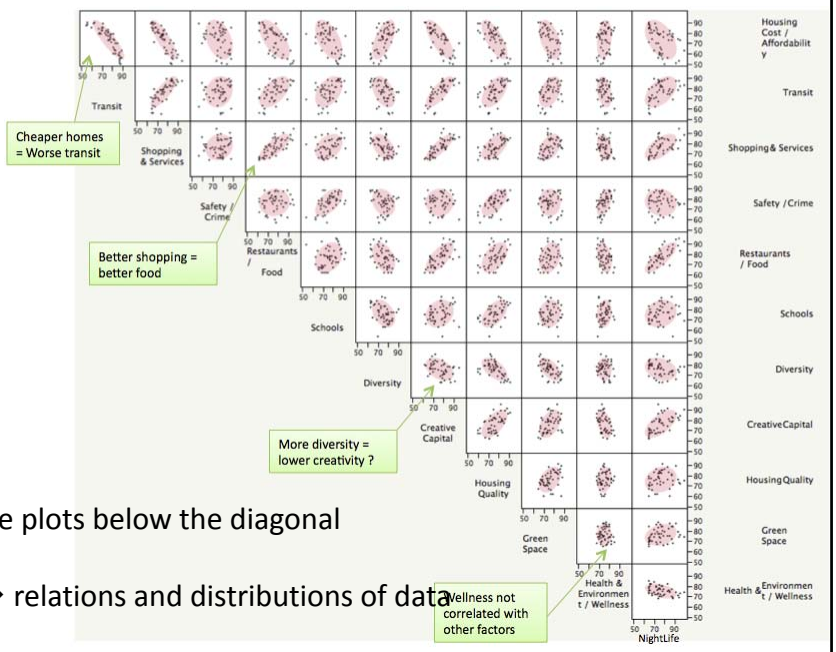
Scatter Plot Matrix

- Given a set of variables $X_1, X_2, \ldots, X_k$, the scatter plot matrix contains all the pairwise scatter plots of the variables on a single page in a matrix format. That is, if there are k variables, the scatter plot matrix will have k rows and k columns and the i^{th} row and j^{th} column of this matrix is a plot of X_i versus X_j.

- **Purpose**: Check pairwise relationships between variables

Scatter Plot Matrix





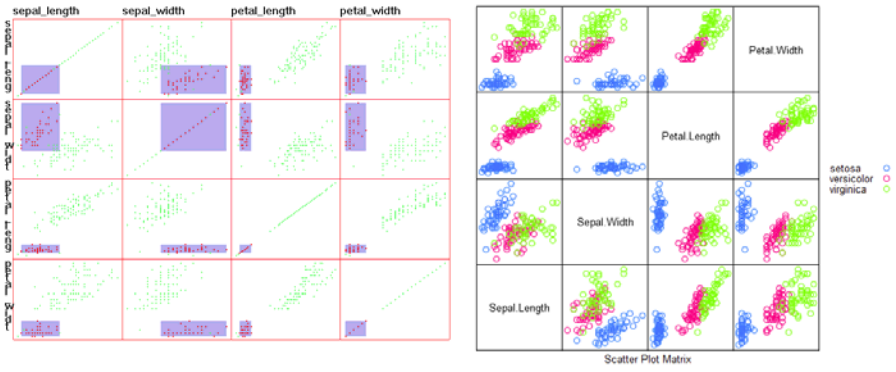
Omit the plots below the diagonal

Color → relations and distributions of data

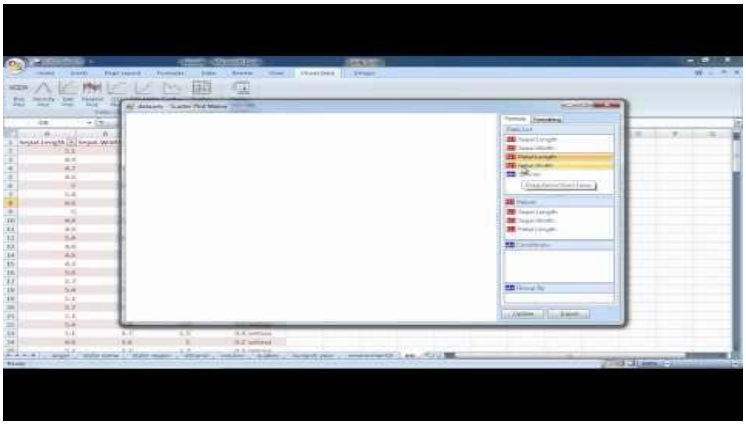
http://junkcharts.typepad.com/junk_charts/2010/06/the-scatterplot-matrix-a-great-tool.html

Scatter Plot Matrix

- Iris Example:

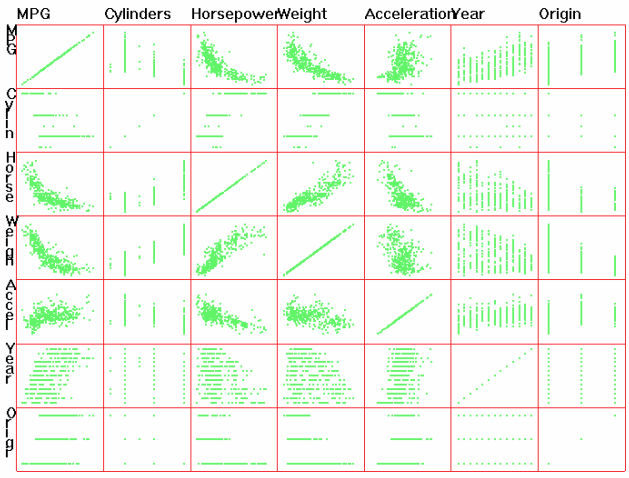


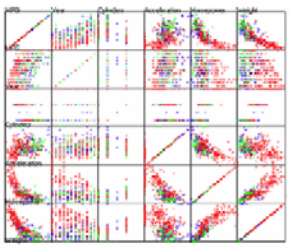
- Implementation in Excel



Scatter Plot Matrix

- Car Example





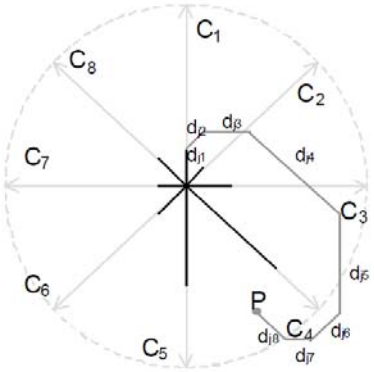
Star Coordinates

Star Coordinates

- The basic idea is to arrange the coordinate axes on a circle on a two-dimensional plane with equal (initially) angles between the axes with an origin at the center of the circle.

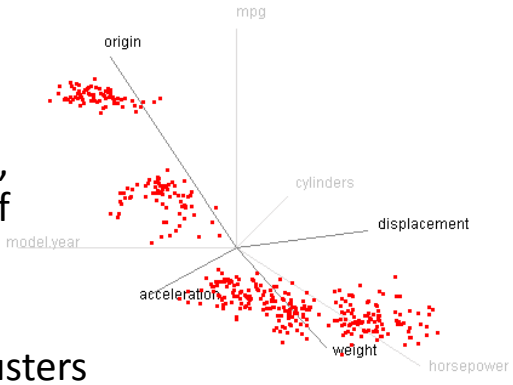
Eser Kandogan, IBM

- 8 dimensional data (C1-C8)
- P=(d1,d2,…,d8)
- P location calculation: extension of typical 2d and 3d scatter-plots to higher dimensions with normalizatior
- Formula: Read Kandogan's paper "Star Coordinates: A Multi-dimensional Visualization Techniqu with Uniform Treatment of Dimensions"



Purpose: Gaining insight into hierarchically clustered datasets.

- Case: 400 cars
- Operations: scaling, rotating, turning off some coordinates
- Results: 4 major clusters



Dimensional Stacking

Dimensional Stacking

- Discretizing and recursively embedding of dimensions
- Each resulting N-dimensional record occupying a unique position on the screen

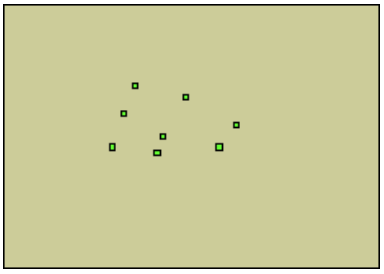
Dimensional Stacking

- Iris case:

	Classes	sepal-length	sepal-width	petal-length	petal-width
1	Iris-virginica	6.7	3	5.2	2.3
2	Iris-virginica	6	2.2	5	1.5
3	Iris-virginica	6.2	2.8	4.8	1.8
4	Iris-virginica	7.7	3.8	6.7	2.2
5	Iris-virginica	7.2	3	5.8	1.6
6	Iris-versicolor	5.5	2.4	3.8	1.1
7	Iris-versicolor	6	2.7	5.1	1.6
8	Iris-versicolor	5.5	2.5	4	1.3
9	Iris-versicolor	5.6	2.9	3.6	1.3
10	Iris-versicolor	5.7	2.9	4.2	1.3
...	...	...	...	...	...

Dimensional Stacking

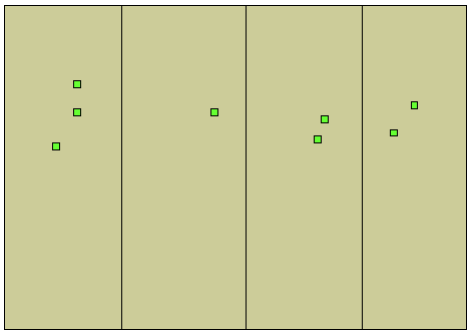
- Imagine each data item (4 attributes) as a small block.
- Place all blocks on a table.



http://coitweb.uncc.edu/~jyang13/6010/class1_intro_multi.pdf

Dimensional Stacking

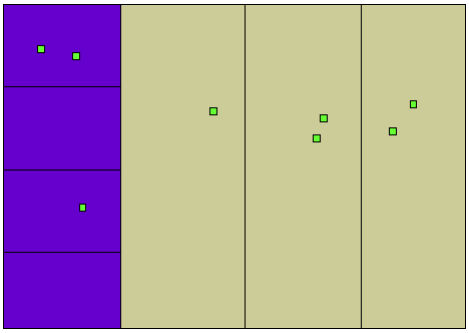
- Add grids on the table.
- Place the blocks in the grids according to their values of attribute1.



http://coitweb.uncc.edu/~jyang13/6010/class1_intro_multi.pdf

Dimensional Stacking

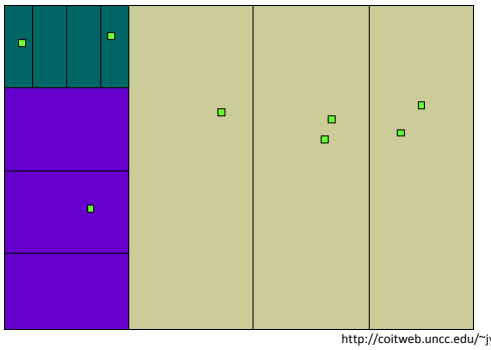
- Add grids in grids.
- Place the blocks in the grids according to their values of attribute2.



http://coitweb.uncc.edu/~jyang13/6010/class1_intro_multi.pdf

Dimensional Stacking

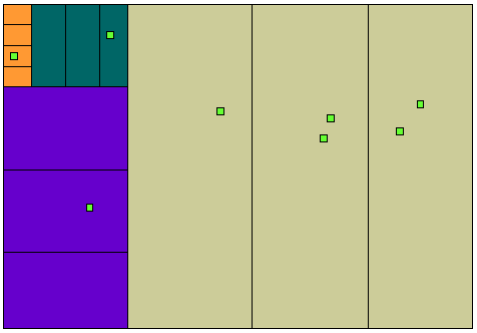
- Add grids in grids.
- Place the blocks in the grids according to their values of attribute3.



http://coitweb.uncc.edu/~jyang13/6010/class1_intro_multi.pdf

Dimensional Stacking

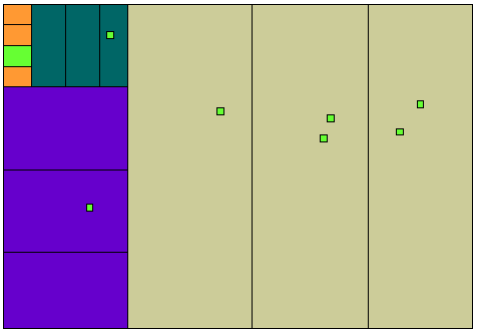
- Add grids in grids.
- Place the blocks in the grids according to their values of attribute4.



http://coitweb.uncc.edu/~jyang13/6010/class1_intro_multi.pdf

Dimensional Stacking

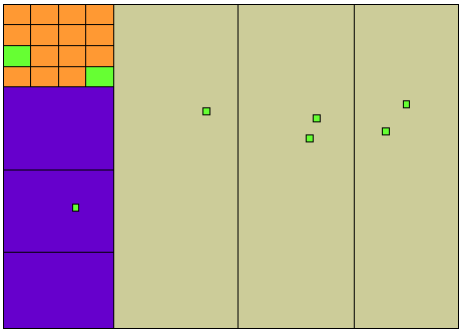
- Fix one block!
- Assign a color to it.



http://coitweb.uncc.edu/~jyang13/6010/class1_intro_multi.pdf

Dimensional Stacking

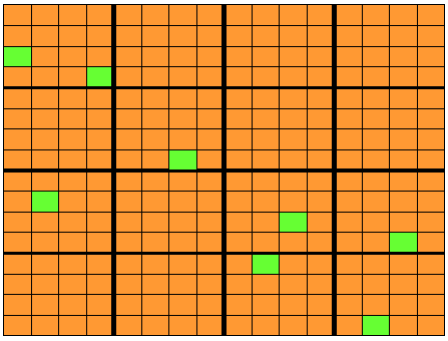
- Fix another block
- Assign a color to it.



http://coitweb.uncc.edu/~jyang13/6010/class1_intro_multi.pdf

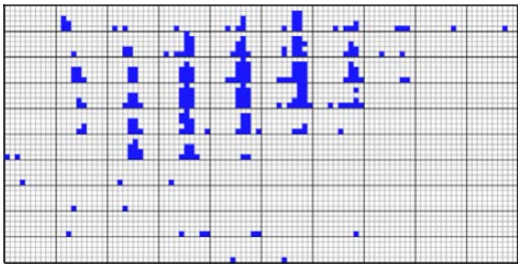
Dimensional Stacking

- Move to next column until done



http://coitweb.uncc.edu/~jyang13/6010/class1_intro_multi.pdf

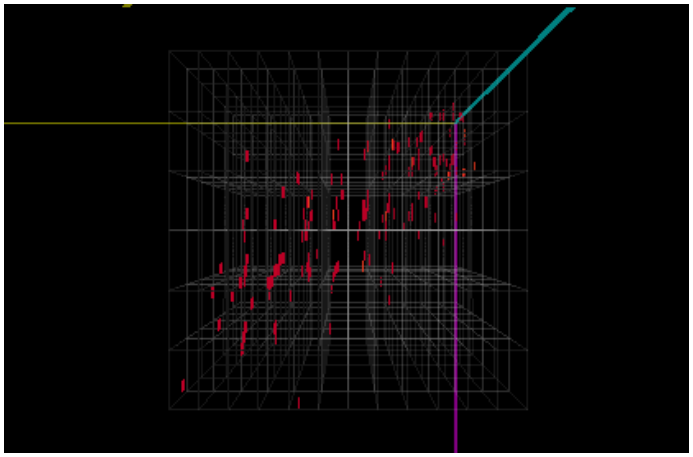
Dimensional Stacking



visualization of oil mining data with longitude and latitude mapped to the outer x-, y- axes and ore grade and depth mapped to the inner x-, y- axes
M. Ward, Worcester Polytechnic Institute

http://coitweb.uncc.edu/~jyang13/6010/class1_intro_multi.pdf

Dimensional Stacking



Dimensional stacking in 3D

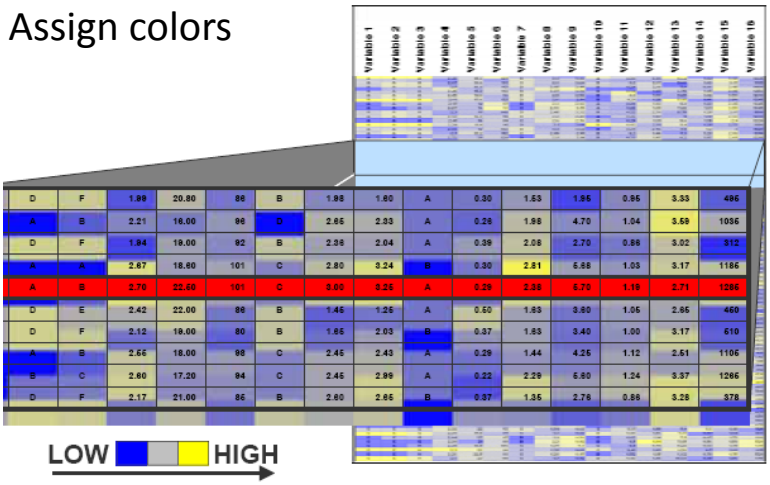
Table Visualization Enhancement

Table Visualization Enhancement

- Visualization that improves the existing table format
  - HeatMap
  - Table Lens

Heat Map

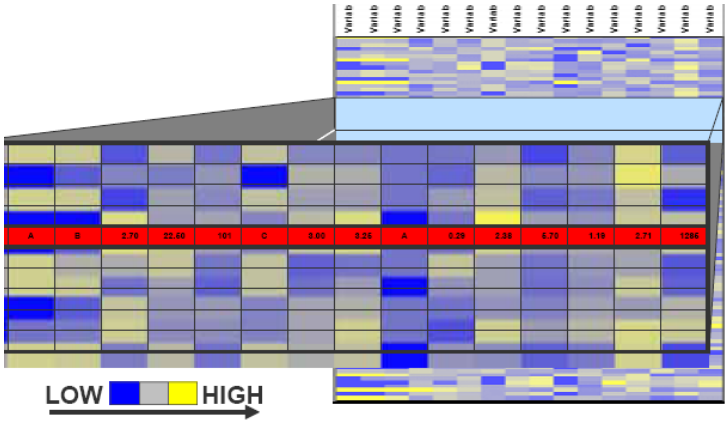
- Assign colors



Mat Ward

Heat Map

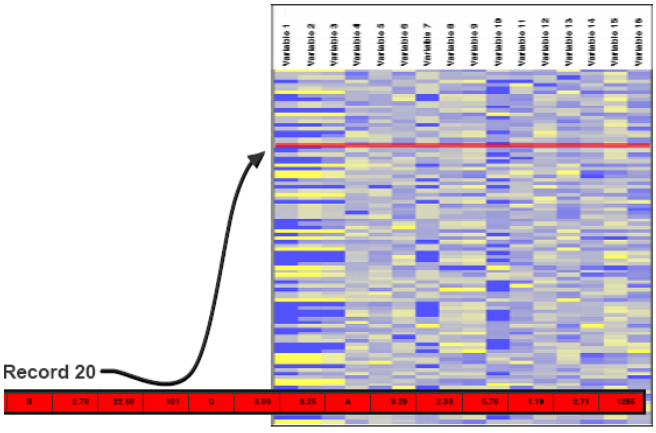
- Remove data



Mat Ward

Heat Map

- Final heatmap



Mat Ward

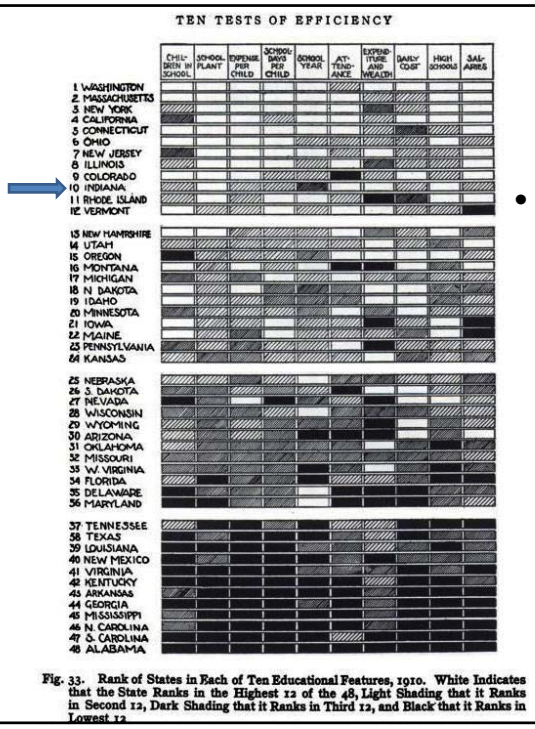


Fig. 33. Rank of States in Each of Ten Educational Features, 1910. White Indicates that the State Ranks in the Highest 12 of the 48, Light Shading that it Ranks in Second 12, Dark Shading that it Ranks in Third 12, and Black that it Ranks in Lowest 12

