7. Hierarchies & Trees
Visualizing topological relations

Vorlesung „Informationsvisualisierung”

Prof. Dr. Andreas Butz, WS 2009/10

Konzept und Basis für Folien: Thorsten Büring

Outline

- Hierarchical data and tree representations
- 2D Node-link diagrams
  - Hyperbolic Tree Browser
  - SpaceTree
  - Cheops
  - Degree of interest tree
  - 3D Node-link diagrams
- Enclosure
  - Treemap
  - Ordererd Treemaps
  - Various examples
  - Voronoi treemap
  - 3D Treemaps
- Circular visualizations
- Space-filling node-link diagram

Hierarchical Data

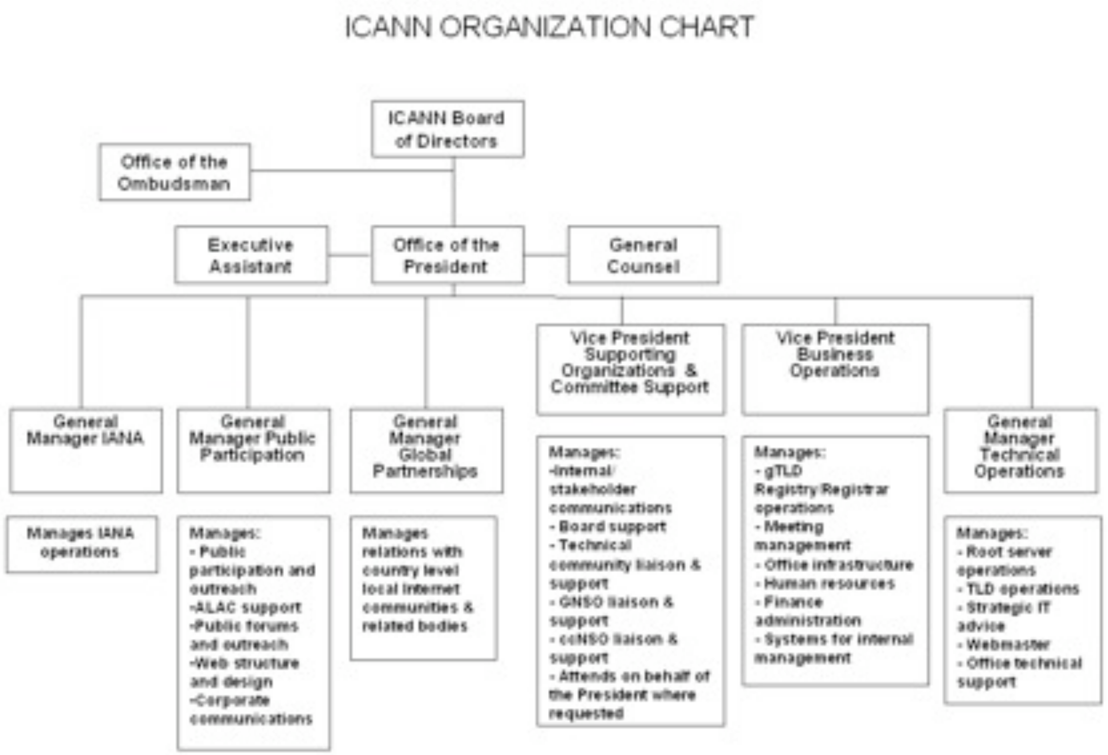
- Card et al. 1999: data repository in which data cases are related to subcases
- Many data collections have an inherent hierarchical organization
  - Organizational Charts
  - Websites (approximately hierarchical)
  - File system
  - Family tree
  - OO programming

Yee et al. 2001

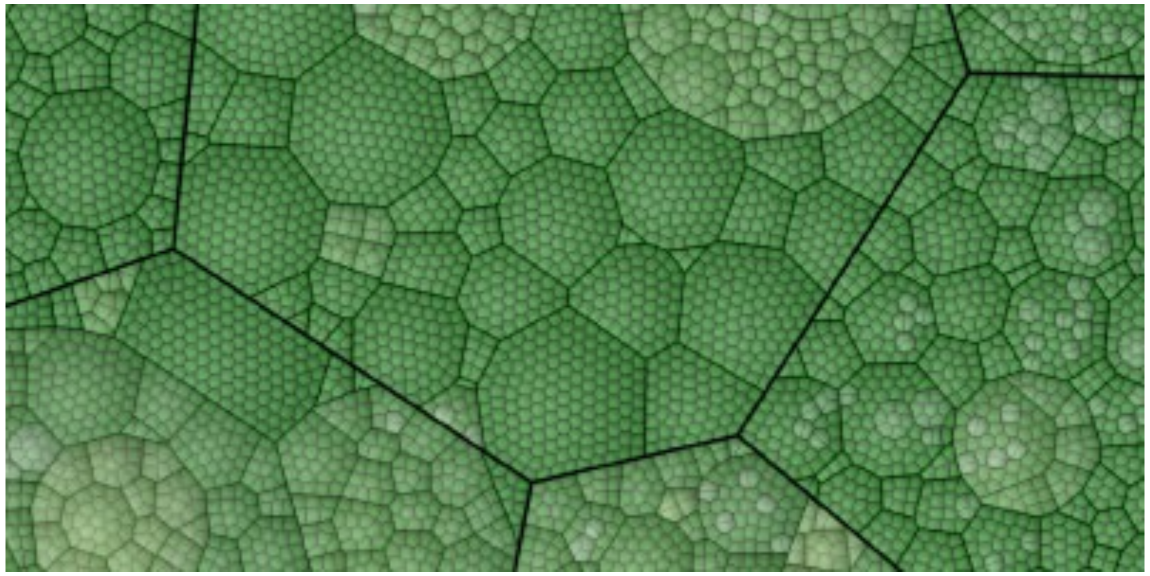
- Hierarchies are usually represented as tree visual structures
- Trees tend to be easier to lay out and interpret than networks (e.g. no cycles)
- But: as shown in the example, networks may in some cases be visualized as a tree

Tree Representations

- Two kinds of representations
- Node-link diagram (see previous lecture): represent connections as edges between vertices (data cases)
- Enclosure: space-filling approaches by visually nesting the hierarchy