- Sorted shaded display from Brinton (1914). The data are ranks of US states on each of 10 educational features assessed in 1910. The matrix has been sorted by the row-marginal ranks.

http://www.cs.uic.edu/~wilkinson/Publications/heatmap.pdf

- Typical heatmap

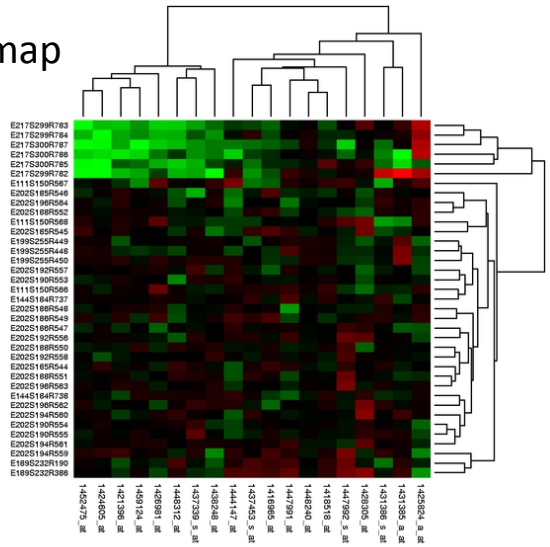


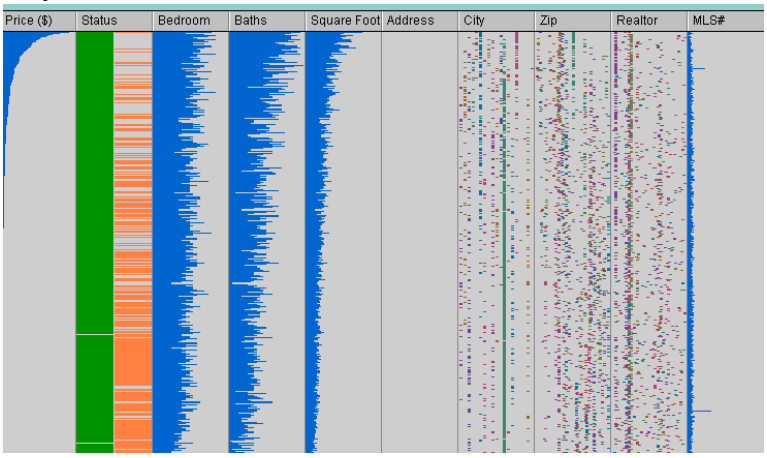
Table Lens

- Rao R., Card S. K.: *'The Table Lens: Merging Graphical and Symbolic Representation in an Interactive Focus+Context* ***Visualization for Tabular Information****', Proc. Human Factors in Computing Systems CHI '94* Conf., Boston, MA, 1994, pp. 318-322.

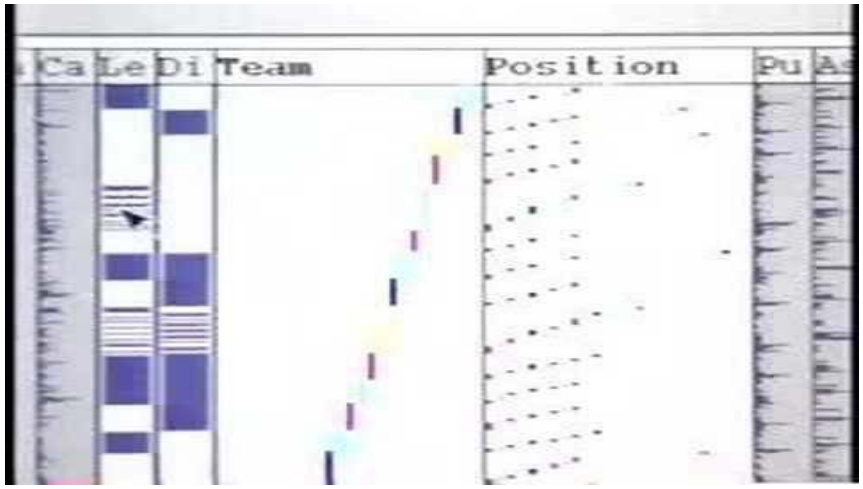
  Demo

Table Lens

- Buy a house



http://www.sapdesignguild.org/community/blinks/ui_blinks_gw_01.asp



Exploring Large Tables with Table Lens -- 1994

- Questions:
- 1) What is the difference between heat map and table lens?
- 2) When is a good time to use table lens?

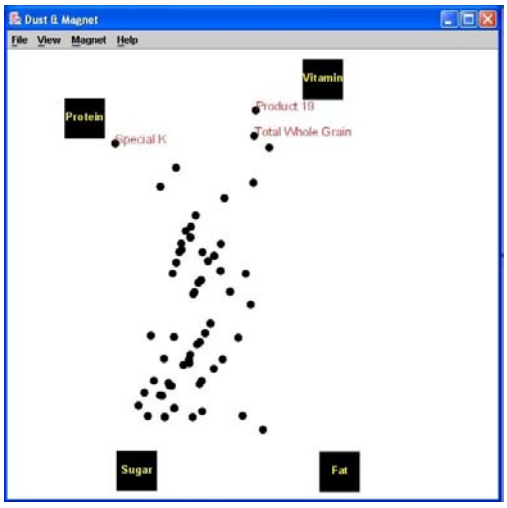
Dust and Magnet

Dust and Magnet

- Uses a magnet metaphor
- Record ←→ Iron dust
- Variable/Attribute ←→Magnet

- When a magnet is dragged, dust particles are attracted to the magnet based on the value of the attribute corresponding to the magnet.

Dust and Magnet



Dust and Magnet

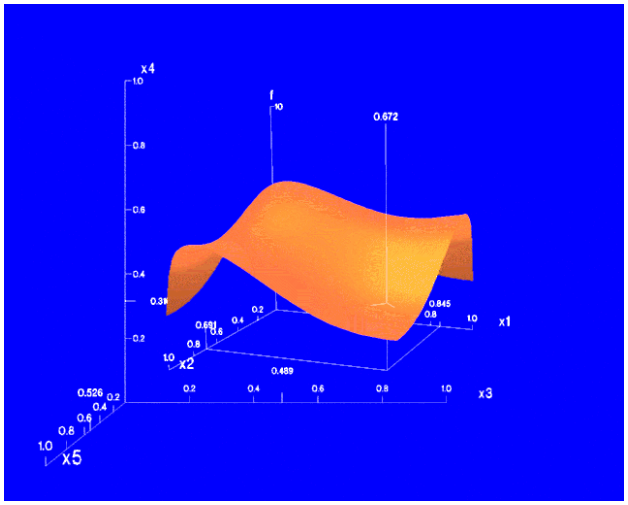
- Especially designed for use by people
  - who struggle with interpreting the complex data of everyday problems
  - who are not experts in information visualization and are not familiar with existing multivariate visualization techniques.

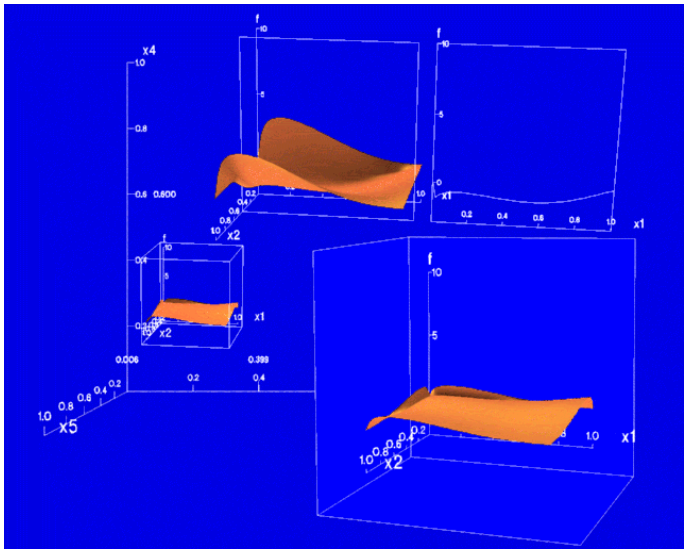
Worlds within Worlds

- Use nested, heterogeneous coordinate systems to map multiple variables onto each of the three spatial dimensions.

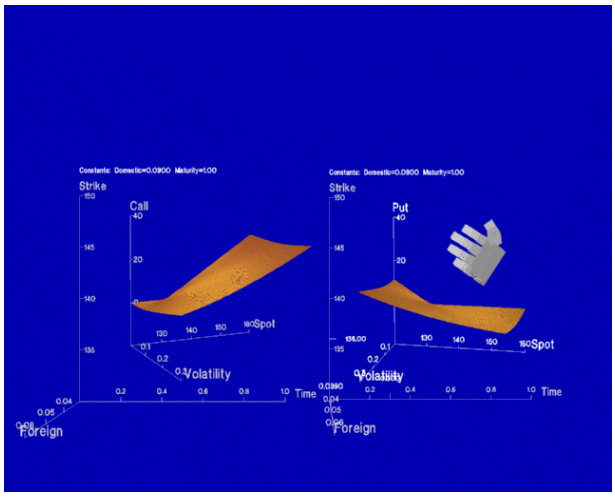
- Example:
- Function: $f(x_1,x_2,x_3,x_4,x_5)$
- Set x_3,x_4,x_5 as constant c_3,c_4,c_5.
- $f(x_1,x_2,c_3,c_4,c_5)$ → surface plot

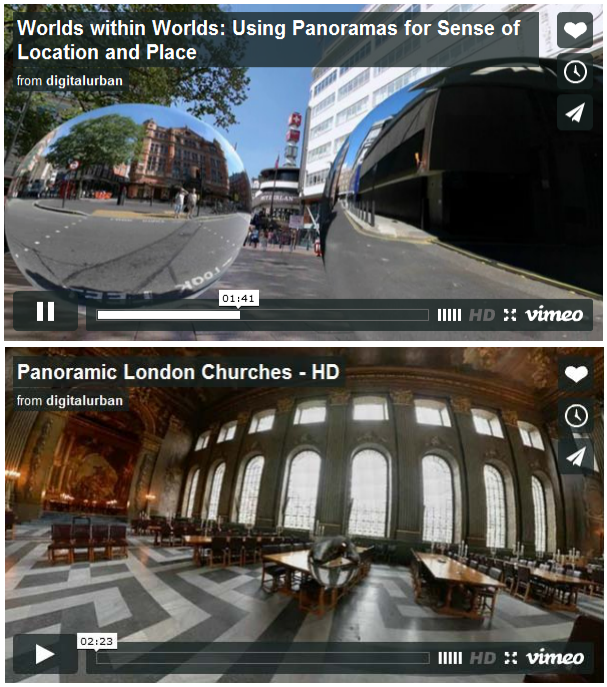
- The height field in the inner world encodes the function for constant values of x_3, x_4, and x_5, determined by the position of the inner world's origin relative to the outer world.





- Financial data visualization: Option

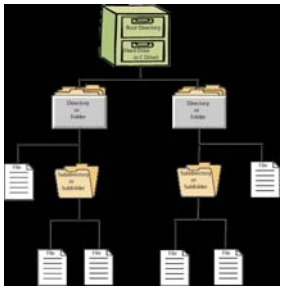


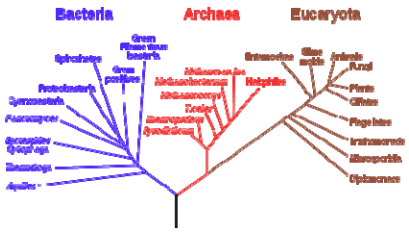


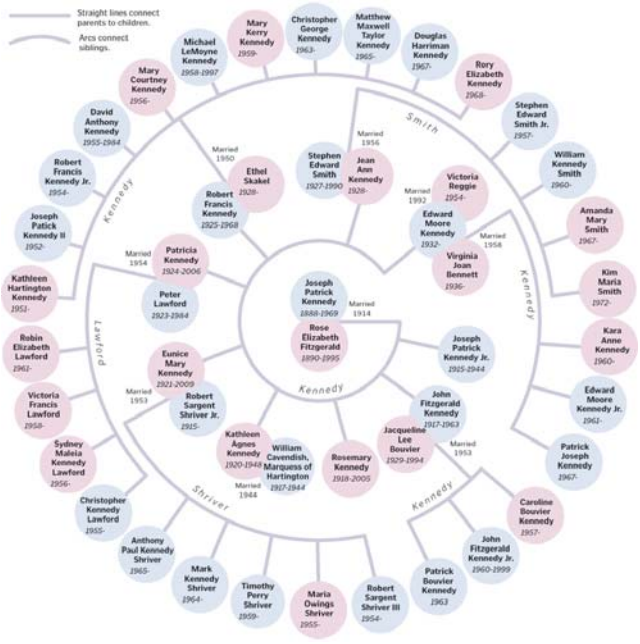
Tree Visualization

Examples:

- File systems
- Organization charts
- OO classes
- Phylogenetic trees
- Family trees
- More??







Kennedy Family

Tree Visualization

Good practice

- Allow adequate space within nodes to display information
- Allow users to understand relationship between a node and its context
- Allow users to find elements quickly
- Fit into a bounded region

Tree Visualization

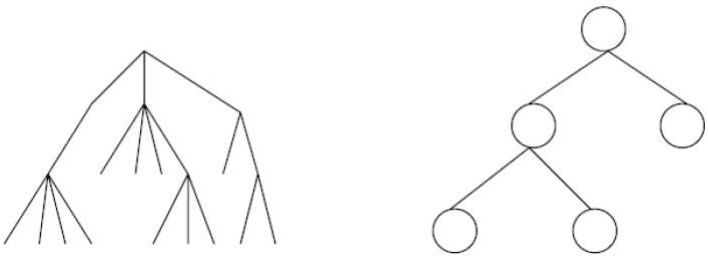
Two main techniques in hierarchical visualization

- Node-link representation (Most Common)
  - Edges – nodes
  - Root – branches – leaves
  - Parents – children
  - Algorithm: Recursive layout algorithm
- Spatial-Filling

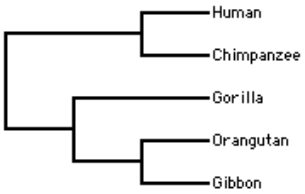
Node-Link

Tree Structure

- Top down trees
  - Most common in node-link diagram
  - Root at the top, leaves at the bottom



- Tree Styles

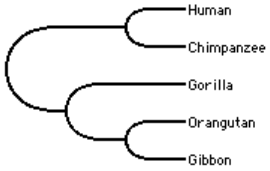


Rectangular: Well suited for displaying labeled/scaled trees.

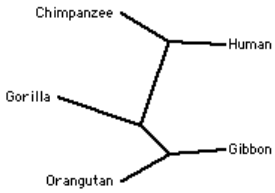
Straight: Works well only on rooted binary trees.

http://www.hyphy.org/docs/GUIExamples/treepanel.html

- Tree Styles



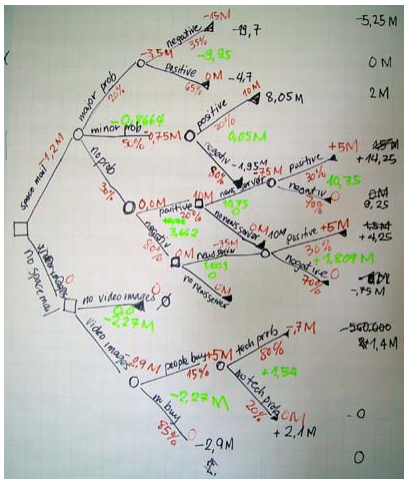
Smooth Edges: Very similar to the rectangular mode.

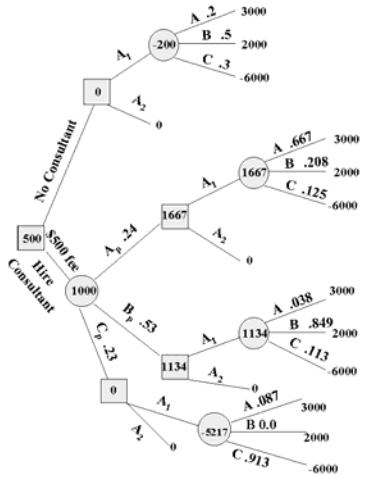


Radial: Works well for visualizing unrooted trees.

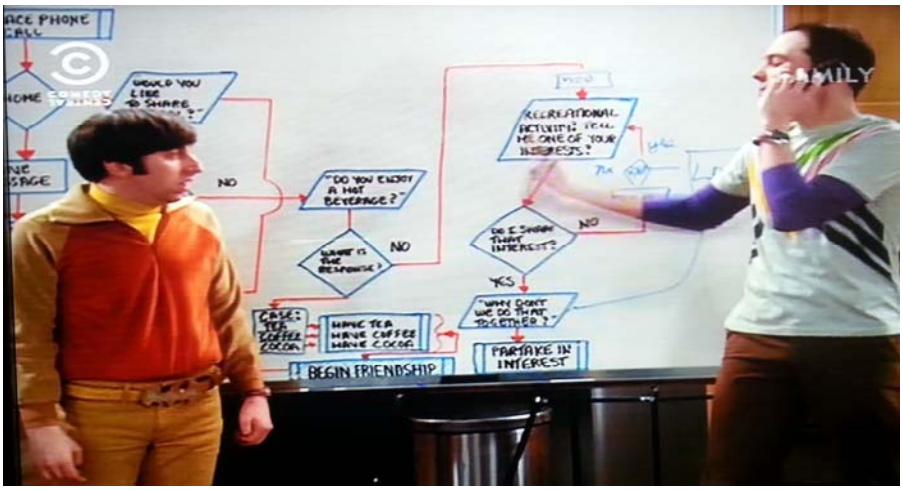
http://www.hyphy.org/docs/GUIExamples/treepanel.html

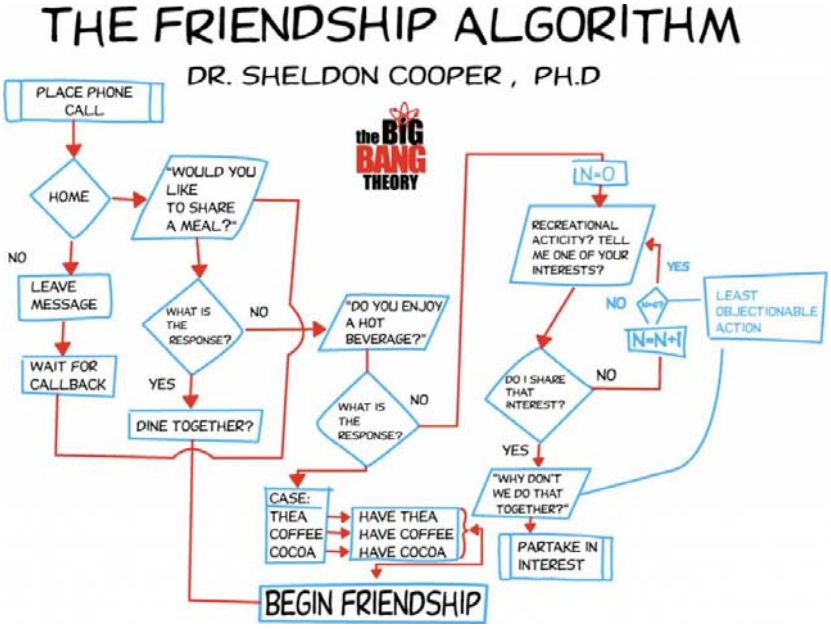
Decision Tree





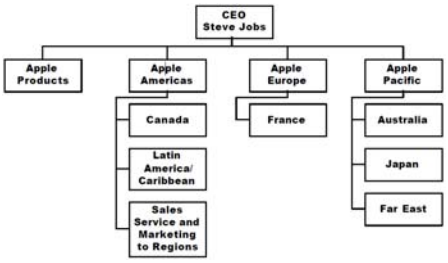
Tree vs flowchart





Q: What is the difference between a Tree and a Flowchart?

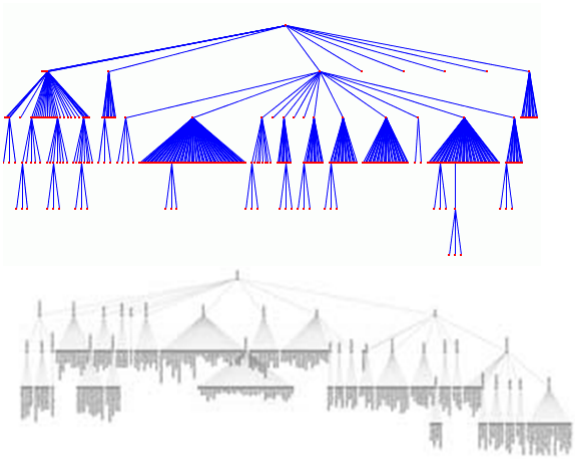
- Organization Chart



Edraw Soft

Question: What are potential problems in the standard node-link visualization?

- Too many nodes and/or leaves



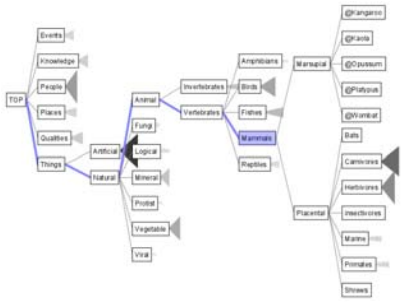
- Potential Problems
- Scalability
  - For top-down, width of fan-out uses up horizontal real estate very quickly
  - Number of nodes increases exponentially. E.g. 2^N nodes at level N.
  - Space increases polynomially
- Tree might grow a lot along one particular branch
- Hard to draw it well in view without knowing how it will branch

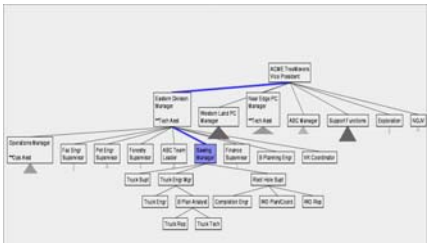
Q: Any thoughts???

John Stasko at GIT

Space Tree

- Conventional layout node link diagrams
- Dynamic rescaling of branches of the tree to best fit the available screen space
- Optimized camera movement
- Preview icons summarizing the topology of the branches that cannot be expanded
- Integrated search and filter functions.

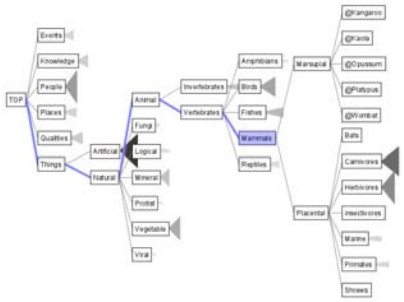


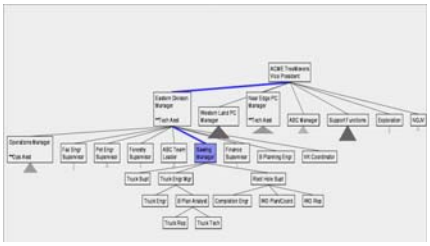


U of Maryland: http://www.cs.umd.edu/hcil/spacetree/

Space Tree

- Conventional layout node-link diagrams
- Vertical or horizontal
  - Subtrees are triangles
  - Size indicates depth
- Shading indicates number of nodes inside
- Navigate by clicking on nodes
  - Strongly restrict zooming

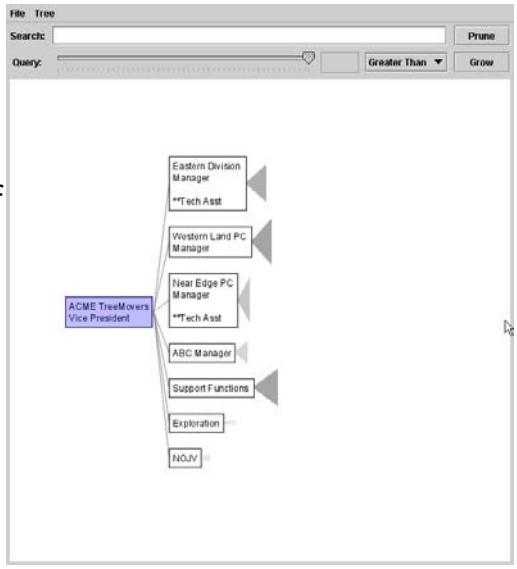


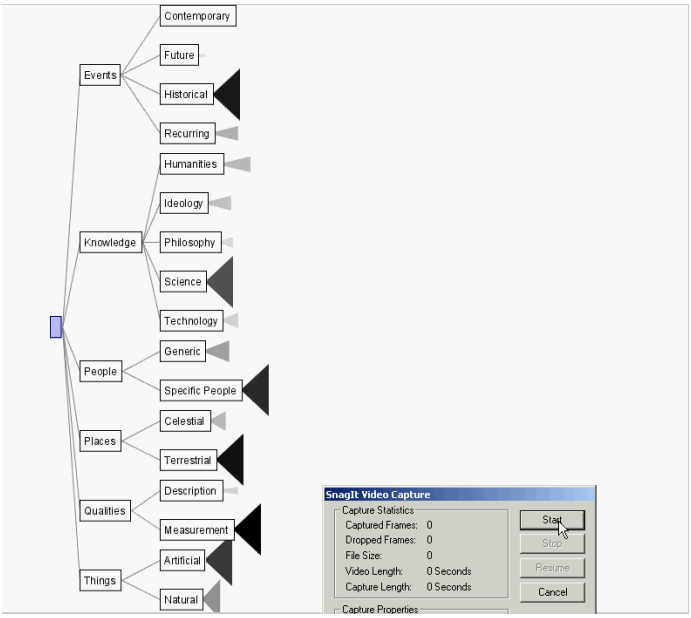


U of Maryland: http://www.cs.umd.edu/hcil/spacetree/

Features of Space Tree

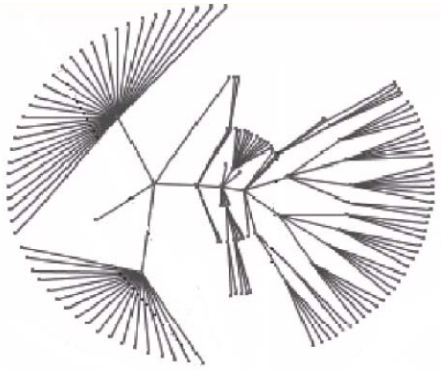
- Make labels readable
- Maximize number of levels opened
- Decompose tree animation
- Use landmarks
- Use overview and dynamic filtering





Radio Tree View

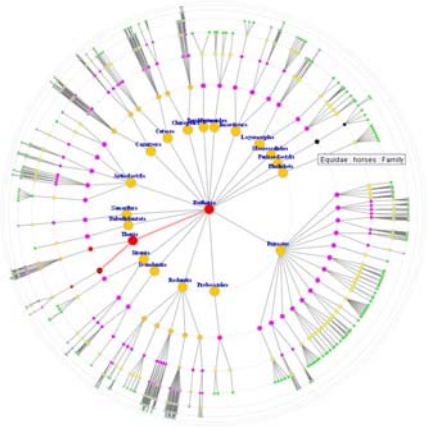
- Recursively position children of a subtree into circular wedges
- The central angle of these wedges are proportional to the number of leaves



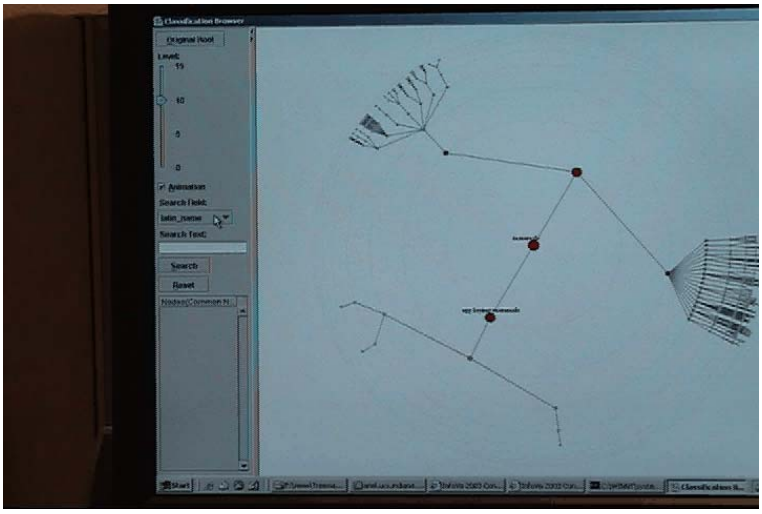
P. Eades, "Drawing Free Trees", *Bulleting of the Institute fro Combinatorics and its Applications, 1992, pp. 10-36.*

Radio Tree View

- Indiana University Bloomington

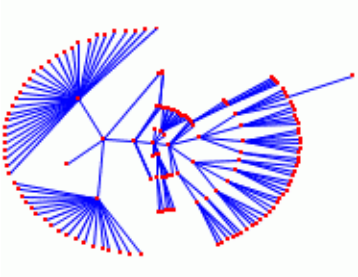


Radio Tree View



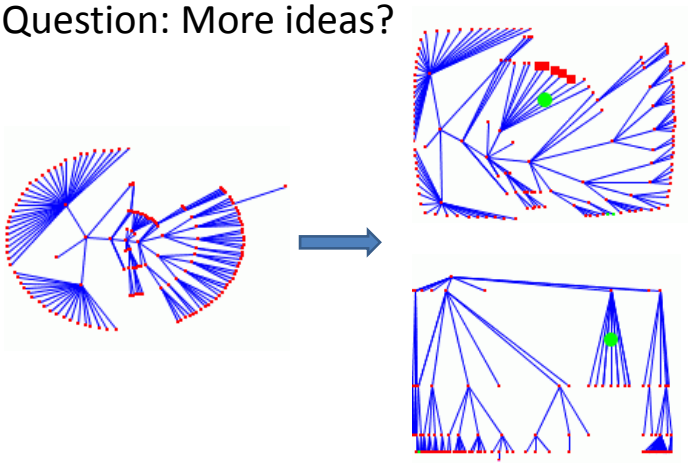
Radio Tree View

- Radio tree view ←→ Fish eye distortion



Radio Tree View

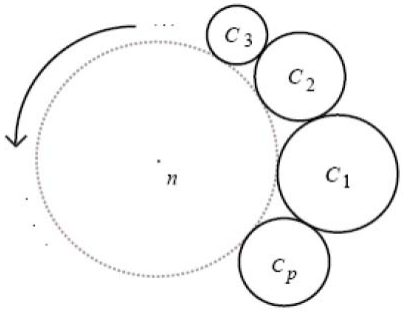
- Radio tree view ←→ Fish eye distortion
- Question: More ideas?



Circular drawing of rooted trees

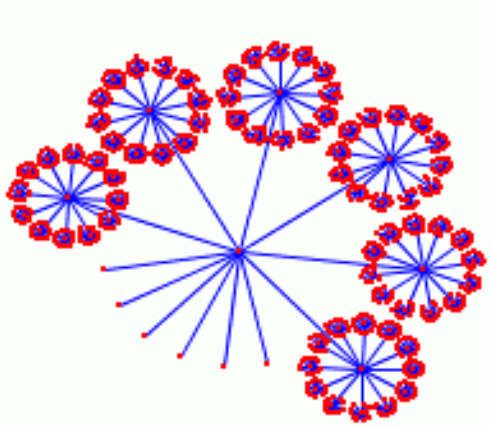
- Balloon View

  Siblings of sub-trees are included in circles attached to the father node.



Circular drawing of rooted trees

- Balloon View



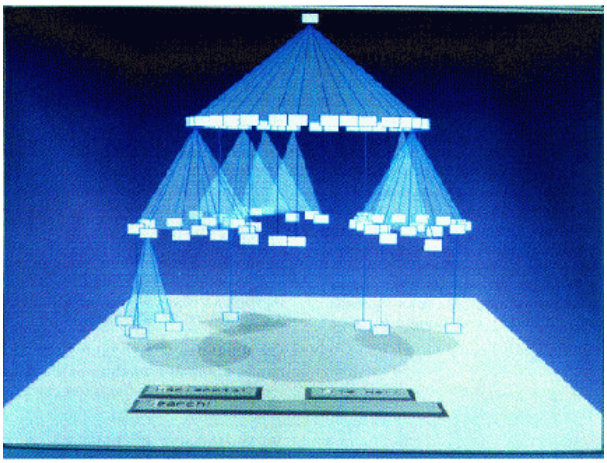
3D Visualization for Trees

- Add a third dimension into which layout can go
- Compromise of top-down and centered techniques mentioned earlier
- Children of a node are laid out in a cylinder “below” the parent
- Siblings live in one of the 2D planes

Robertson, Mackinlay, Card CHI ‘91

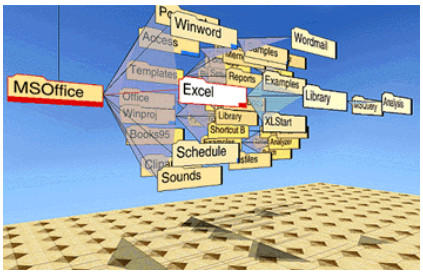
Cone Tree

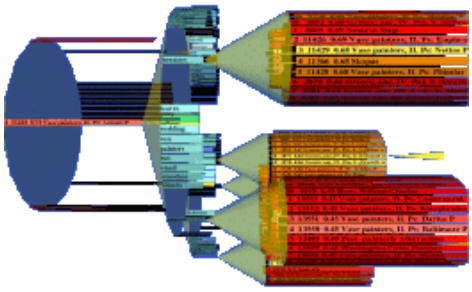
- Question: Advantages and disadvantages?

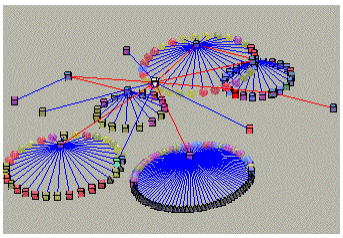


http://davis.wpi.edu/~matt/courses/trees/

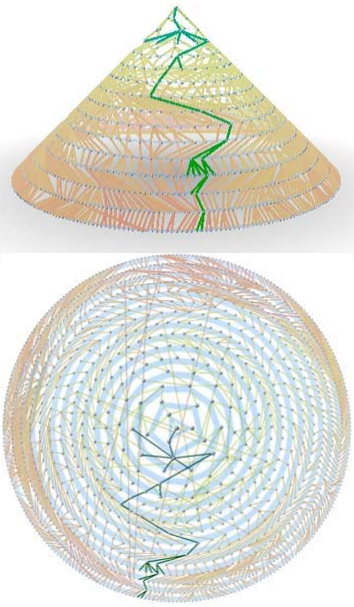
Cone Tree







A file system



A path through the social network

Cone Trees

Advantages

- More effective area to lay out tree
- Use of smooth animation to help person track updates
- Aesthetically pleasing ?