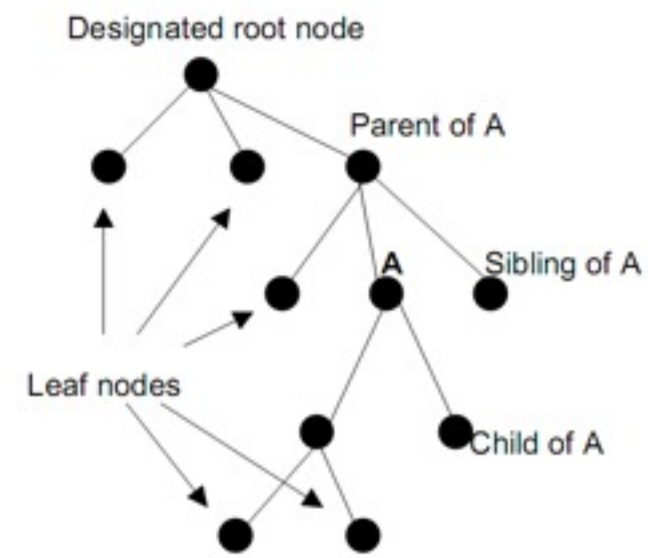


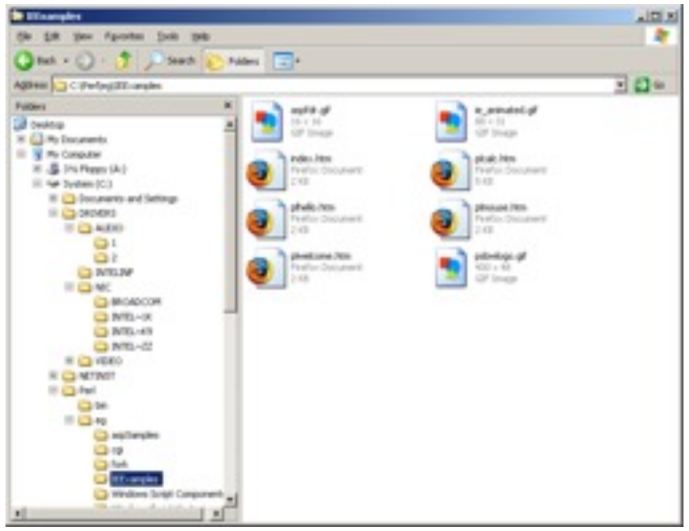
http://www.icann.org

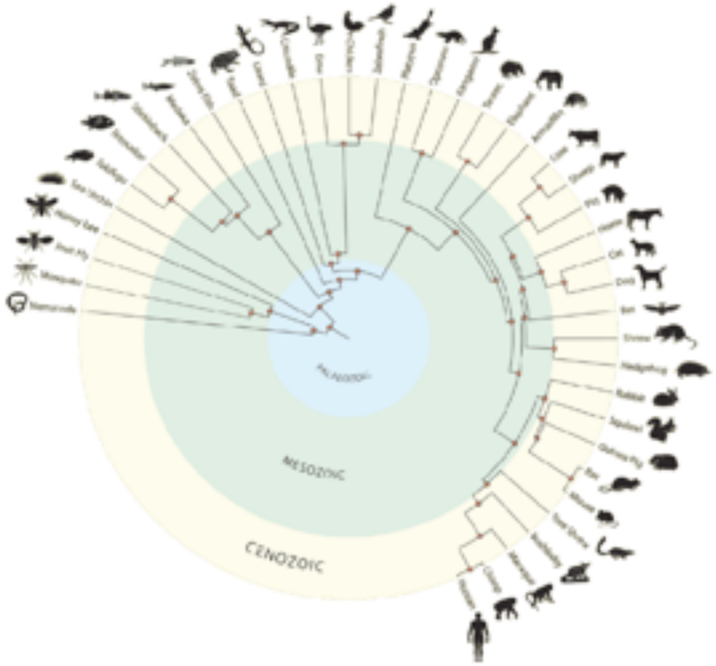


Node-Link Diagram

- Most conventional layout
  - Tree-depth is mapped to an ordinal Y-axis
  - X-axis is nominal – mainly used to separate siblings
- Can also be turned around
- Circular layout – root in the center with levels growing outward







Node-Link Diagram

- Unlike space-filling methods node-link diagrams provide an effective overview of the topology of a tree
- Problems
- Large trees require an extreme aspect ratio
  - Example: branching factor of 2
  - Width: Trees gets wider approximately proportionally 2^n (n= level)
  - Height: Only proportionally to n
  - Large trees become to resemble a straight line
- Trees usually contain considerably empty space (about 50%)
- InfoVis approaches to address these problems
  - Interaction
  - Distortion

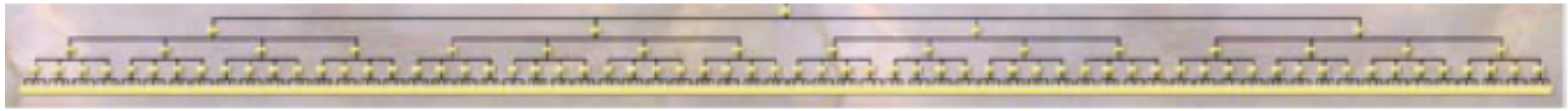


Image from: http://davenation.com/doitree/doitree-avi-2002.htm

Hyperbolic Tree Browser

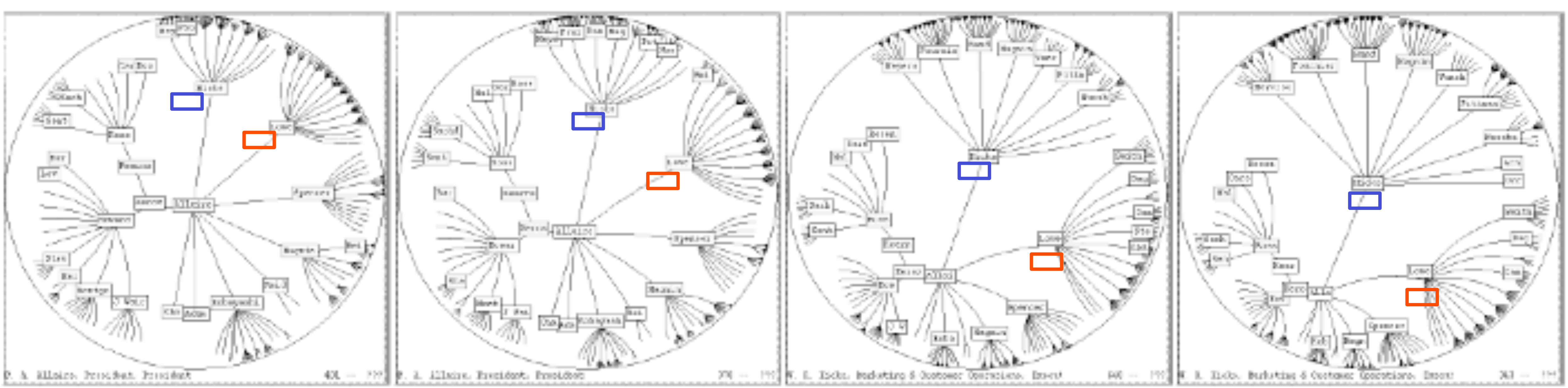
Inspiration:
Circle Limit IV
M.C. Escher

- Lamping et al. 1995
- Comparable to fisheye distorion
  - Nodes in the center are displayed at higher granularity
  - Neighboring nodes are displayed in diminishing size
- Maximum number of nodes displayed in a 600 x 600 pixel window
  - Standard 2D hierarchy browser: typically 100 nodes with 3 characters text labels
  - Hyperbolic browser: can display 1000 nodes with 50 nearest the focus can show from 3 to dozens of characters text labels
- Approach exploits hyperbolic geometry
  - Lay out hierarchy on hyperbolic plane and map plane onto a circular display region
  - Property of hyperbolic plane: circumference of a circle grows exponentially with its radius
  - Hierarchies tend to expand exponentially with depth
  - Elegant match!