Disadvanges

- As in all 3D, occlusion obscures some nodes
- Non-trivial to implement and requires some graphics horsepower

John Stasko

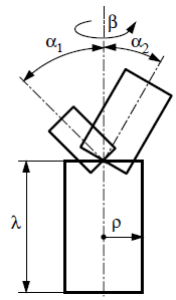
Botanical Tree

- Basic idea: People can easily see the branches, leaves, and their arrangement in a botanical tree
- Inspiration: Strand model of Holton
- Strands: internal vascular structure of a botanical tree

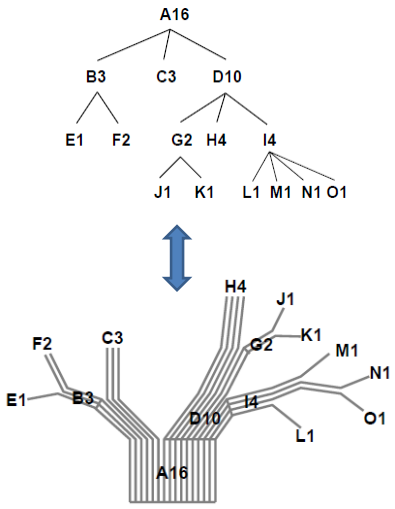
- Paper

Botanical Visualization of Huge Hierarchies
Ernst Kleiberg, Huub van de Wetering†,
Jarke J. van Wijk‡
Department of Mathematics and Computer Science
Eindhoven University of Technology

Botanical Tree



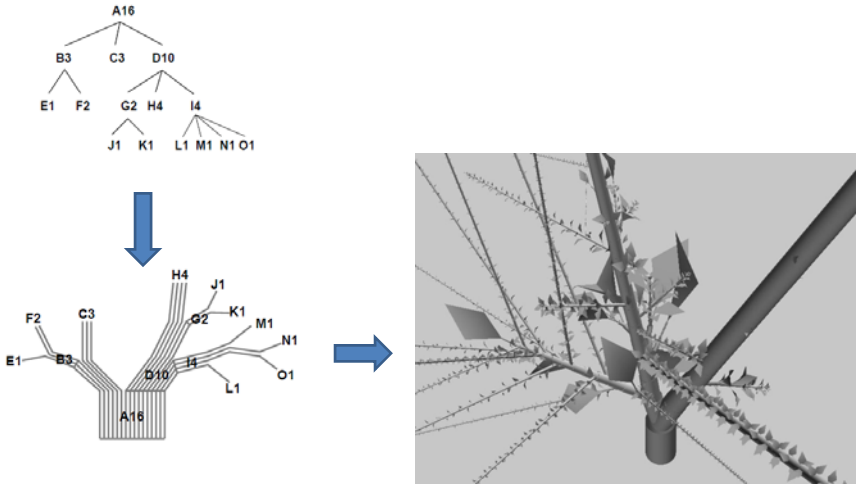
Stem and two subbranches



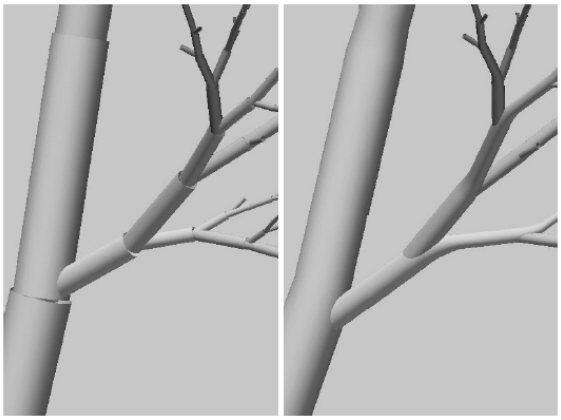
Node-link diagram

Corresponding strands model

Botanical Tree

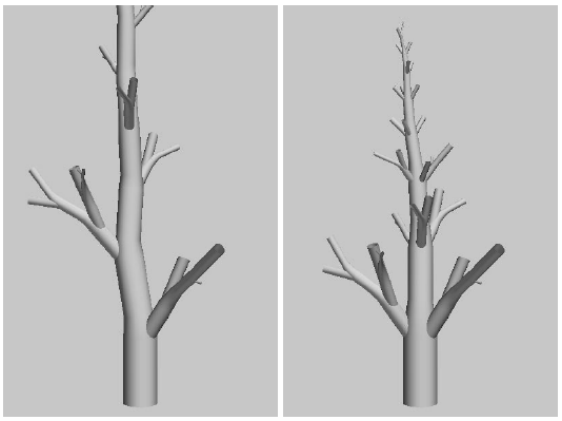


Botanical Tree



Cylinders or smoothed transition

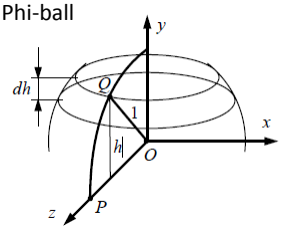
Botanical Tree



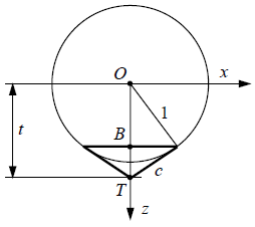
Binary tree or ‘real’ tree

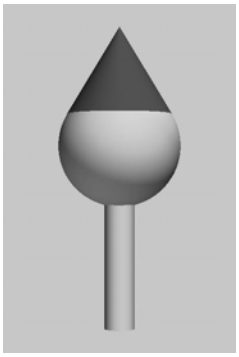
Botanical Tree

Phi-ball



Phi-ball cone

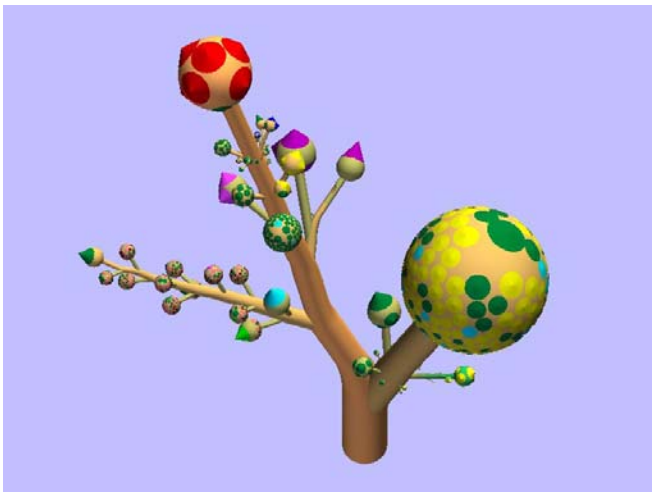




Phi-ball with one item

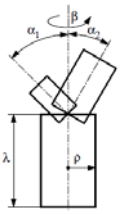
Many items

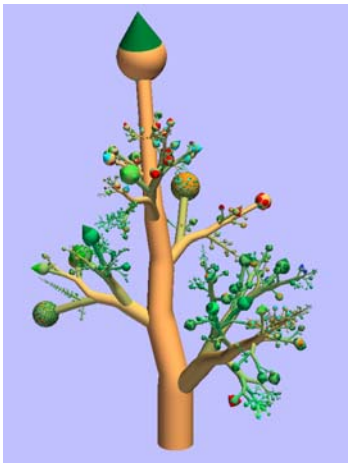
Botanical Tree



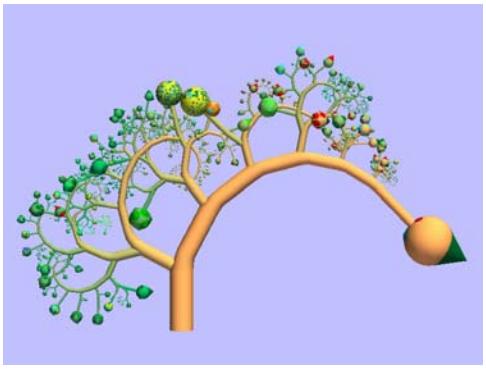
Final model with contraction, extrusion, and phiballs

Botanical Tree



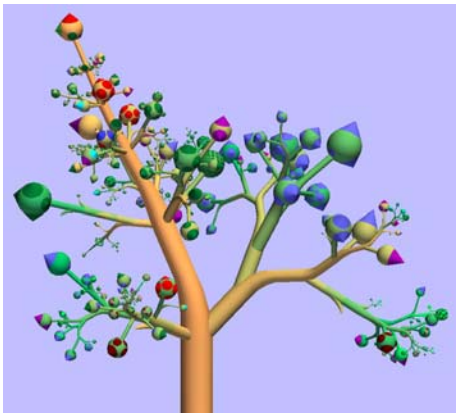


Complete hard disk α=45°, β=180°

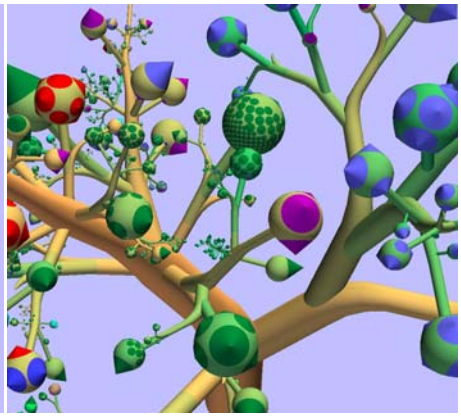


Complete hard disk α=90°, β=0°

Botanical Tree



Unix home directory



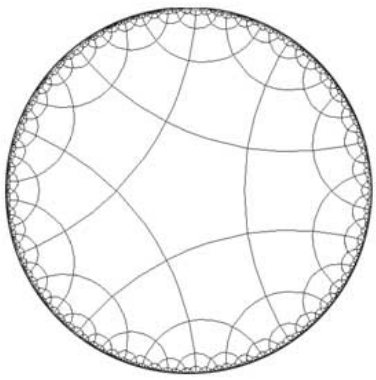
Details of the left picture

Collapsible Cylindrical Tree

- Basic idea: use a set of nested cylinders according to the telescope metaphor
- Limitation: one path is visible in once
- Interactions: rotation, go down/up

Tree in Hyperbolic Space

Hyperbolic Space



A Hyperbolic Tessellation of the Circle

Escher's *Circle Limit IV*

http://hollindale.co.uk/chris/images/hyperbolic.jpg

Hyperbolic

- Models of hyperbolic space
  - The hyperboloid model
  - The Klein model
  - The Poincaré models
- Hyperbolic math

Hyperbolic Space for Tree Visualization

- Main Contributors
  - H3 -- Munzer 97,98
  - Webviz -- Munzer and Burchard 95
  - 2D Hyperbolic Trees -- Lamping and Rao 94,95
  - Fractal trees -- Koike and Yoshihara 93
  - Cone Trees -- Robertson 91
  - Xerox PARC patent

- Apply a hyperbolic transformation to the space
- Root is at center, subordinates around
- Apply idea recursively, distance decreases between parent and child as you move farther from center, children go in wedge rather than circle

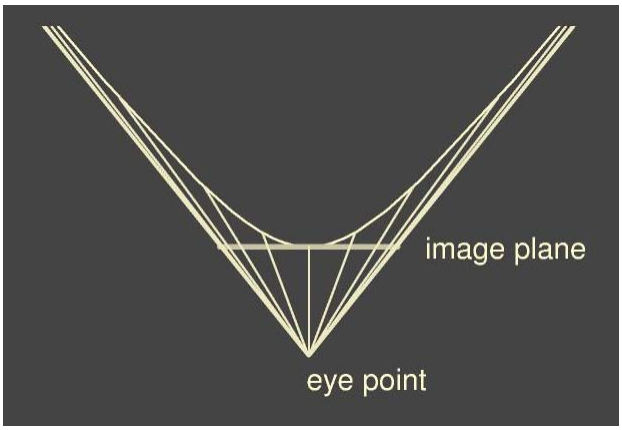
Stasko

Key idea:

- Find a space (hyperbolic space) that increases exponentially, lay the tree on it
- Transform from the hyperbolic space to 2D Euclidean space

1D Hyperbolic Space

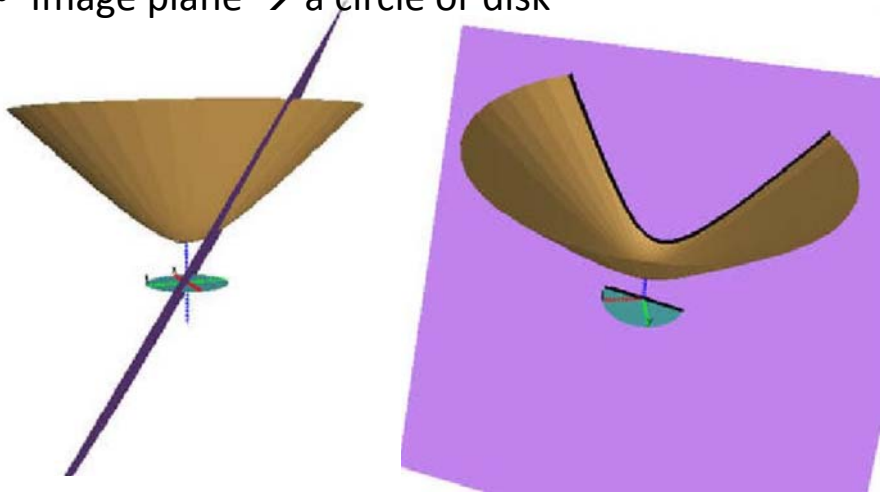
- Image plane → a line



http://graphics.stanford.edu/~munzner/talks/calgary02/mgp00032.html

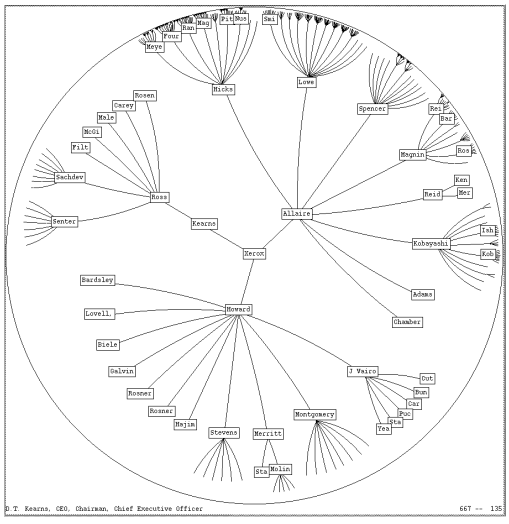
2D Hyperbolic Space

- Image plane → a circle or disk



Formula	Euclidean	Hyperbolic
right-angle triangle	$\tan\theta = \frac{opp}{adj}$	$\tan\theta = \frac{\tanh(opp)}{\tanh(adj)}$
right-angle triangle	$\sin\theta = \frac{opp}{hyp}$	$\sin\theta = \frac{\sinh(opp)}{\sinh(hyp)}$
circle area	πr^2	$2\pi(\cosh(r) - 1)$
hemisphere area	$2\pi r^2$	$2\pi \sinh^2(r)$
spherical cap area[1]	$2\pi r^2(1 - \cos\phi)$	$2\pi \sinh^2 r(1 - \cos\phi)$

Lamping and Rao, 1995



Approach:

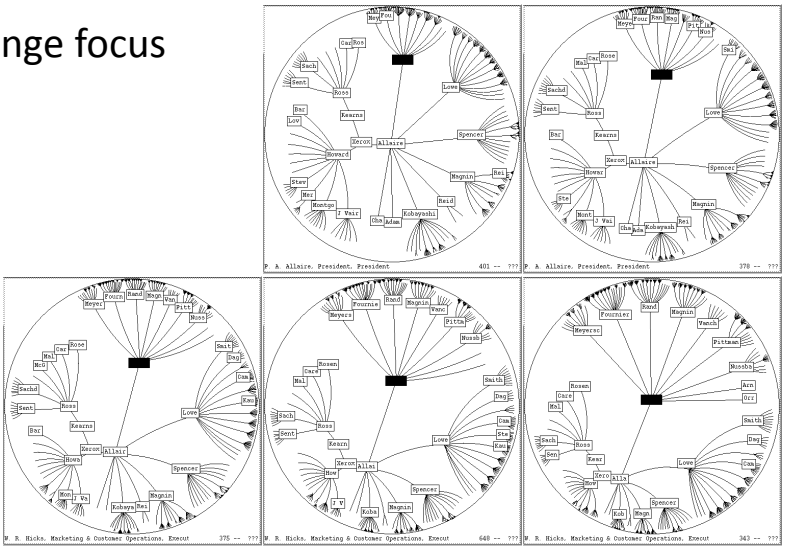
- Lay out the hierarchy on the hyperbolic plane and map this plane onto a display region.

Comparison

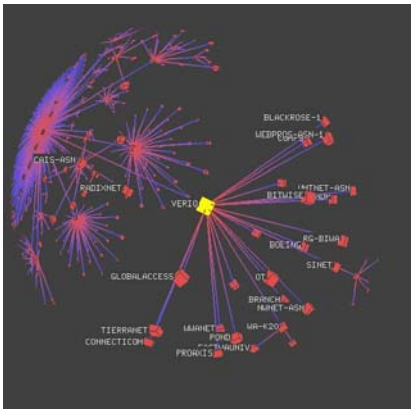
- A standard 2D browser: 100 nodes (w/3 character text strings)
- Hyperbolic browser: 1000 nodes, about 50 nearest focus can show from 3 to dozens of characters

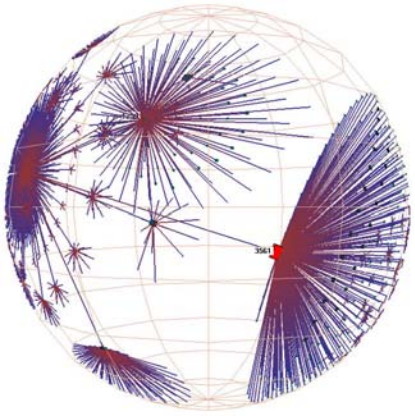
Lamping and Rao, 1995

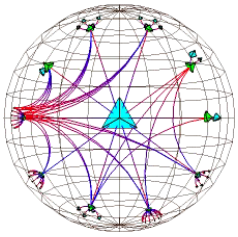
- Change focus



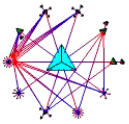
- Effects



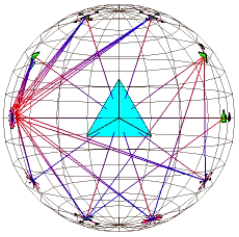




Conformal Model



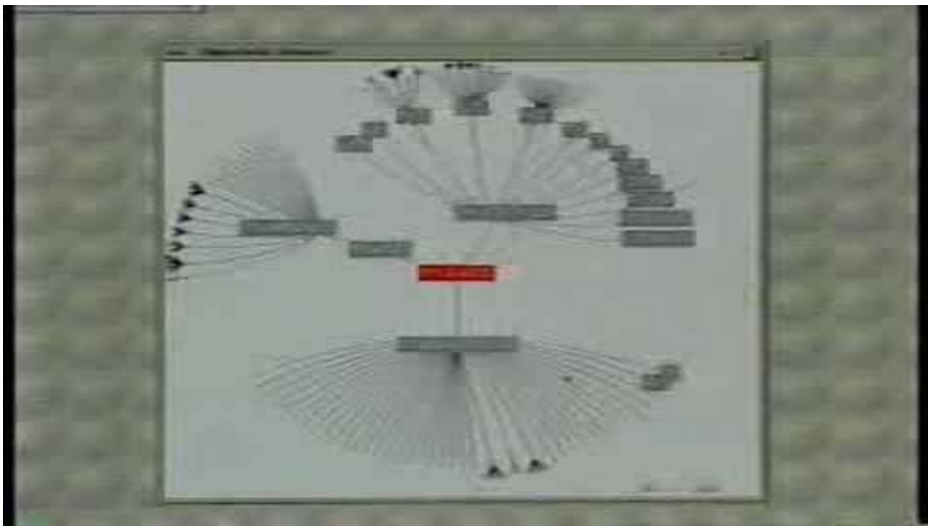
"Insider" Model



Projective Model

- Natural magnification (fisheye) in center
- Layout depends only on 2-3 generations from current node
- Smooth animation for change in focus
- Don't draw objects when far enough from root (simplify rendering)

Original Authors

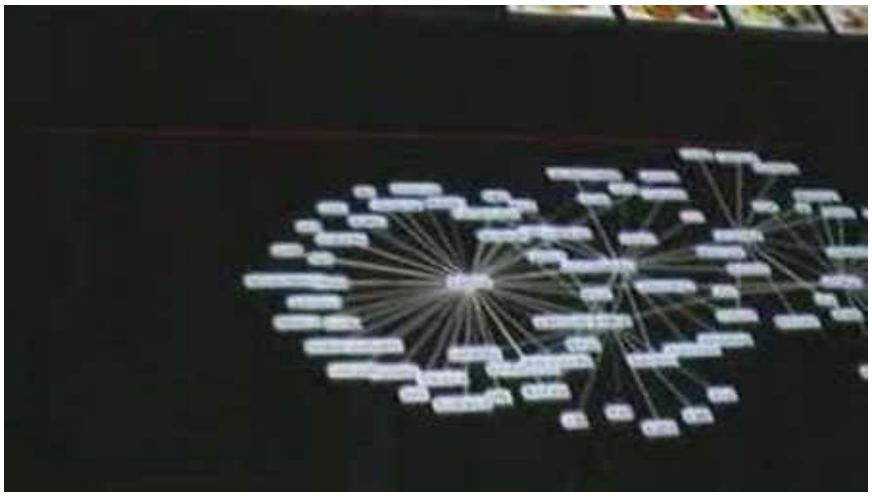


[InfoVis SpaceTree Demo]

[InfoVis HyperTree Demo]

Question:

- The difference between SpaceTree and HyperTree?
- When to use SpaceTree or HyperTree?