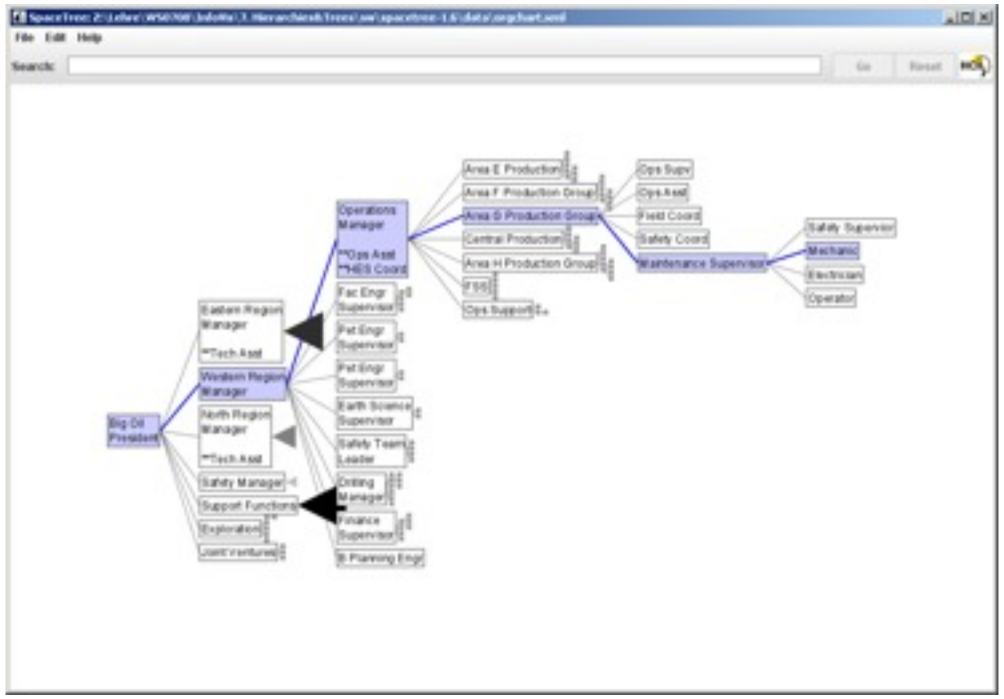
Hyperbolic Tree Browser

- Navigation: users select nodes to become the new center node (animated transitions)
- Potential problem with orientation:
  - nodes rotate during pure translation, e.g. node “Lowe” moves from top right to bottom right
  - Not suitable to present data such as organizational charts
- Small-scale user test (4 subjects, within-subjects design, IV: type of browser, DV: number of actions, time, preference)
  - No significant performance advantage over a 2D hierarchy browser with horizontal tree layout
  - Participants preferred the hyperbolic tree browser - provided “weaker sense of directionality of links”, but helped to “get(ting) a sense of the overall tree structure”
- http://www.inxight.com/products/sdks/st/index.php - Demo

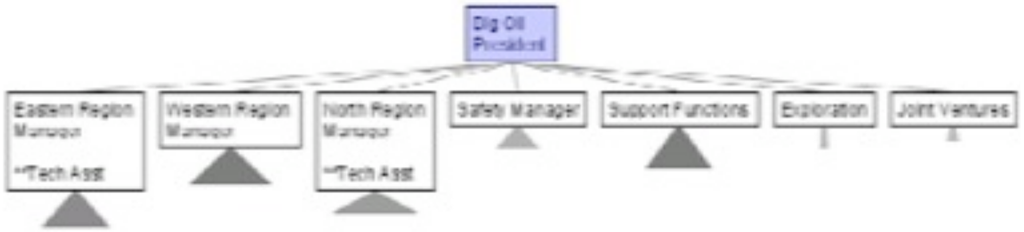
Lamping et al. 1995



SpaceTree



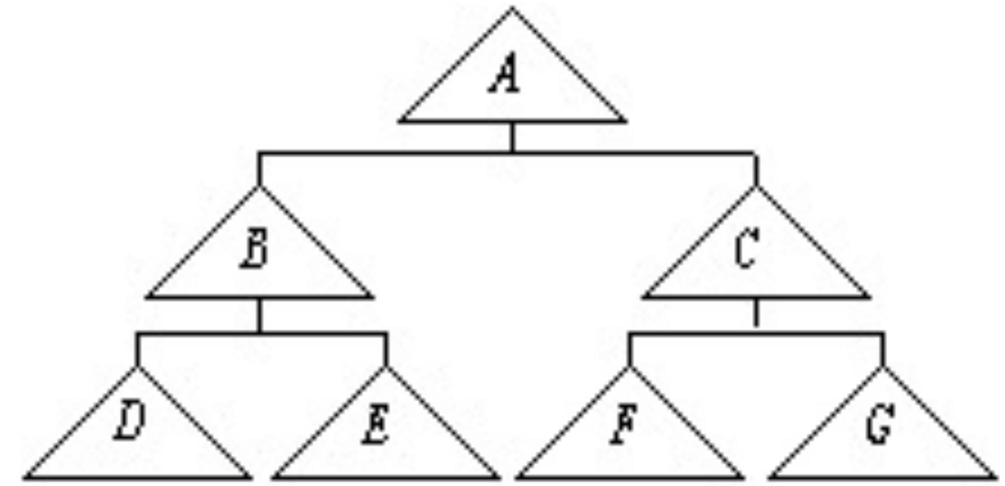
- Plaisant et al. 2002
- Mechanisms to facilitate large tree exploration / navigation
  - Dynamic rescaling of branches to fit the screen
    - De-composed animated transitions
  - Optimized camera movement
  - Preview icons summarizing branches collapsed (see top-down order)
    - Shading of triangle is proportional to the total number of nodes in the subtree
    - Height of triangle represents depth of subtree
    - Base of triangle proportional to average width (number of items / depth)
  - Search and filter functionality
- Movie



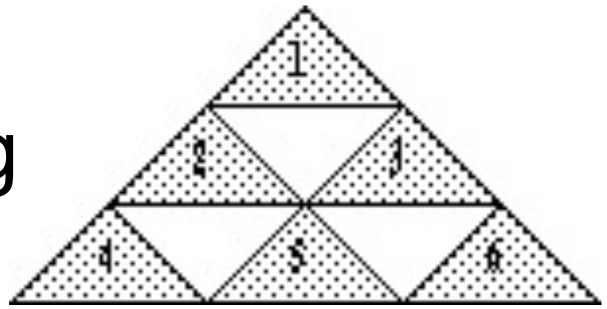
SpaceTree

- Experiment comparing 3 tree-browsing interfaces
  - Microsoft Explorer
  - Hyperbolic tree browser
  - SpaceTree
- Counterbalanced repeated-measures within-subject design
- 18 participants
- Tree with 7000 nodes
- Three task types
  - Node searches
  - Search of previously visited nodes
  - Answering topology questions
- Results
  - Hardly significant performance differences between the interfaces
  - Users found MS Explorer significantly less attractive then the other two interfaces

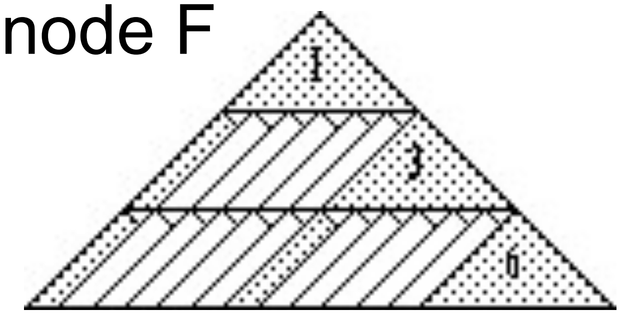
Cheops



- Beaudoin et al. 1996
- Exploring and navigating large graphs
  - Maintain context
  - Provide easy access to details