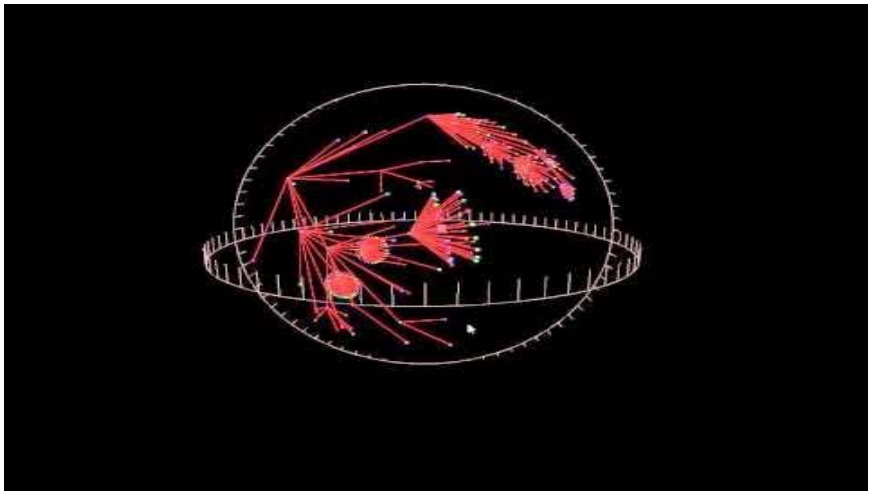


Potential Applications: Migrate to smart phone systems?

gesture-based user interface -- Minority Report

Hyperbolic Visualization

- Handle much larger graphs, i.e. >100,000 edges
- Support dynamic exploration & interactive browsing
- Maintain a guaranteed frame rate

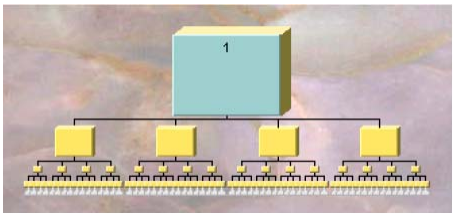


2D is Back

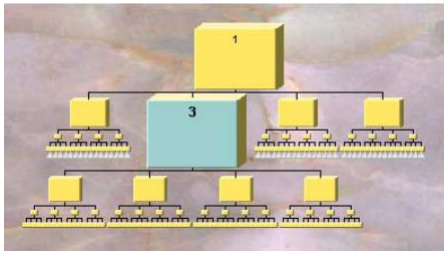
- After all the interest in 3D and hyperbolic techniques in the 1990s, recently, there has been renewed interest in the old 2D methods

- Recall SpaceTree

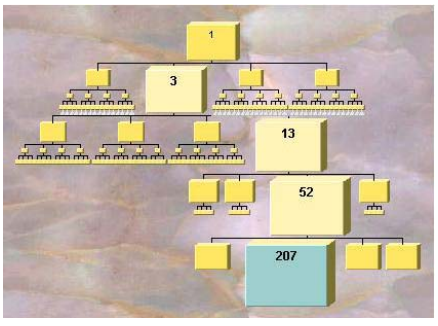
Degree-of-Interest Trees



Display of a uniform tree of 4 levels

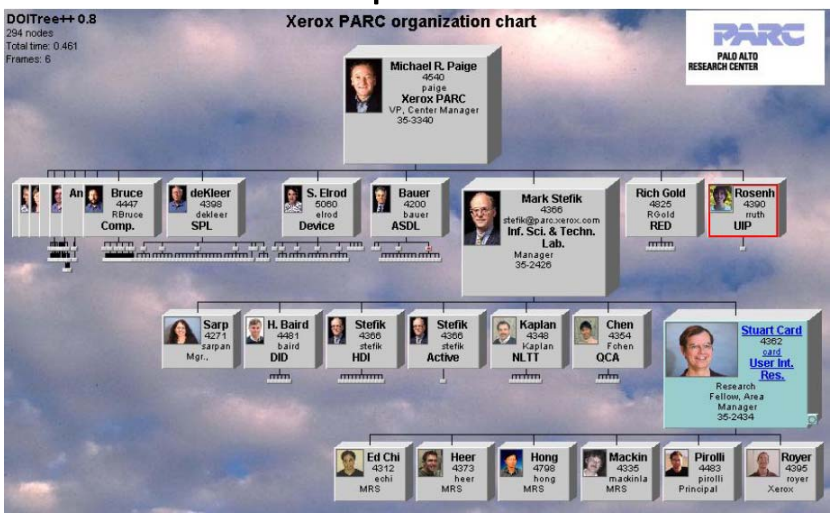


Same table with focus on Node 3

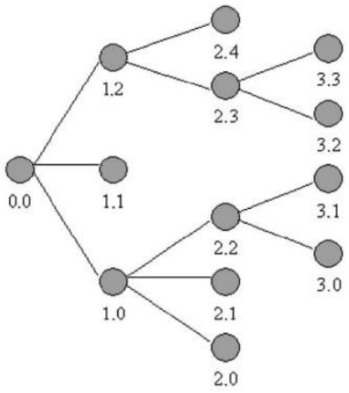


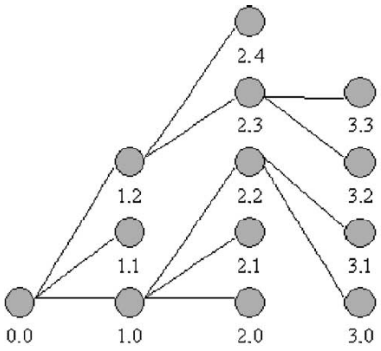
Same tree expanded down to a leaf node

Degree-of-Interest Trees with Compression



FlexTree





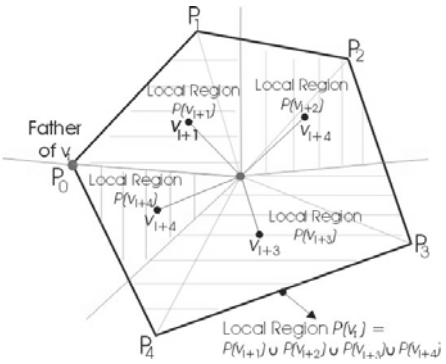
FlexTree view

Question: What is the key concept in FlexTree?

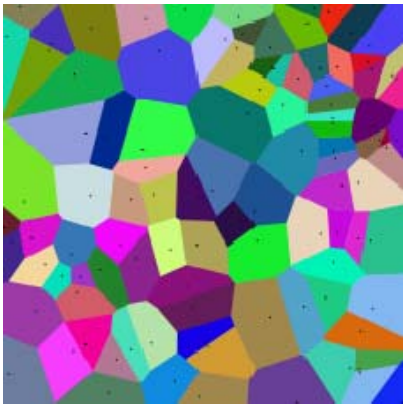
Basic idea: Nodes as hard balls. Press them down.

Space-Optimized Tree

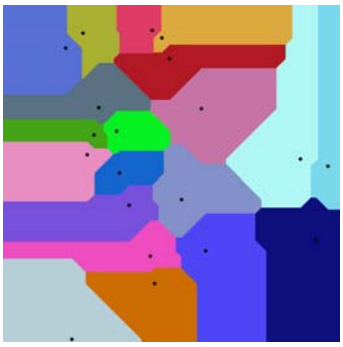
- Goal: Show relationships and optimize space



- Voronoi diagram of a set of points



- Voronoi diagrams of 20 points under two different metrics

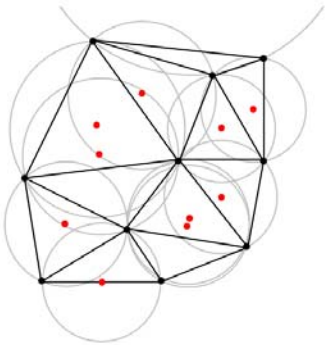


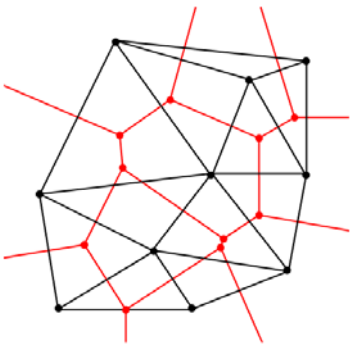
Euclidian distance = $\sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2}$

Manhattan distance = $|a_1 - b_1| + |a_2 - b_2|$

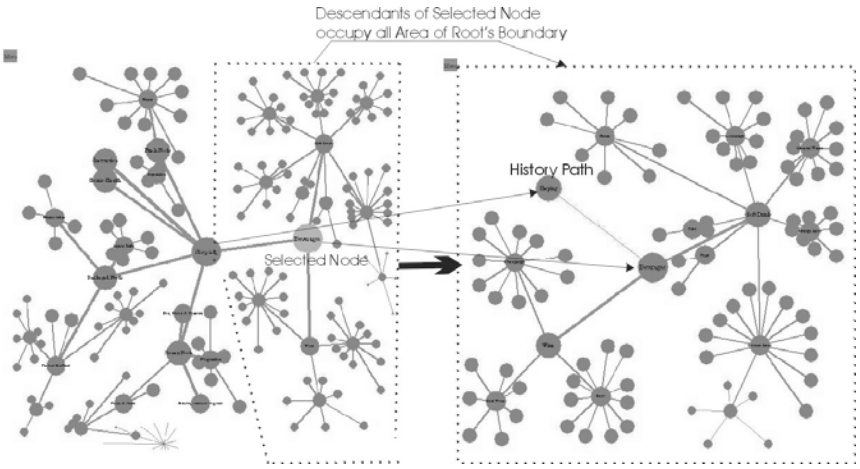
http://en.wikipedia.org/wiki/Voronoi_diagram

- Delaunay triangulation and Voronoi Diagram





Space-Optimized Tree



Nguyen and Huang, 2002

Summary

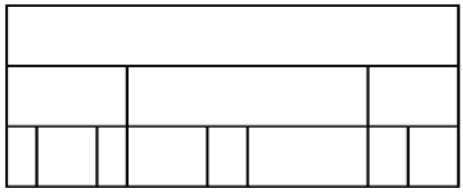
- Original tree view
- Space Tree
- Radio tree
- 3D Cone tree
- Hyperbolic tree
- Botanic tree
- Collapsible Cylindrical Tree
- Degree of interest tree
- Flex tree
- Space-optimized tree

New view → solve problems.

Space-Filling

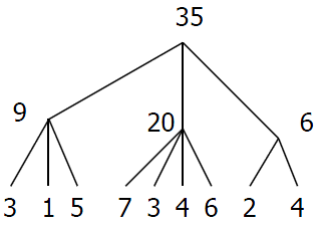
Space-Filling

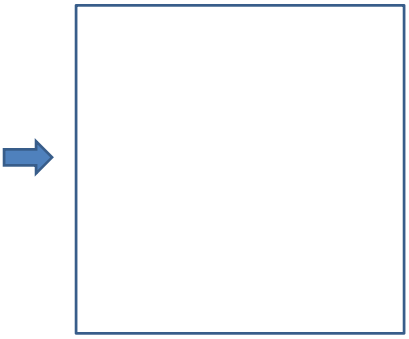
- Children are drawn inside their parents
- Alternate horizontal and vertical slicing at each successive level
- Use area to encode other variable of data items

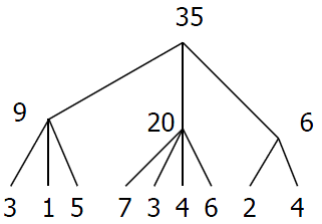


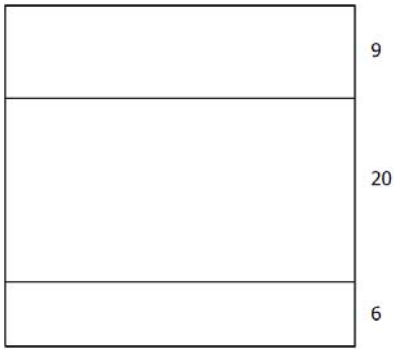
Space-filling representation developed by Shneiderman and Johnson, Vis91

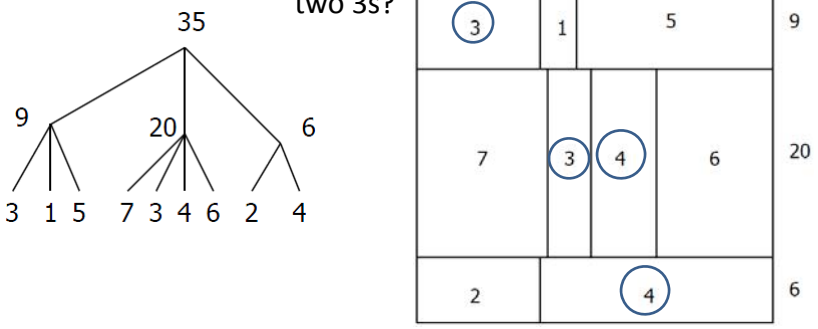
- Map a tree to an area







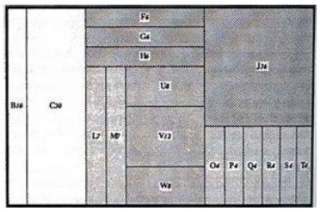




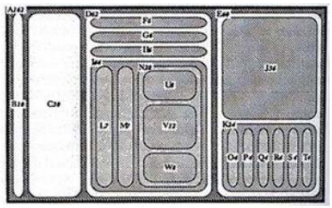
Question: two 4s have the same size (area)?

- Better use of space → Why??
  - Rectangular shape
- More attributes → Name some??
  - color and area
- Not as good at representing structure
  - Aspect ratios
  - Balanced tree, items with similar sizes

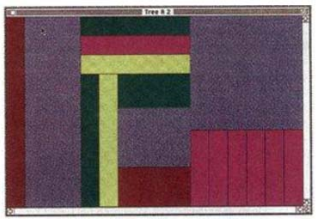
Nested and Non-Nested

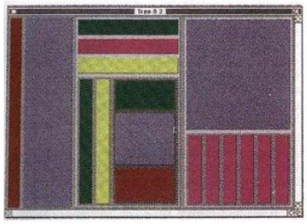


Non-nested Tree-Map



Nested Tree-Map





TreeMaps: Tiling

- Tiling: a way to divide a rectangle into sub-rectangles of specified areas.
- Good practice
  - Create rectangles of **aspect ratio** close to one
  - Preserve some sense of **the ordering** in the input data
  - Change to reflect changes in the underlying data

http://en.wikipedia.org/wiki/Treemapping

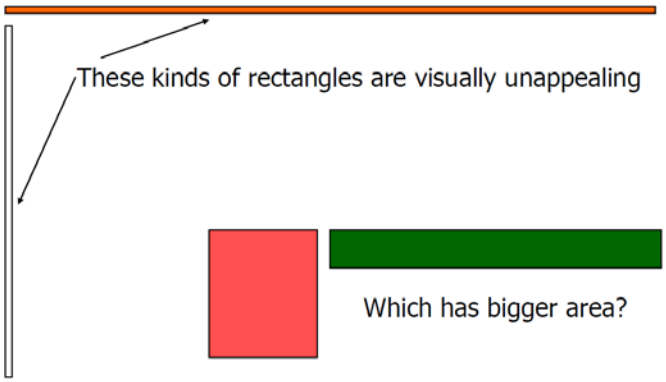
TreeMaps: Tiling

- Difficulties:

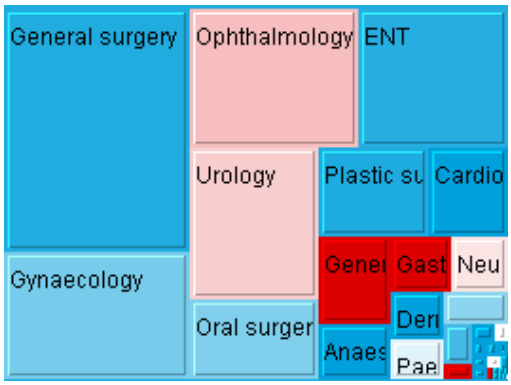
  Inverse relationship between properties
  - Optimized aspect ratio → unpredictable order of placement
  - Stable order → degraded aspect ratio

http://en.wikipedia.org/wiki/Treemapping

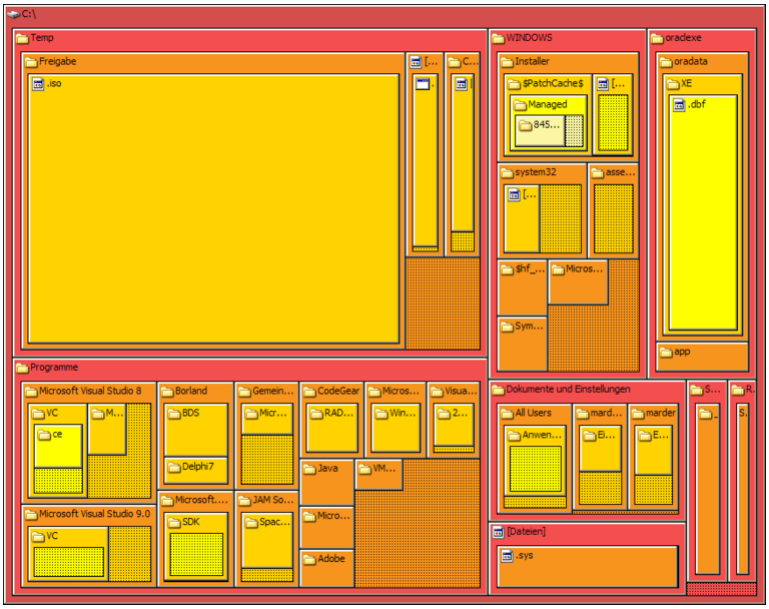
- Aspect ratios



- Tree visualization?