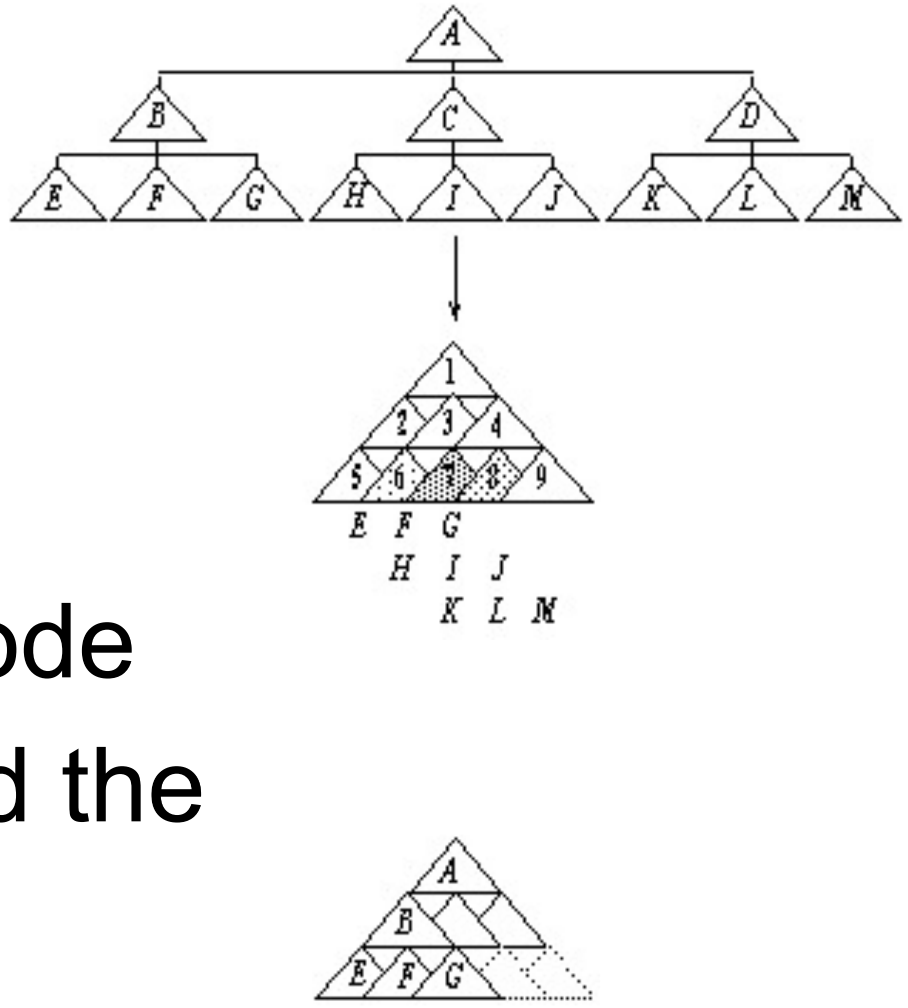


- Cheops provides effective compression by reusing visual components based on interaction
- Compress the hierarchy by tessellation of triangles
  - In the example triangle 5 could represent either node E or node F
  - If triangle 2 is selected, triangle 5 will become node E …
  - Overlapping triangles to indicate larger hierarchy
  - The example shows an expansion by adding 5 children per parent



- But: users cannot compare topologically remote parts of a structure

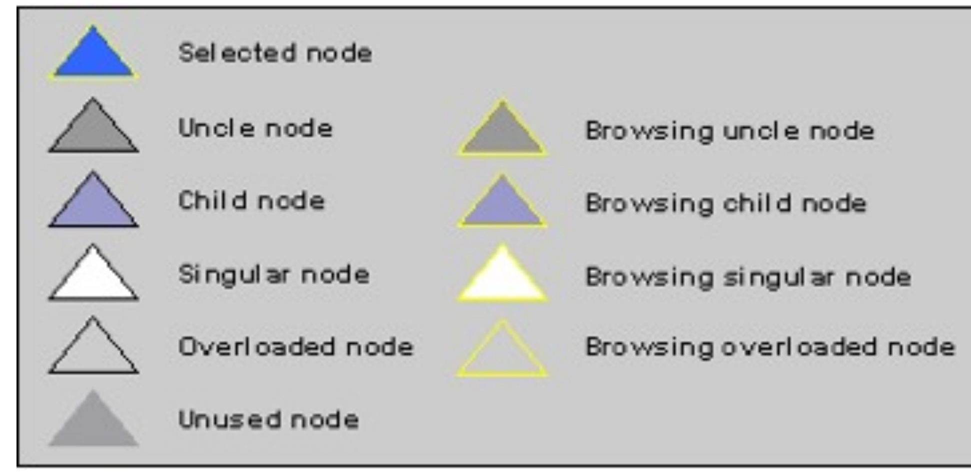
Cheops

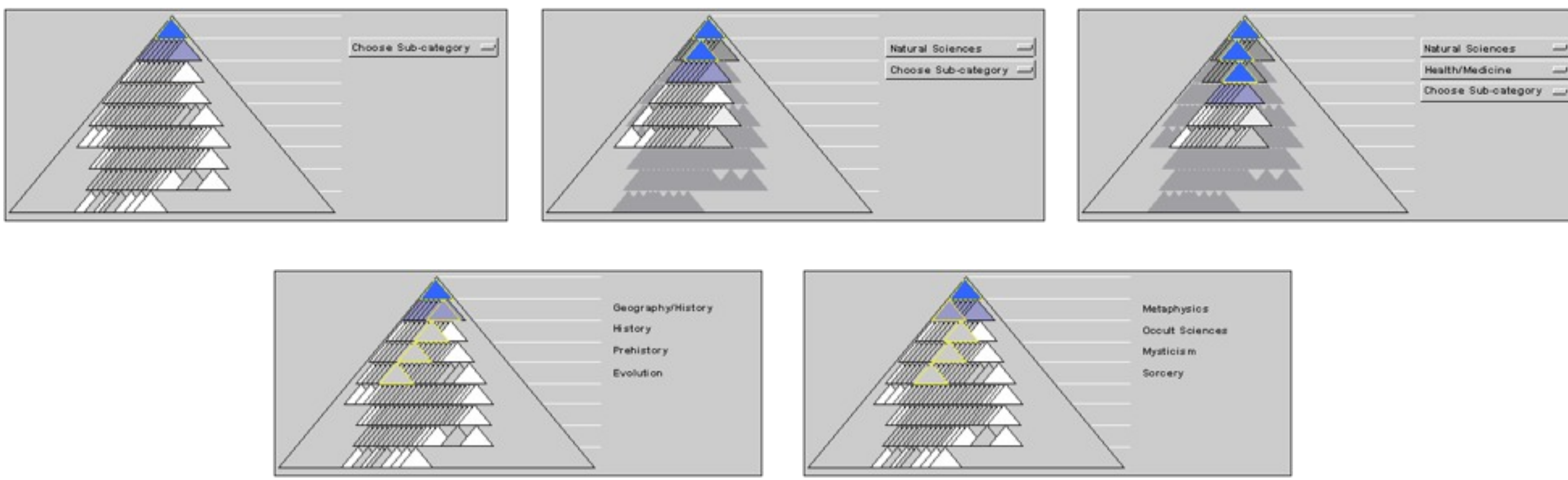


- Another example
- Three triangles in the last level represent more than one logical node
- If a parent node (e.g. B) is selected the visual components become unambiguous
- Selection of a node implies previous selection of all its parent nodes
- Nodes are represented as paths of visual objects going down from the root – not isolated triangles

Cheops

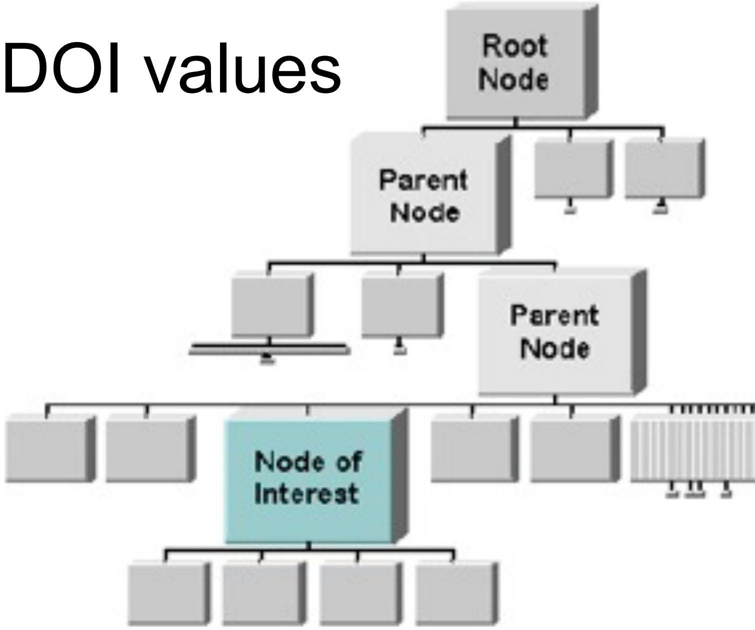
- Visual cues and terminology to aid interpretation of the compressed visualization
- Selection: deployment of branches
- Pre-selection: direct access to any node