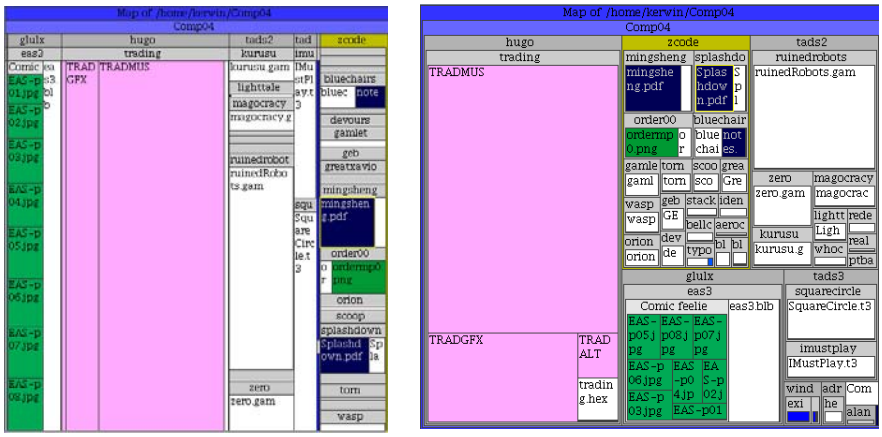


Changes in waiting times for patients



http://en.wikipedia.org/wiki/Treemapping

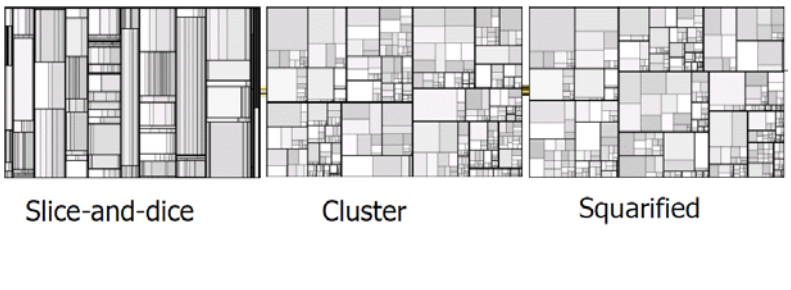
- Same dataset



Original treemap

Squarified treemap

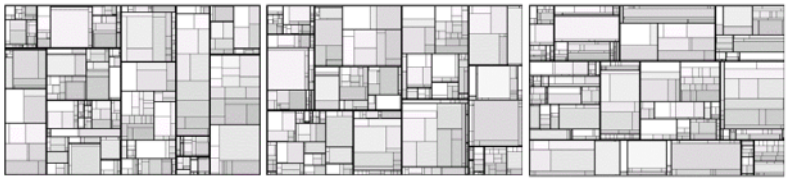
http://www.cse.ohio-state.edu/~kerwin/treemap-survey.html



Slice-and-dice

Cluster

Squarified



Pivot-by-middle

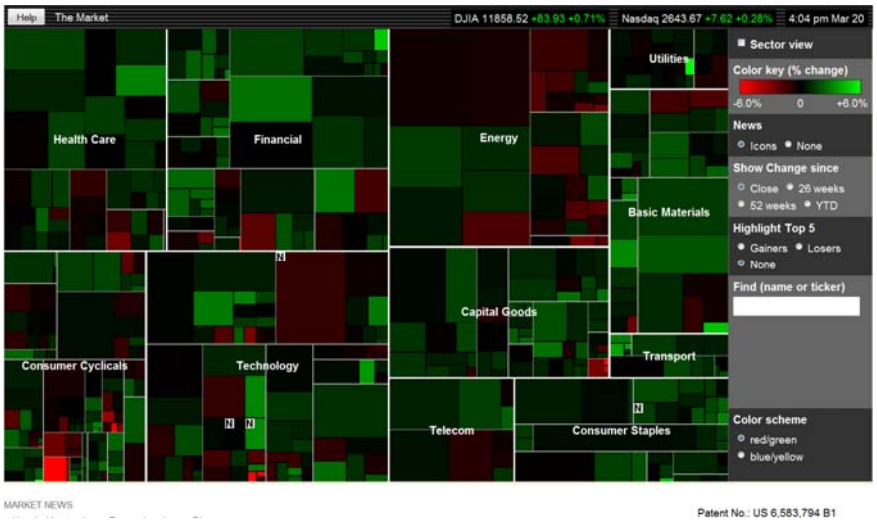
Pivot-by-size

Strip

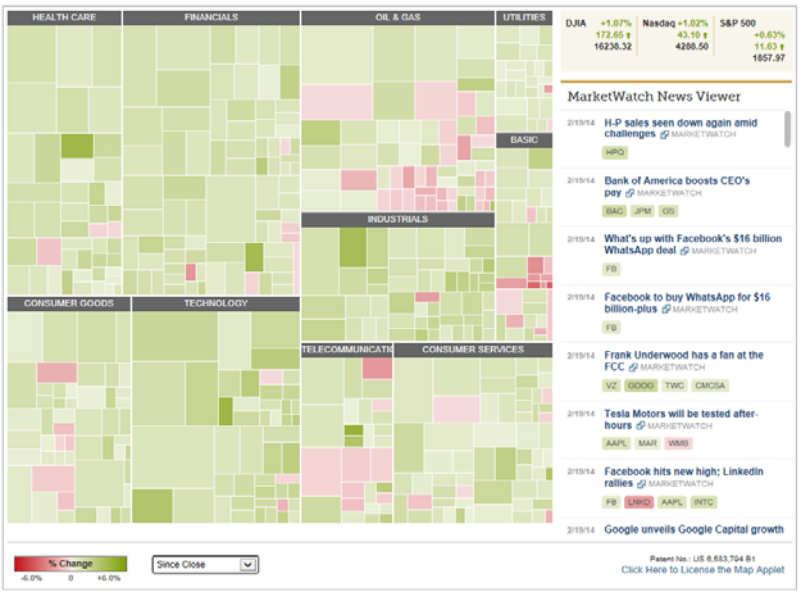
- Techniques by
  - aspect ratio
    - width to height
  - structural change
    - metric designed to measure movements of items
  - Readability
    - metric based on changes in direction of eye gaze as items scanned

Demo: Dynamic treemap layout comparison

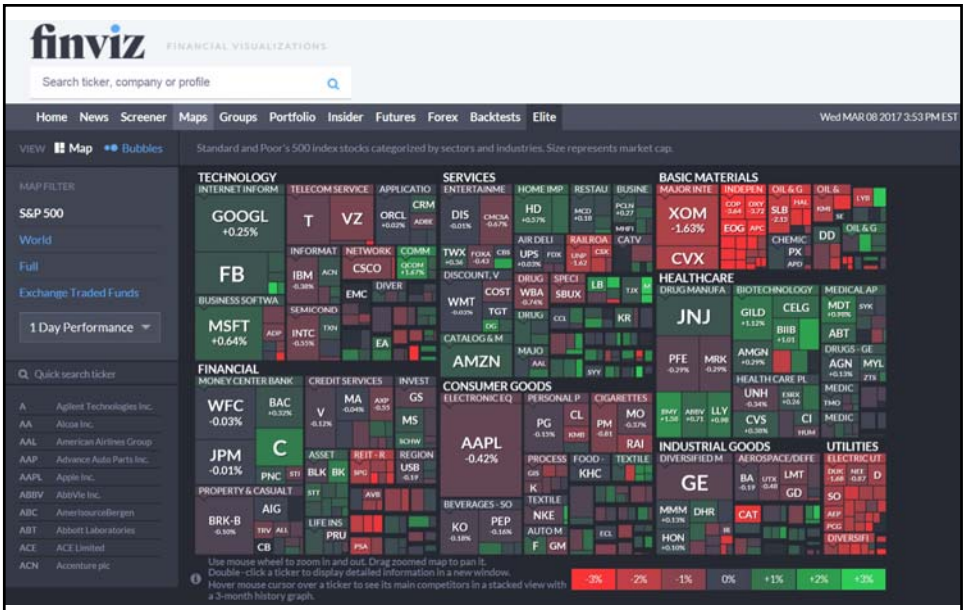
Treemaps: SmartMoney (3/20/2011)



Market Watch 3/17/2014



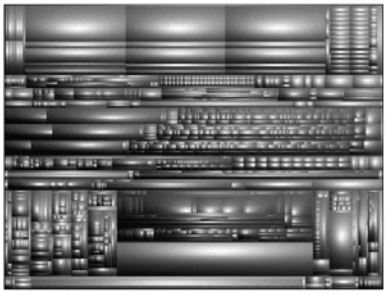
Interactive: http://www.smartmoney.com/map-of-the-market/



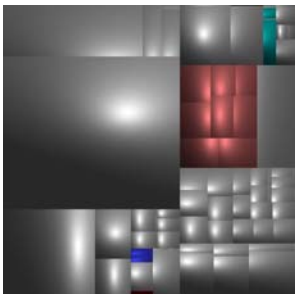
https://www.finviz.com/map.ashx

Visual Improvements

- Cushion treemap



Add shading and texture to help convey structure of hierarchy

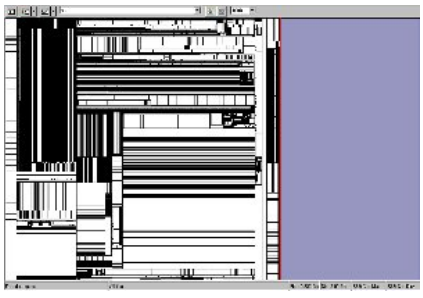


Add color

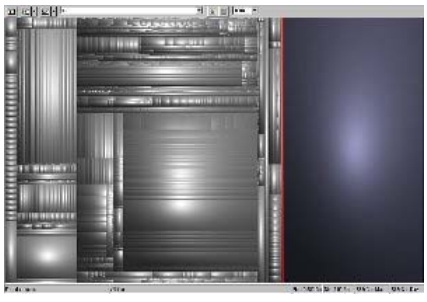
Van Wijk & van de Wetering, InfoVis 99

TreeMap Example

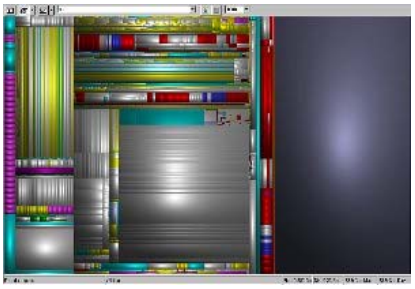
- **sequoiaView** -- disk browsing tool



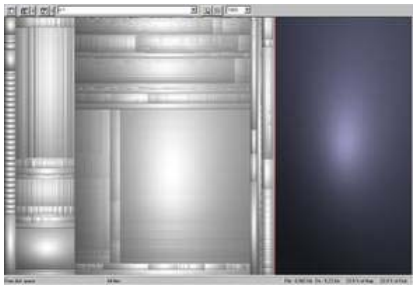
The original treemap



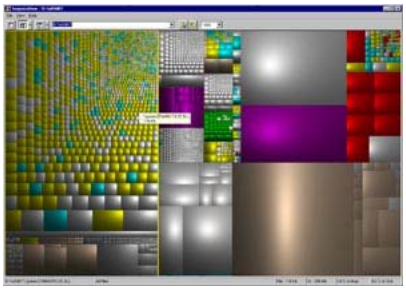
Coloring files of different types



Cushion treemaps

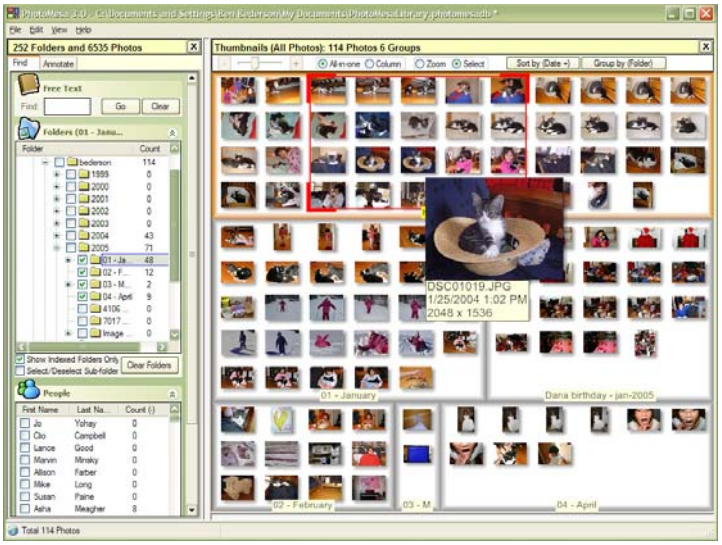


Cushion treemap showing less detail



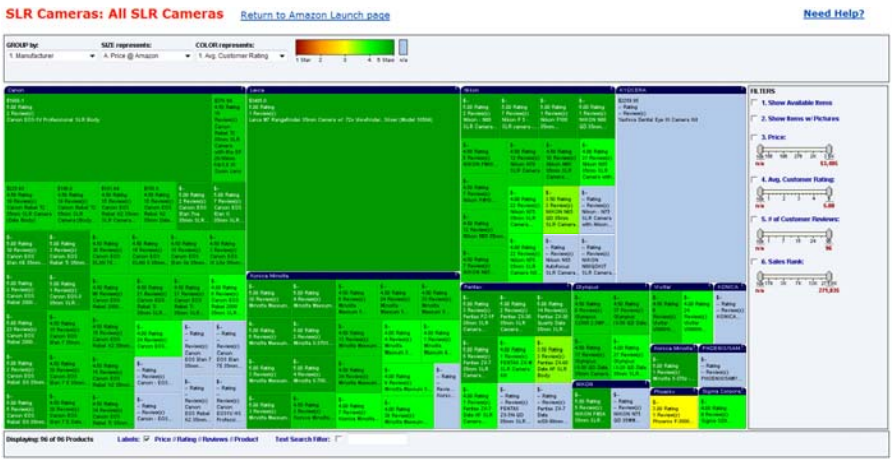
Squarified cushion treemap (different system)

Example: Photo management



PhotoMesa: http://www.windsorinterfaces.com/photomesa.shtml

Example: Product Sale



Demo HiveGroup: http://www.hivegroup.com/

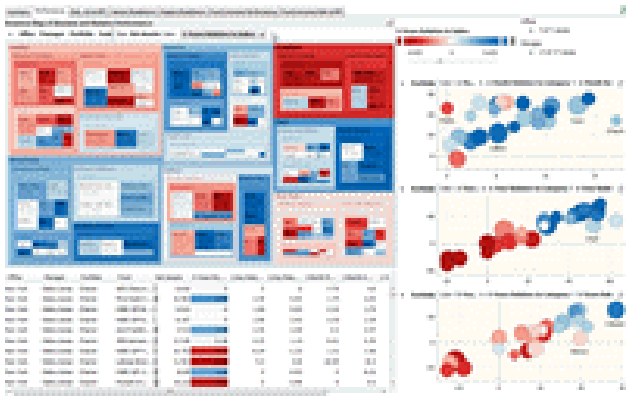
Example: News

- News Map

Demo: NewsMap http://newsmap.jp/ (Needs Flash)

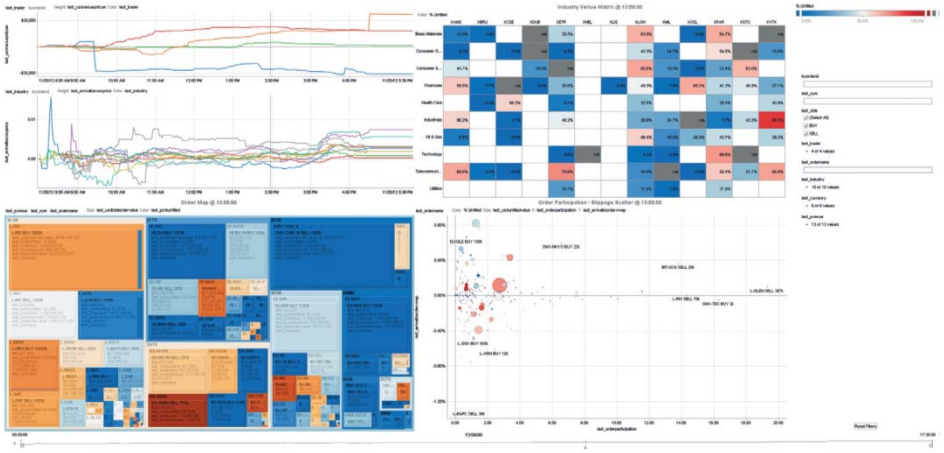
Example: Investment

- Panopticon



http://www.panopticon.com/

- Panopticon

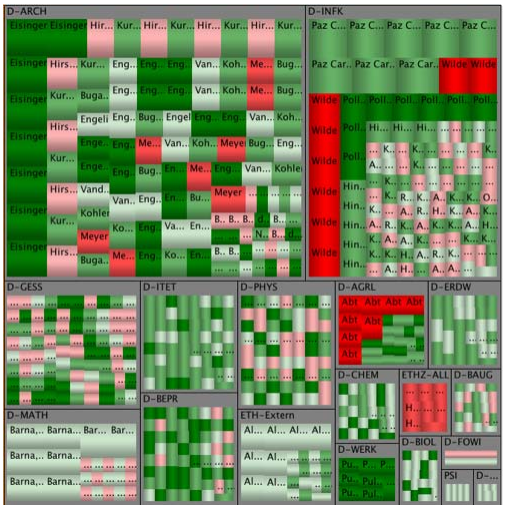


10 Lessons in Treemap Design

- Choose the right measures for size and color
- Space matters
  - size represents value in a treemap
  - distorts the values by arbitrarily using space, making it harder for the viewer to visually compare sizes.
- Labels should add value

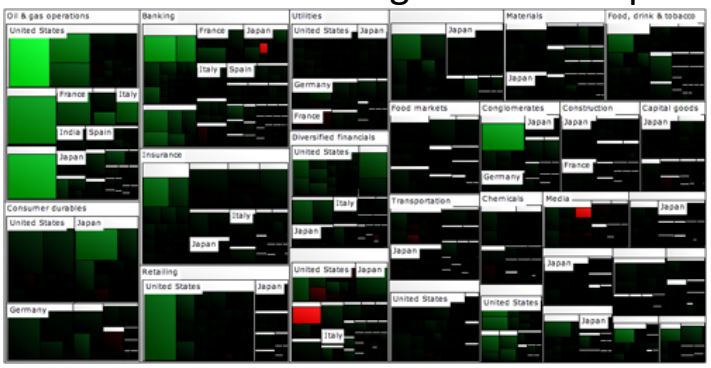
http://www.juiceanalytics.com/writing/10-lessons-treemap-design/

- Bad example
  - MicroFocus TreeMap
  - majority of labels get reduced to just a few letters



http://www.juiceanalytics.com/writing/10-lessons-treemap-design/

- Labels must stand-out against treemap colors



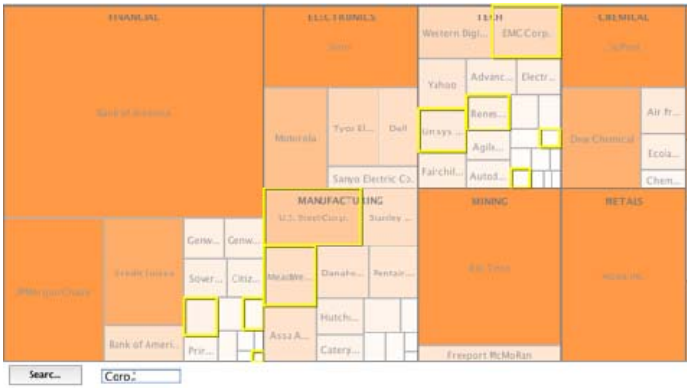
The ILOG Elixir treemap chooses to put the labels in a white text box. Unfortunately these text boxes look clunky, obscure some of the data, and don't always fit into the allotted space.

http://www.juiceanalytics.com/writing/10-lessons-treemap-design/

- Explanatory legends
- Color ranges fit the data
  - Avoid to use complicated color schemes

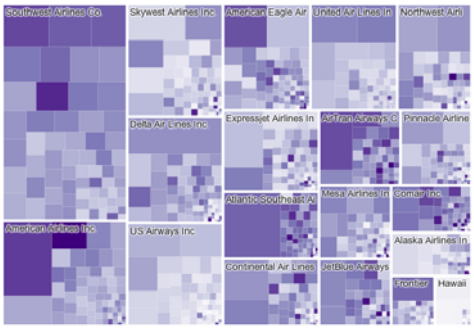
http://www.juiceanalytics.com/writing/10-lessons-treemap-design/

- Show correlation by highlighting



http://www.juiceanalytics.com/writing/10-lessons-treemap-design/

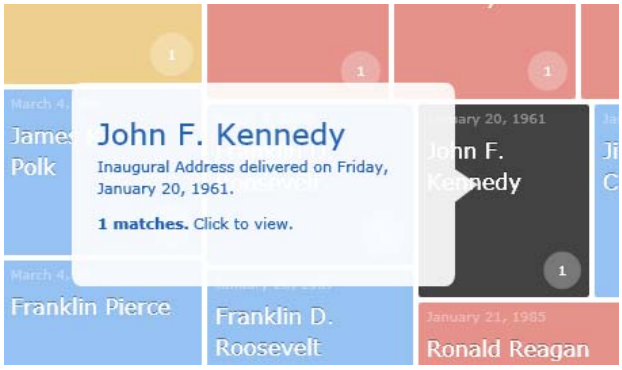
- Show changes with animation



Demo: http://users.design.ucla.edu/~akoblin/work/faa/us.html

http://www.juiceanalytics.com/writing/10-lessons-treemap-design/

- Simple presentation of node detail



http://www.juiceanalytics.com/writing/10-lessons-treemap-design/

- Gradually reveal detail

Panopticon choose to show as much detail as possible, but in a faint grey text.