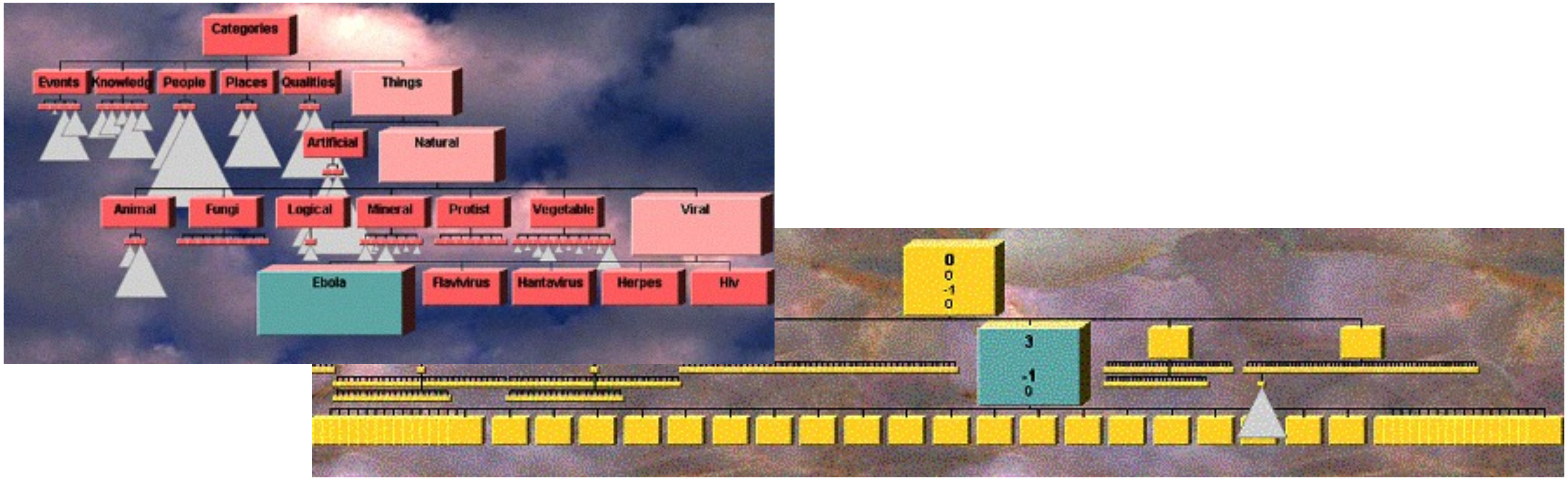
Degree of Interest (DOI) Tree

- Nation et al. 2002
- For interactive display of hierarchies within a web browser
- Based on Furnas Degree-of-interest function
  - Each node is assigned a value
  - Degree-of-interest value is determined by a function of a node’s distance from the root of the tree and its distance from the focus of interest
  - Topic of later lecture on focus+context presentation techniques!
- DOITree
  - Upon selection: focused node is allocated most space
  - Remaining space is allocated to nodes based on their DOI values
  - Nodes with more space present more details



Degree of Interest Tree

- Animated transitions
- Reset the tree layout by clicking on the root node
- Tree does not fit the screen in the Y-dimension
  - Prune parts of the tree below a given DOI threshold
  - Pruned branch is represented by a symbol
- Tree does not fit the screen in the X-dimension – visually compress peripheral nodes



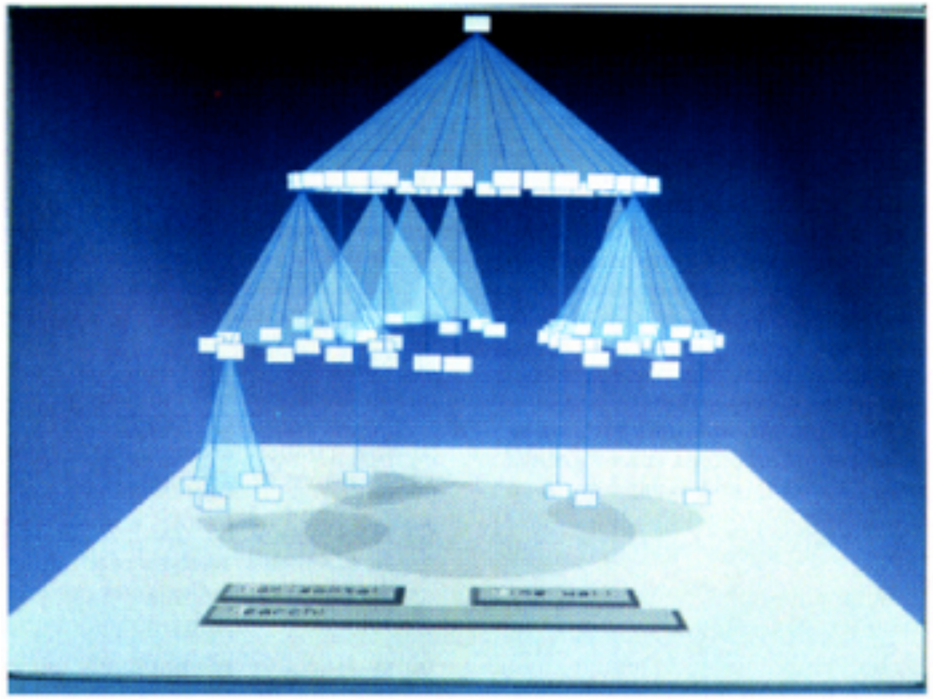
Images from: http://davenation.com/doitree/doitree-avi-2002.htm

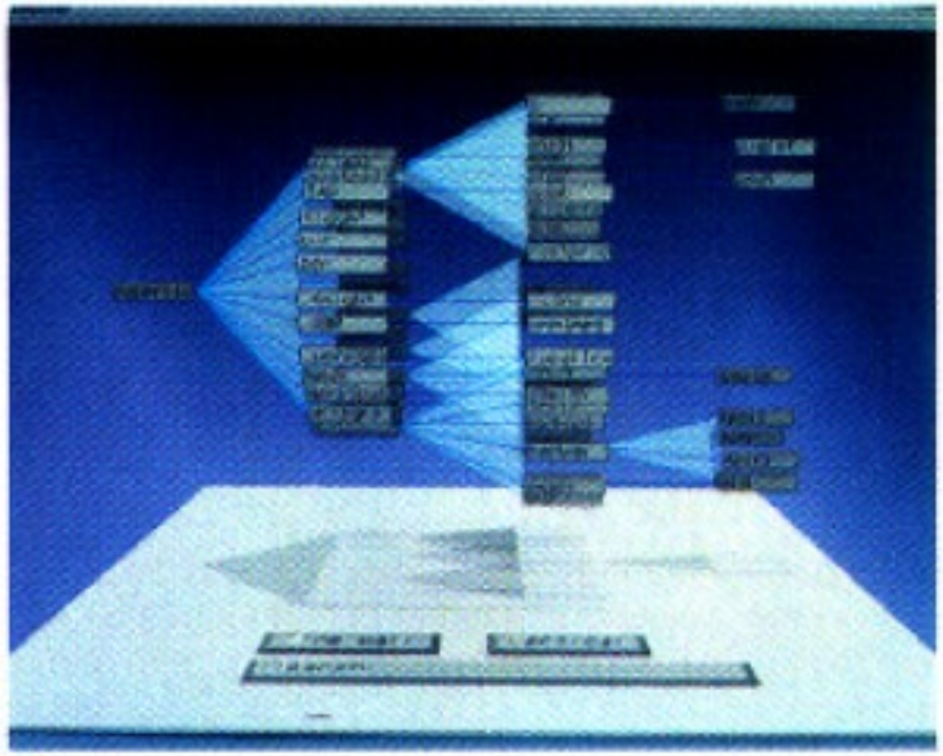
3D Approaches

- Why not use an additional dimension to visualize nodes that would otherwise be pruned / collapsed?
  - Cone Tree
  - H3Viewer
- HCI research produced mixed results about the usability of 3D interfaces
- Ongoing research question: do 2D interfaces better exploit the abilities of the human perceptual system?
  - Utilize spatial memory?
  - Controlling 3D navigation with 2D input devices?
- 3D node-link approaches have been mainly researched in the 90s

Cone Tree

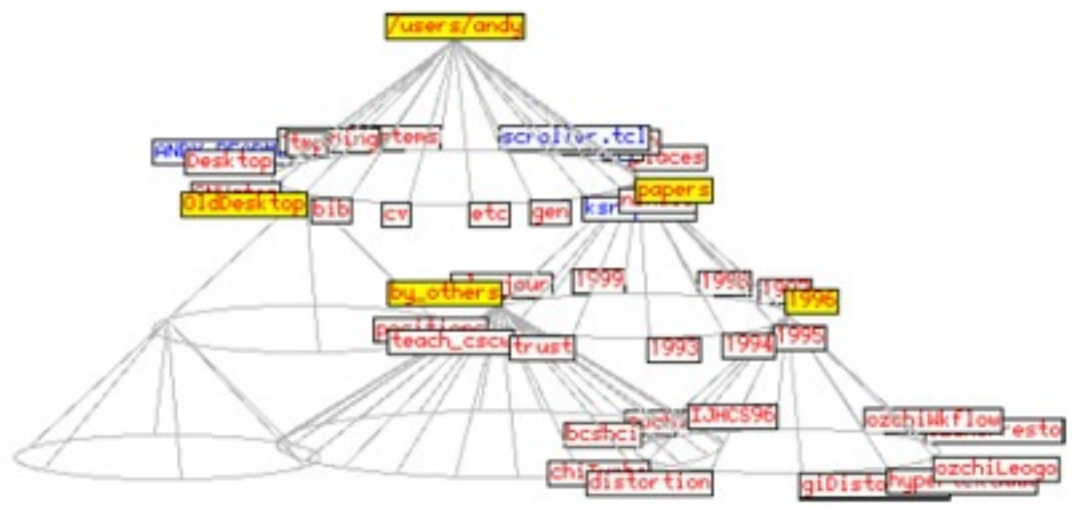
- Robertson et al. 1991
- Use depth to make more effective use of screen space
- Hierarchies laid out uniformly in three dimensions
- When a node is selected by a user the tree rotates to bring the node to the front
- Animation to make the users comprehend the rotation
- Problem: still clutter and occlusion
- Movie

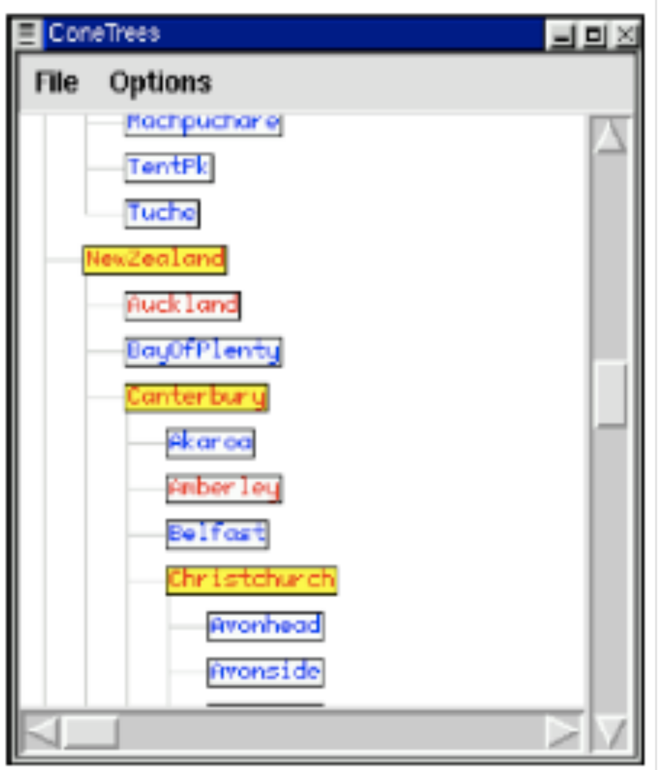




Cone Tree

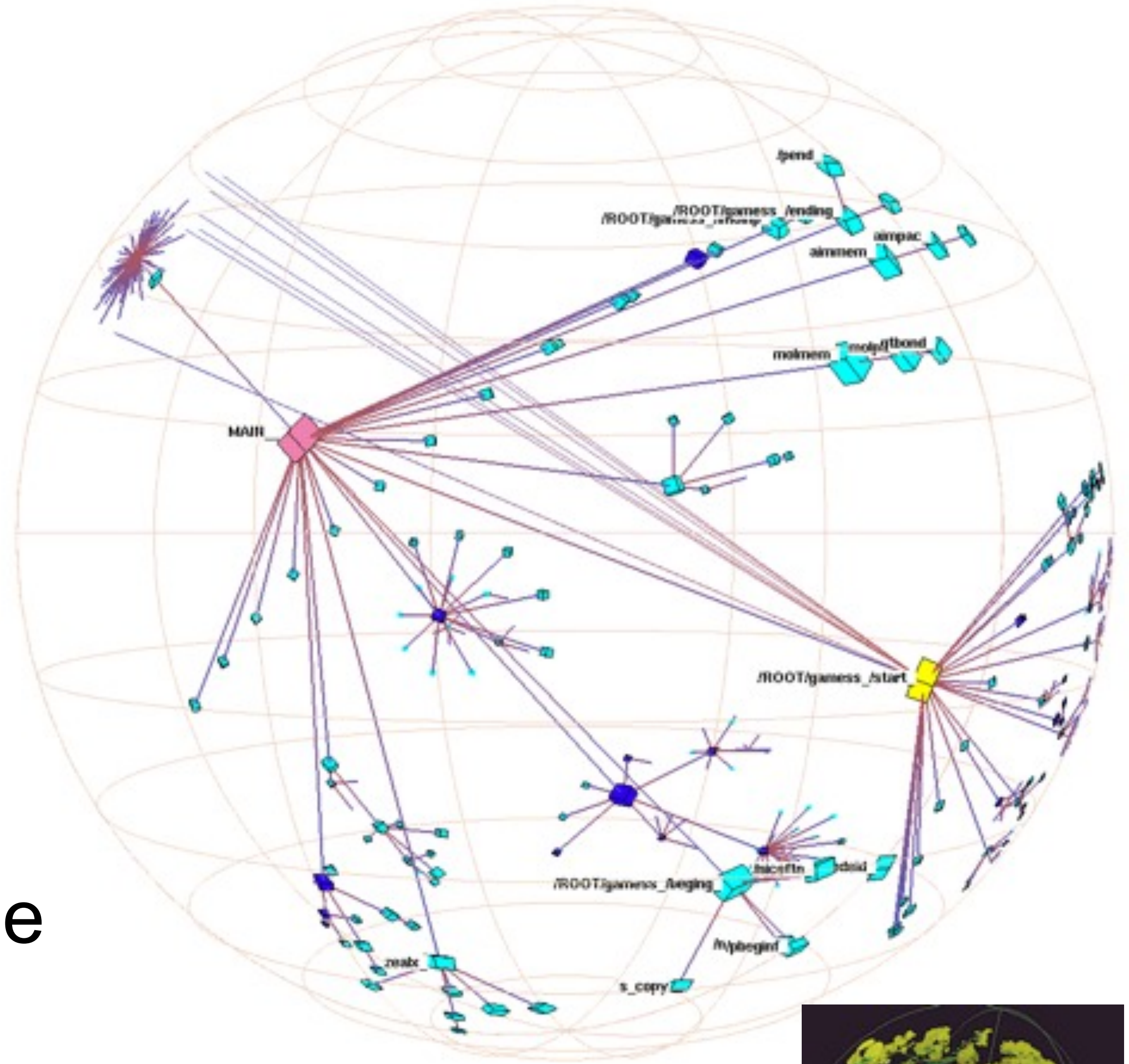
- Usability evaluation by Cockburn & McKenzie 2000
- Compare Cone Tree to conventional explorer-like 2D tree browser
- User test with 12 participants
- Independent variables: depth, density of tree, interface type
- Dependent variables: task-completion time, user preference
- Results
  - Users were slower in locating data using the Cone Tree
  - Performance deteriorated rapidly with a growing branching factor
  - But: participants clearly preferred the Cone Tree…