http://www.juiceanalytics.com/writing/10-lessons-treemap-design/

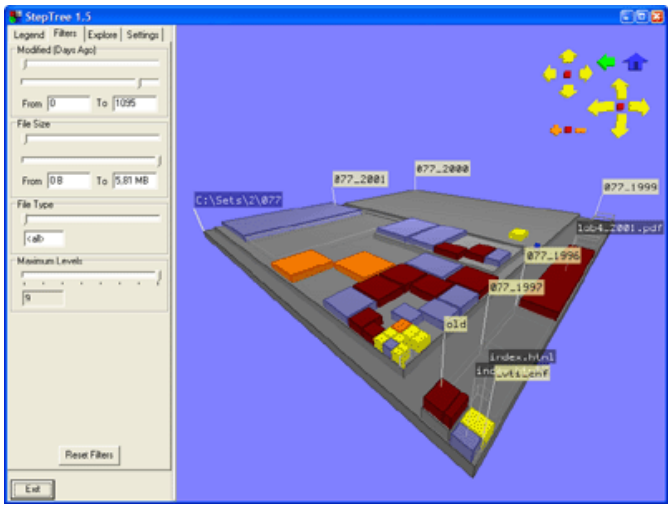
- What if nodes with zero value (mapped to area) are very important?
  - Example: Stock or mutual fund portfolios: Funds you don't currently hold have zero value in your portfolio, but you want to see them to potentially buy them

Stasko

- Context Treemap – Treemap with small distortion
  - Give zero-valued items (all together) some constant proportion of screen area
  - Provide dynamic query capabilities to enhance exploration leading to portfolio diversification

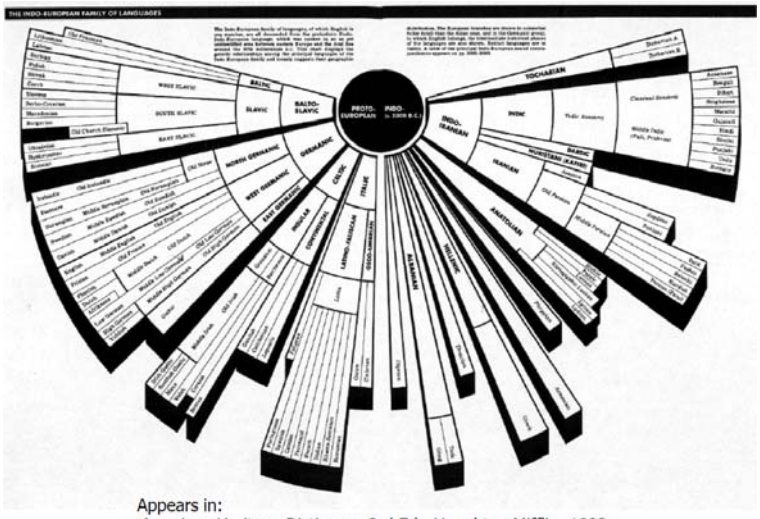
Stasko

Treemap in 3D



http://www.sm.luth.se/csee/csn/visualization/filesysvis.php

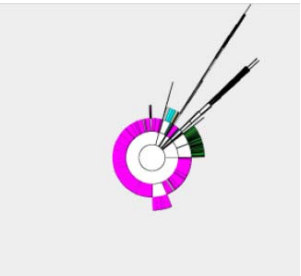
Radio Space-Filling



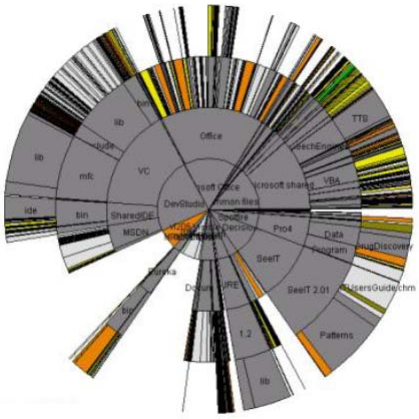
Appears in:
American Heritage Dictionary, 3rd Ed. Houghton Mifflin, 1992

Stasko

- Potential Problems

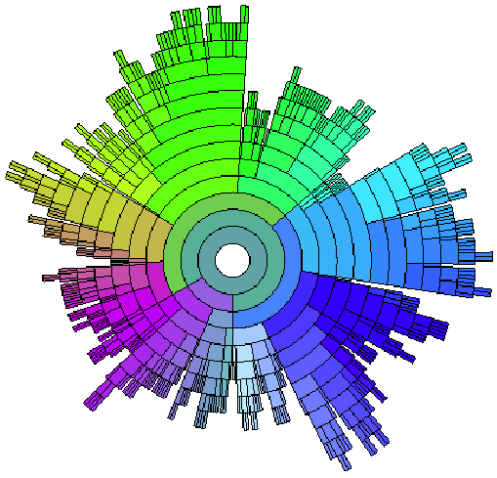


One branch with many nodes



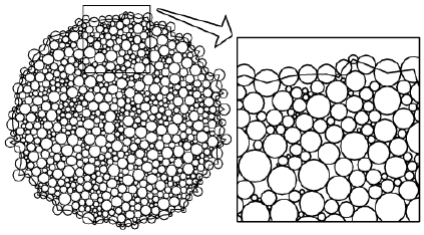
Tiny nodes at the periphery in a large tree

- InterRin

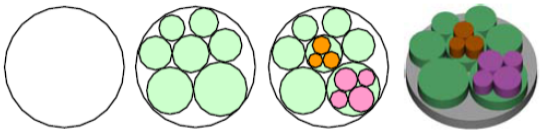


Yang, Ward & RudensteinerInfoVis „02

Visualization of Large Hierarchical Data by Circle Packing



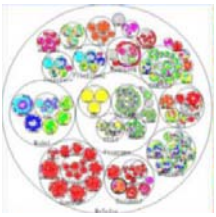
Pack circles

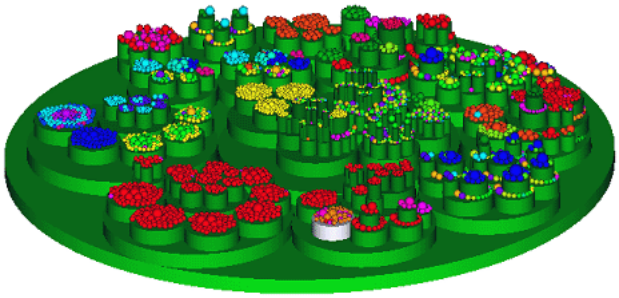


(a) Level 0 (b) Level 1 (c) Level 2 (d) 3D view

Pack circles in circles

Wang, Wang, Dai & Wang , CHI 06

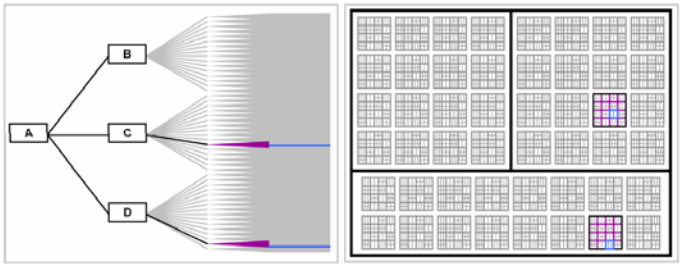




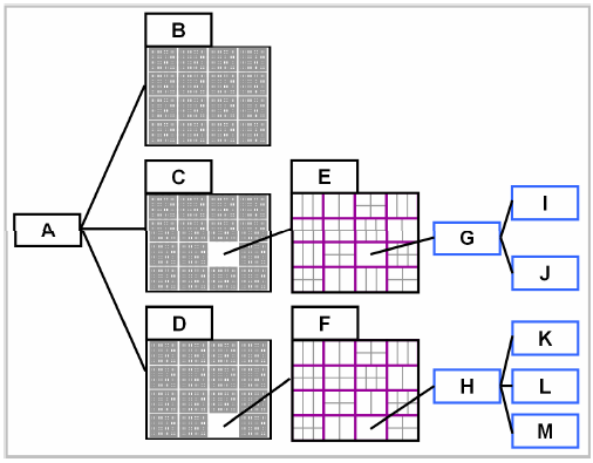
- Grokker: browsing Amazon for “Siberian Huskies”

Hybrid

- Elastic Hierarchies: Combining Treemaps and Node-Link Diagrams



Node–Link Diagram Treemap



Elastic Hierarchy

Node-Link or Space Filling

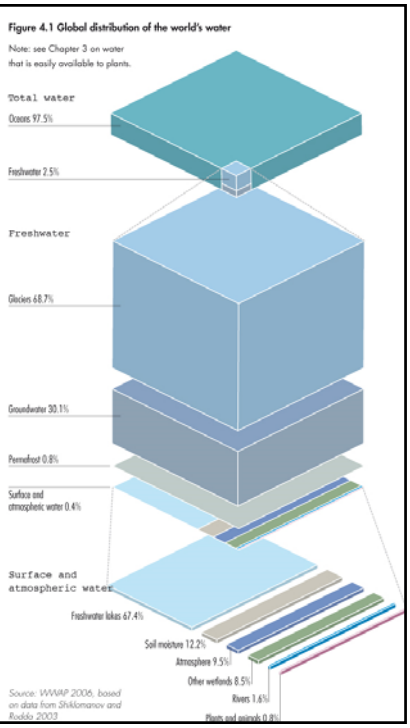
- Depends on the properties of the data
- Node-link typically better at exposing information structure
- Space-filling good for focusing on one or two additional variables of cases

Commercially available software

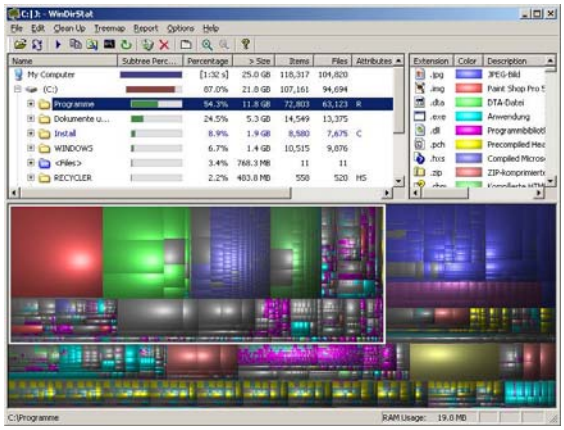
Software	Price	Windows	Mac OS X	Linux	Web service
DrasticData	?	Yes	Yes	Yes	Yes
HiveOnDemand	USD 425	No	No	No	Yes
Honeycomb	?	Yes	Yes	Yes	Yes
Incito Mira	GBP 1,199	Yes	Yes	Yes	Yes
Lab Escape Heat Map Explorer	USD 1,295	Yes	No	No	Yes
Lab Escape Enterprise Tree Map SDK	?	Yes	Yes	Yes	Yes
Macrofocus TreeMap	USD 195	Yes	Yes	Yes	Yes
MagnaView	?	Yes	No	Yes	Yes
Panopticon EX Enterprise Application and Developer SDK	USD 900	Yes	Yes	Yes	Yes
UMD Treemap	?	Yes	?	?	No

- Global distribution of the world's water
- Space-filling??

http://www.wired.com/images_blogs/photos/uncategorized/2008/06/10/where_is_the_water.jpg



Disk Space Management



Demo: SpaceSniffer and Scanner
Discussion: How to visualize the disk usage?

Summary

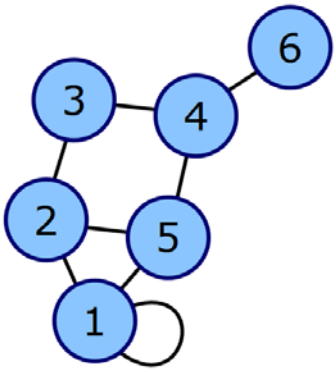
- Original space-filling
- (Tiling techniques)
- Cushion treemap
- 3D
- Radio space-filling
- Circle packing
- Hybrid. e.g. Elastic Hierarchies

Graph Visualization

- Drawing
- Adjacency list
- Adjacency matrix

$$\begin{pmatrix} 2 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

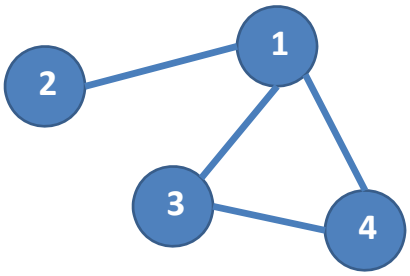
Coordinates are 1–6.



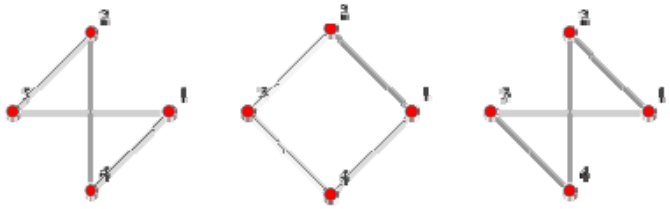
https://en.wikipedia.org/wiki/Adjacency_matrix

Graph Representation

- Drawing
- Adjacency list
- Adjacency matrix

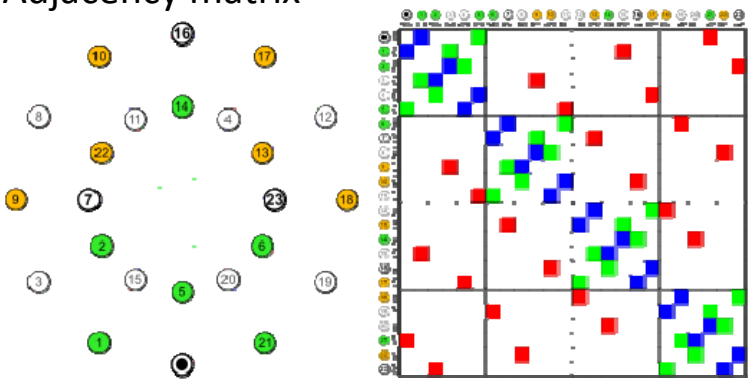


	1	2	3	4
1	0	1	1	1
2	0	0	1	0
3	1	0	0	1
4	1	0	1	0



Graph Representation

- Drawing
- Adjacency list
- Adjacency matrix



Nauru graph

http://en.wikipedia.org/wiki/Adjacency_matrix

Euler Characteristic

- The **Euler characteristic** χ was classically defined for the surfaces of polyhedra, according to the formula

  $\chi = V - E + F$

  where V, E, and F are respectively the numbers of vertices(corners), edges and faces in the given polyhedron.
- (Convex surface = 2)

- Graphs can have cycles
- Graph edges can be directed or undirected
- The degree of a **vertex** is the number of **edges** connected to it
- Nodes/vertices
  - *Degree of a vertex is the number of its edges*
    - In-degree and out-degree for directed graphs
- Edges/links
  - Common to associate *weights with edges*
    - Cost to travel on that edge (road networks, etc)

Real World Examples

- In information visualization, any number of data sets can be modeled as a graph
  - WWW
  - Phone System
  - Social network

Main Challenges

- Graph layout and positioning
  - No intrinsic position info
- Navigation/Interaction
  - Change focus
  - Navigate graph
- Scale
  - Large graph → Perceptual and technical limits

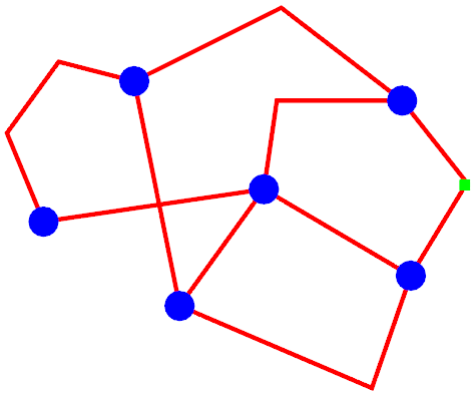
Graph Positioning

Constrains and Requirements

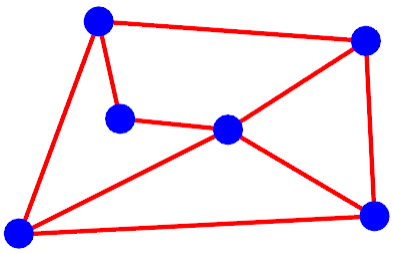
- Minimize edge crossings
- Minimize total edge length
- Minimize area of graph
- Minimize longest edge
- Make edge lengths uniform
- Minimize number of edge bends
- … …

Impossible to satisfy all constraints!

Graph Drawing Conventions

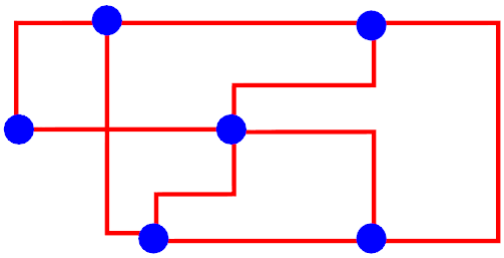


Poly-line drawing

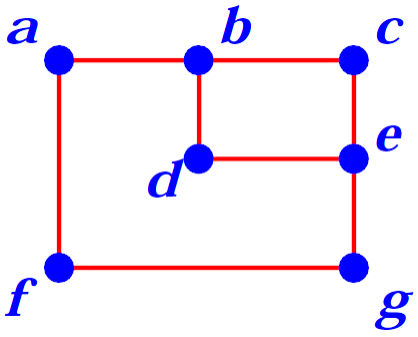


Straight-line drawing

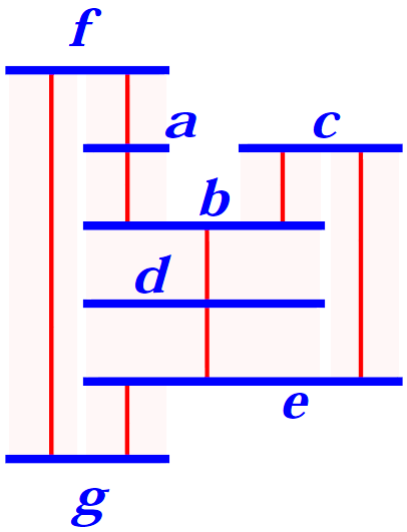
Graph Drawing Conventions



Orthogonal drawing

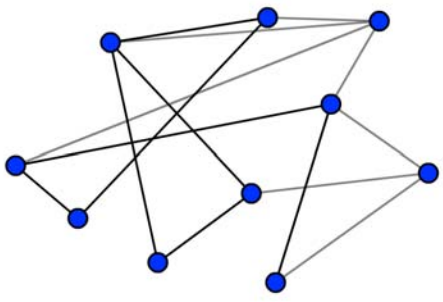


Orthogonal Straight-line drawing



strong visibility representation

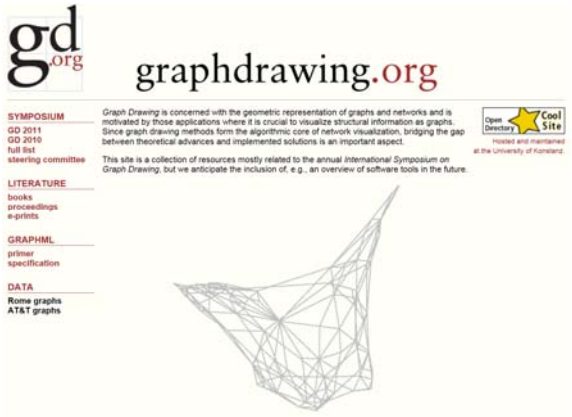
- Impossible to satisfy all constraints!