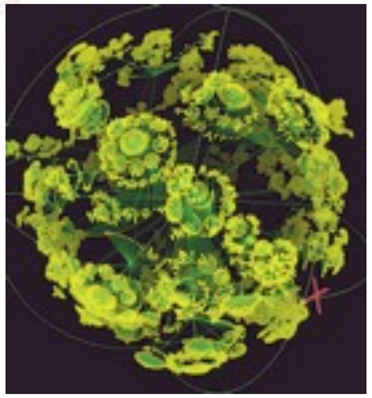


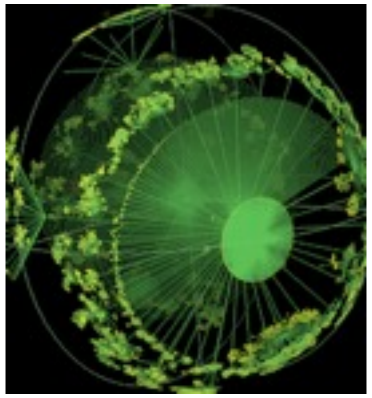


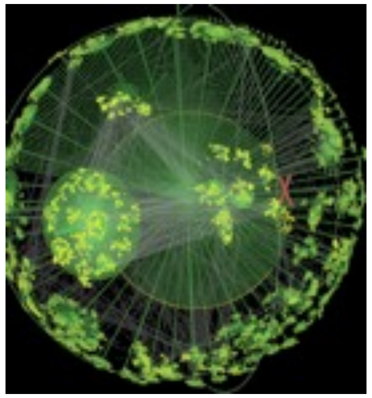
H3Viewer

- Munzner 1997
- H3Viewer supports interactive exploration of large graphs (> 100,000 edges)
- Graph is presented in 3D hyperbolic space
- Child nodes are distributed on the surface of a hemisphere
- Users can drag and rotate graph
- Demo
- Java 3D implementation and gallery: http://www.caida.org/tools/visualization/walrus/









Treemap

- Johnson & Shneiderman1992
- Basic idea
  - Map hierarchical data to rectangular 2D display area by recursively partitioning the screen into rectangular boxes representing nodes
  - Utilize 100% of the screen
- Less good for analyzing the topology of a tree
- Advantages
  - Very effective when focusing on leaf nodes and their attributes
  - More suitable for additional encoding via color, size, shape
  - Present large hierarchies on a single screen

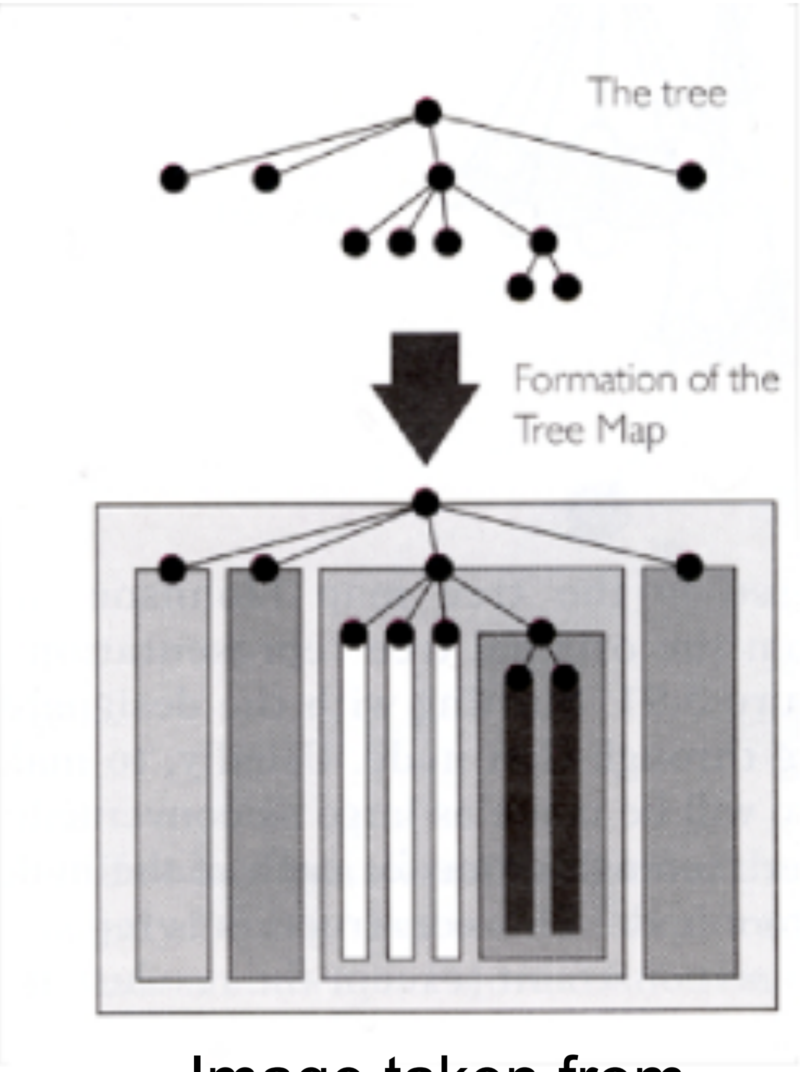
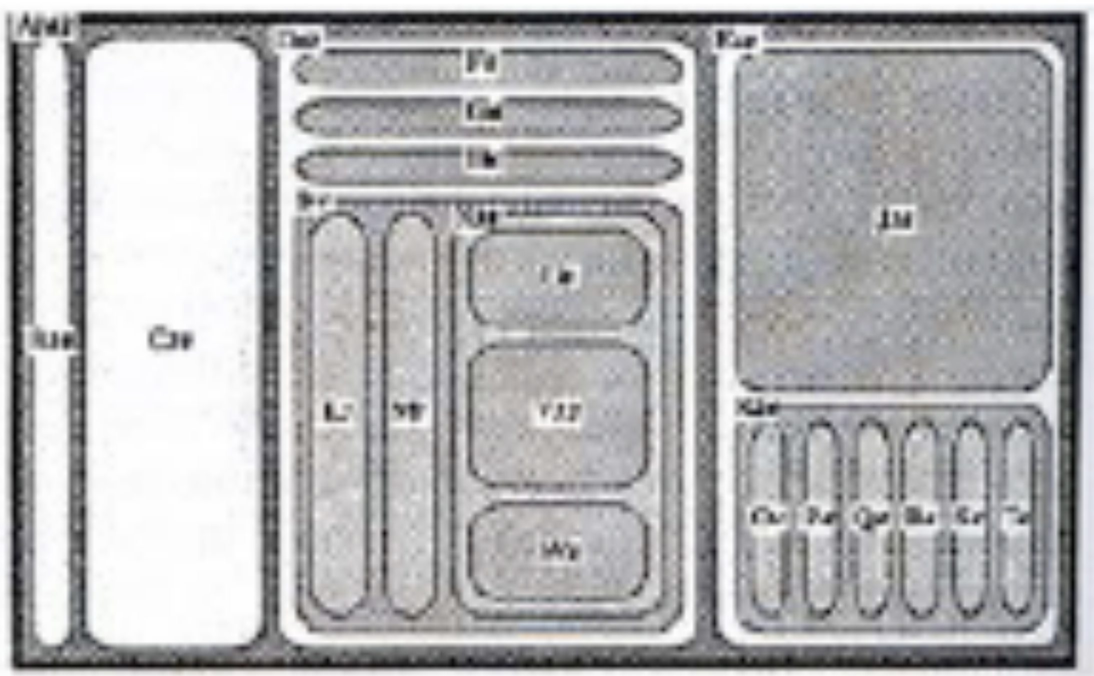
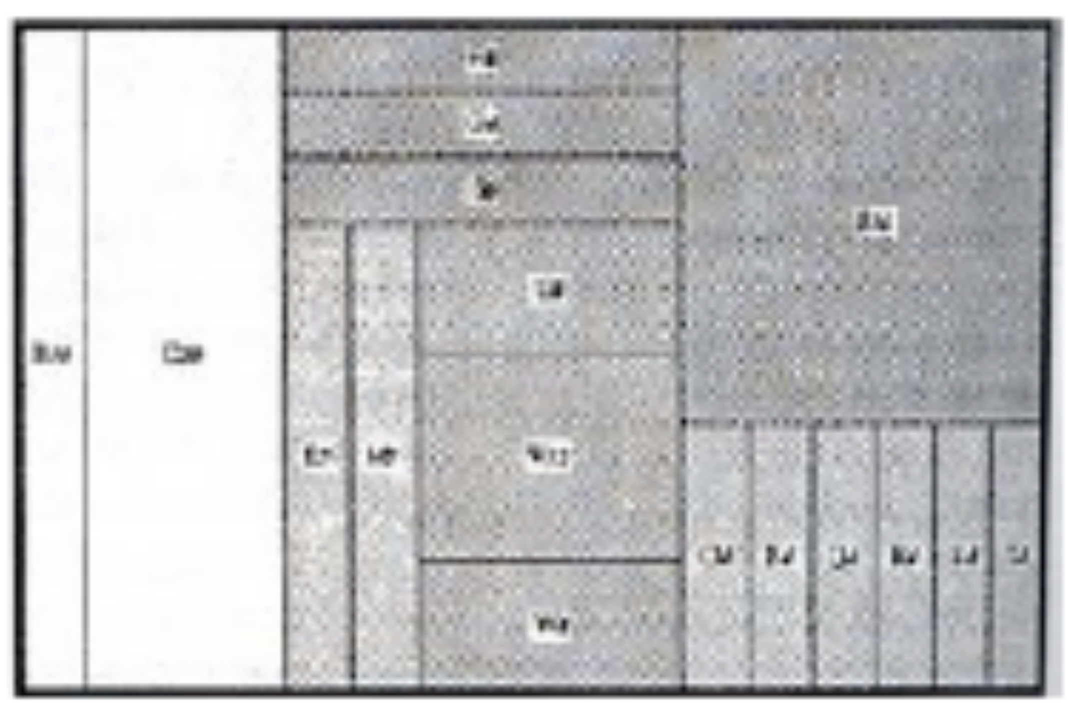