- Question: The most important contain?

  Most cases: Edge crossing

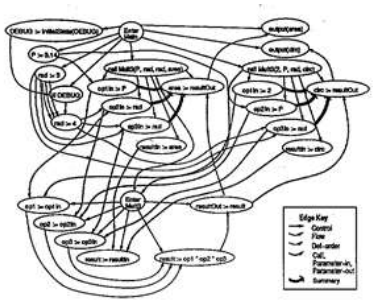
- Large research community on graph drawing
- http://www.graphdrawing.org/



Vertex and Edge

Vertex
- Shape
- Color
- Size
- Location
- Label
- Spring

Edge
- Color
- Size
- Label
- Form



Software Development
http://www.umcs.maine.edu/~ftp/wisr/wisr9/final-papers/Mili.gif

NetViz Nirvana

- Every node is visible
- Every node's degree is countable
- Every edge can be followed from source to destination
- Clusters and outliers are identifiable

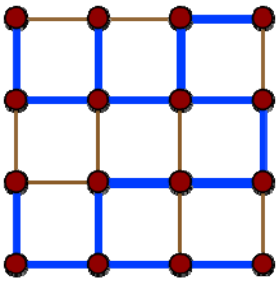
[Dunne and Shneiderman, 2009]

Common Graph Layout Techniques

- Hierarchical
- Force-directed
- Circular
- Geographic-based
- Clustered
- Attribute-based
- Matrix

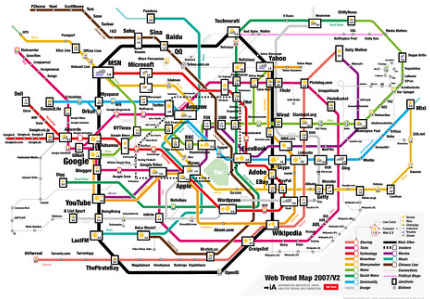
Hierarchical Layout

- Many graphs have a tree-like structure
- Simple layout idea
- Compute **spanning tree** of graph
- Lay out tree using tree layout algorithm
- Add edges for full graph



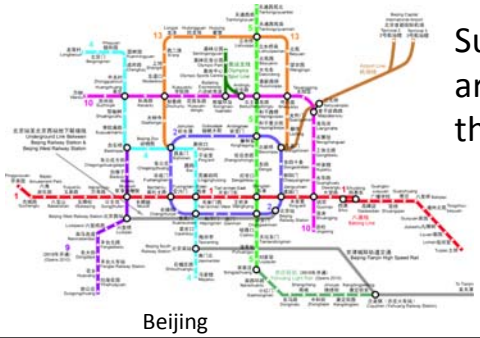
- High performance, not always optimal results

http://en.wikipedia.org/wiki/Spanning_tree



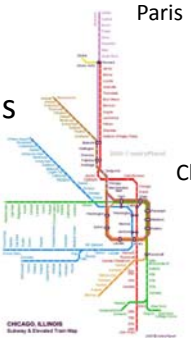
New York

Paris



Beijing

Subway Maps are more graphs than maps



Chicago

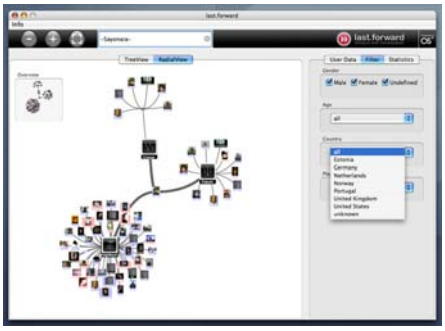
Motivations

Commercial Software

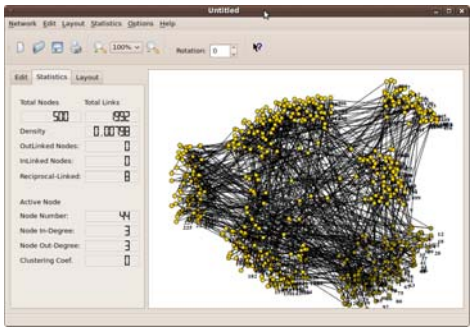
- A range of different relationship types are supported. Edges can be directed, undirected, and can show flow in both directions.
- Text and numerical attributes can be associated with nodes and edges. Tables display the attributes and allow sorting.
- Images can be associated with nodes.
- Advanced cluster computation reveals inherent groupings.
- Co-citations and co-occurrence analysis clarifies dense networks.

TouchGraph.com

Social Network



Last.Forward



SocNetV

Music Visualization

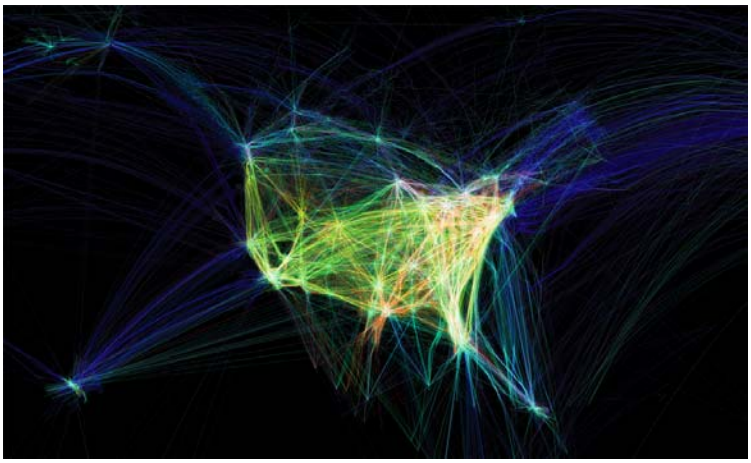
- Example:
  - The Shape of Song
  - Live plasma

http://www.liveplasma.com/

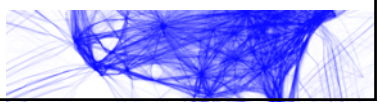
Madonna, Like A Prayer

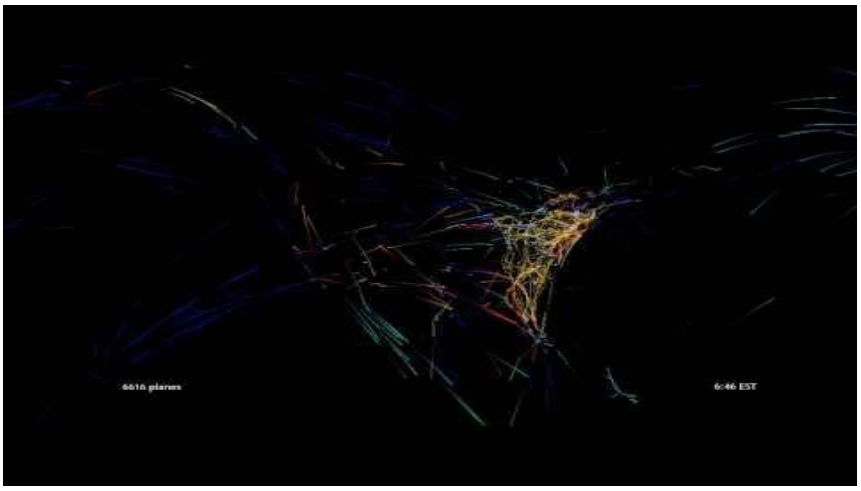
Bach, Three of the Goldberg Variations

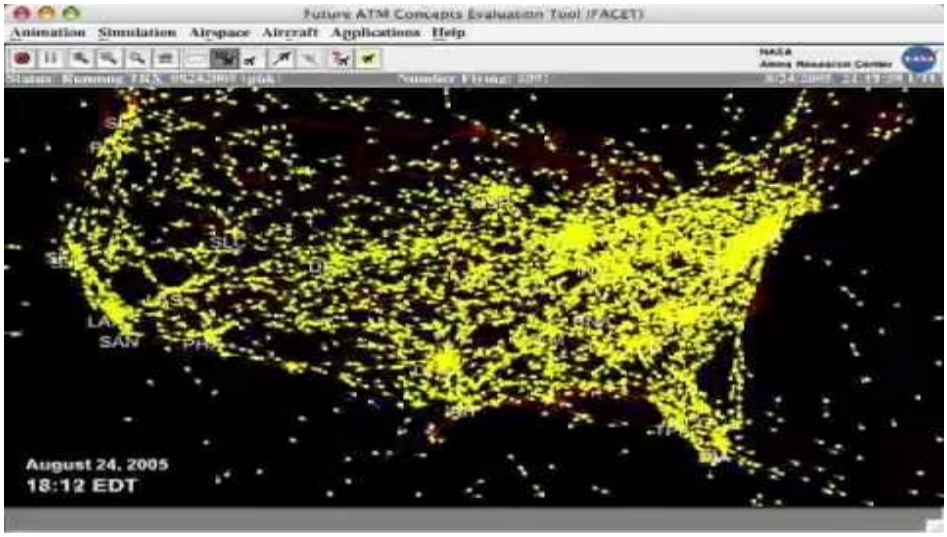
Fly Pattern (Aaron Koblin)



National Science Foundation 1st Pl. Science Visualization

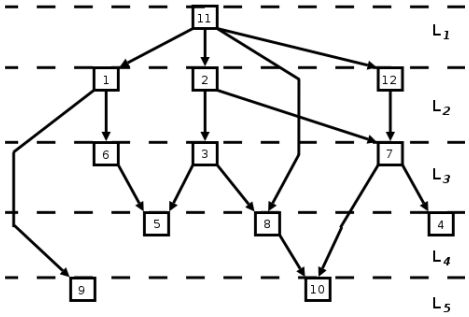



6:46 EST


Future ATM Concepts Evaluation Tool (FACET)
Animation Simulation Airspace Aircraft Applications Help
August 24, 2005
18:12 EDT

Hierarchical Layout

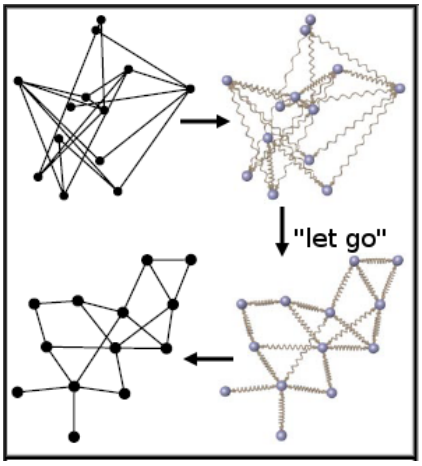
- Also called Sugiyama layout



http://www.csse.monash.edu.au/hons/se-projects/2006/Kieran.Simpson/output/html/node7.html#sugiyamaexample

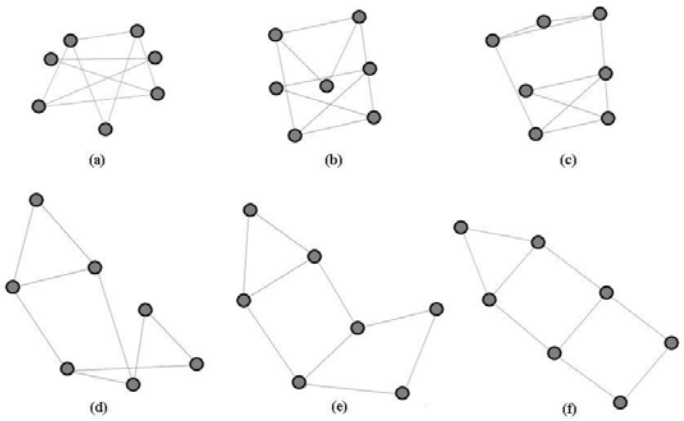
Force-Directed Layout

- Spring model (common)
- Edges –Springs (gravity attraction)
- Vertices –Charged particles (repulsion)
- Equations for forces
- Iteratively recalculate to update positions of vertices

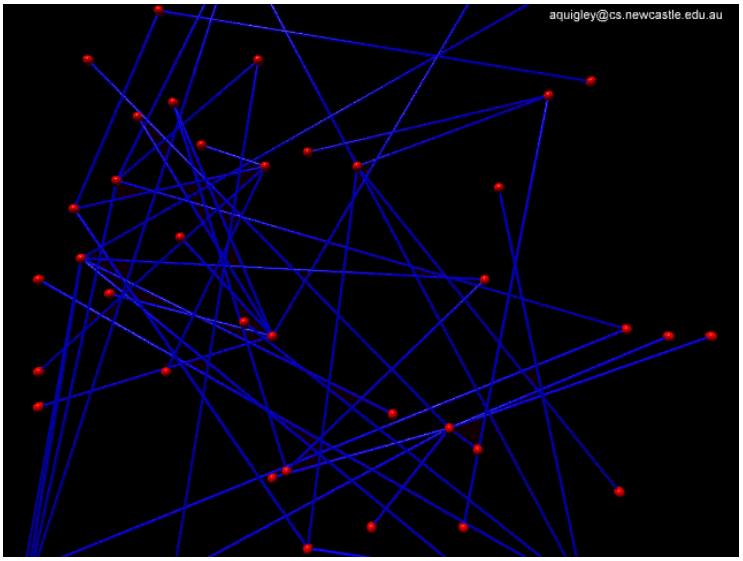


Spring model

http://www.csse.monash.edu.au/hons/se-projects/2006/Kieran.Simpson/output/html/node8.html



A graph drawing through a number of iterations of a force directed algorithm

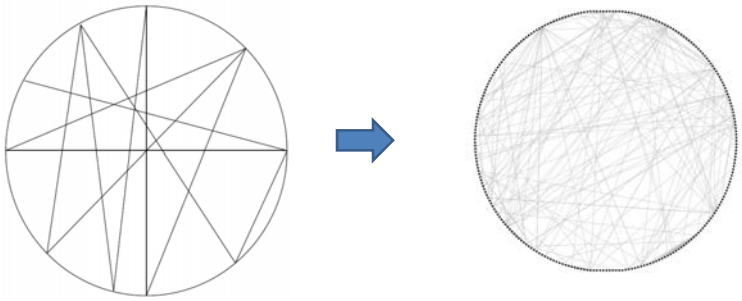


Spring Model

http://rp-www.cs.usyd.edu.au/~aquigley/3dfade/

Circular Layout

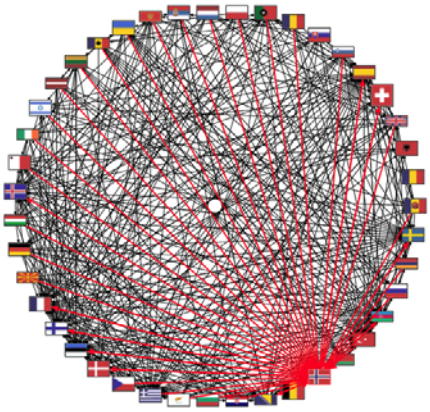
- Extremely simple



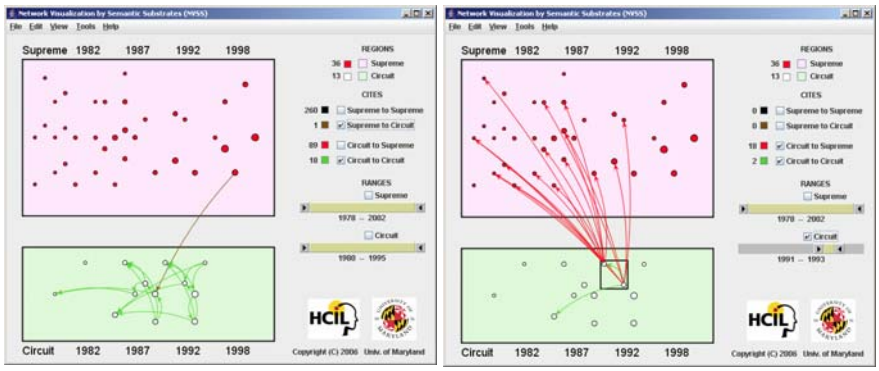
Many improvements.

Eurovision Song Contest

- Annual competition held among active member countries of the European Broadcasting Union (EBU).
- Each member country submits a song to be performed on live television and then casts votes for the other countries' songs to determine the most popular song in the competition.
- Each country participates via one of their national EBU-member television stations, whose task it is to select a singer and a song to represent their country in the international competition.



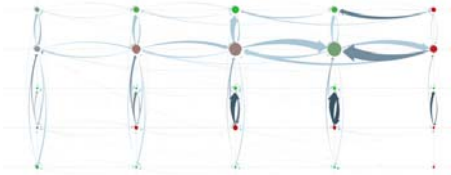
Network Visualization by Semantic Substrates

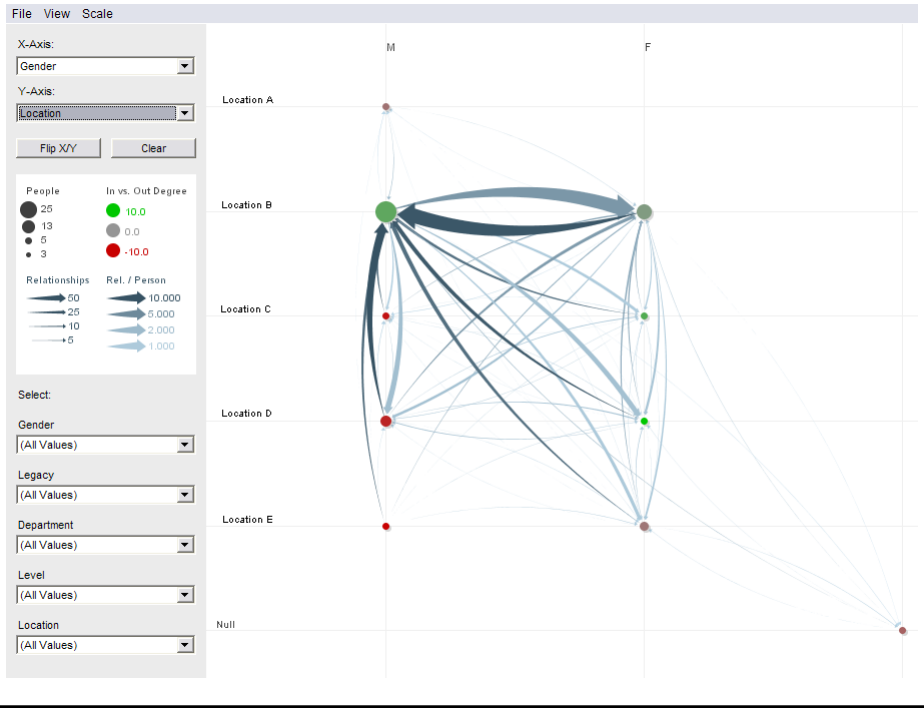


http://www.cs.umd.edu/hcil/nvss/#video

PivotGraph

- Cluster on common node attributes
  - Put all A‟s together, all B‟s together, …
- Edges show how they are related
  - Draw edge from A to B depending on how many edges from some A to some B
- Position nodes into a grid based on attributes
- Node size represent number for each value





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