Image taken from Spence 2007

Treemap

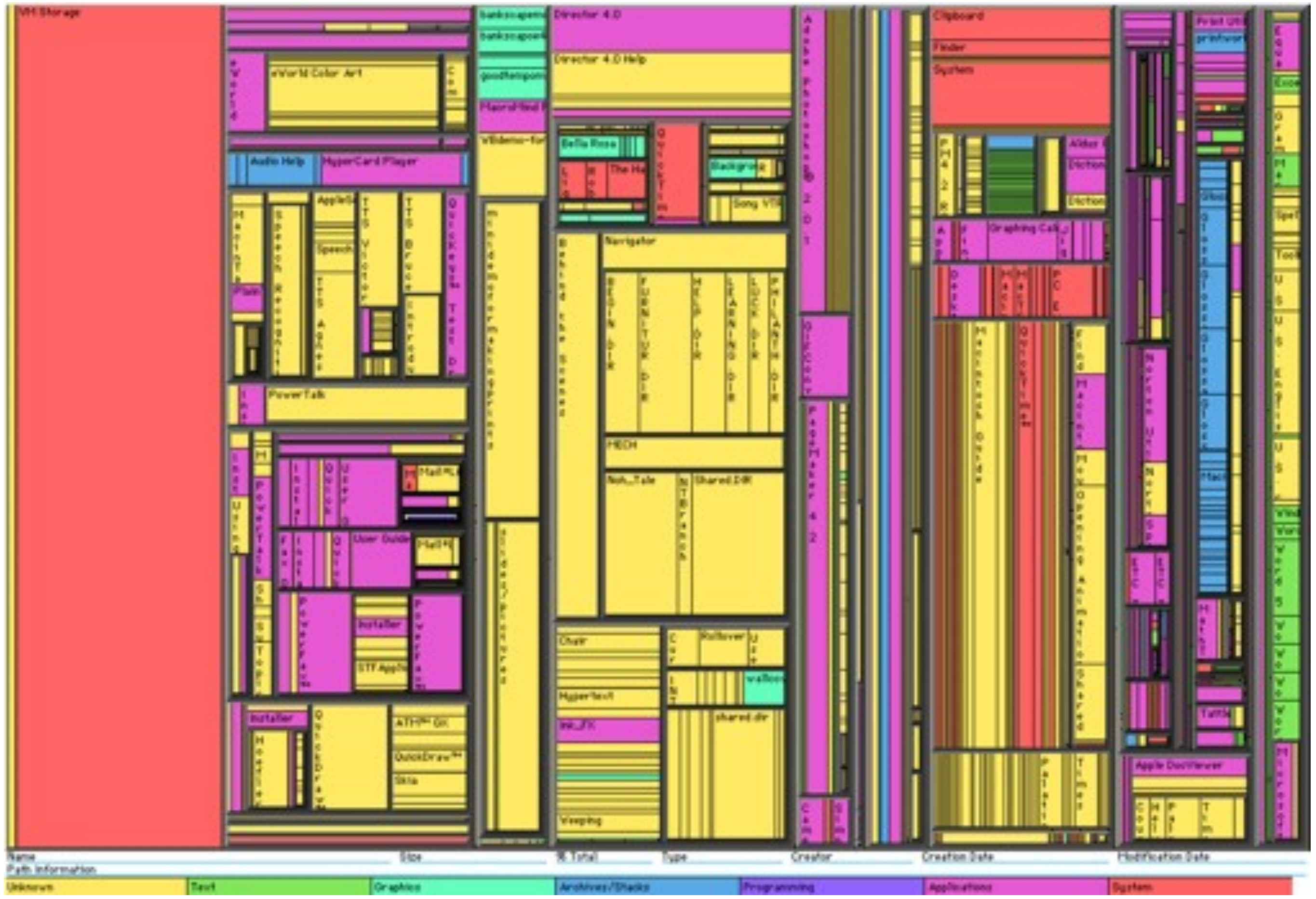
- Nested versus non-nested Treemaps

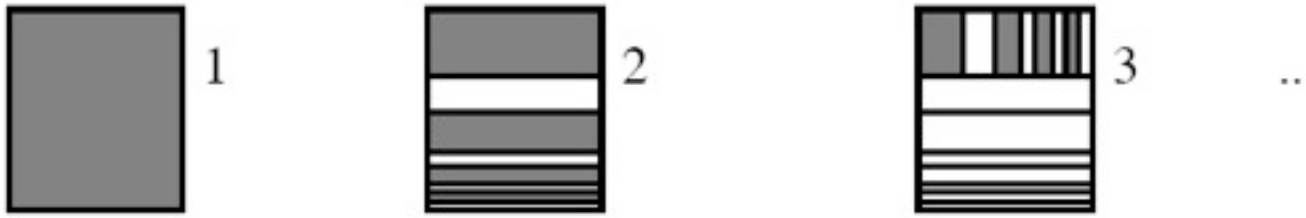




Treemap

- Shneiderman 1992
- Slice and dice algorithm
  - Use parallel lines to divide a rectangle representing an item into smaller rectangles representing the item's children
  - Each child is allocated a size proportional to some property (additional encoding by color)
  - At each level of the hierarchy switch the orientation of the lines (vertical vs. horizontal)
- Example application: file browser
  - Size: file size, color: file type
  - Users can easily identify large file
  - Detect duplicate directories

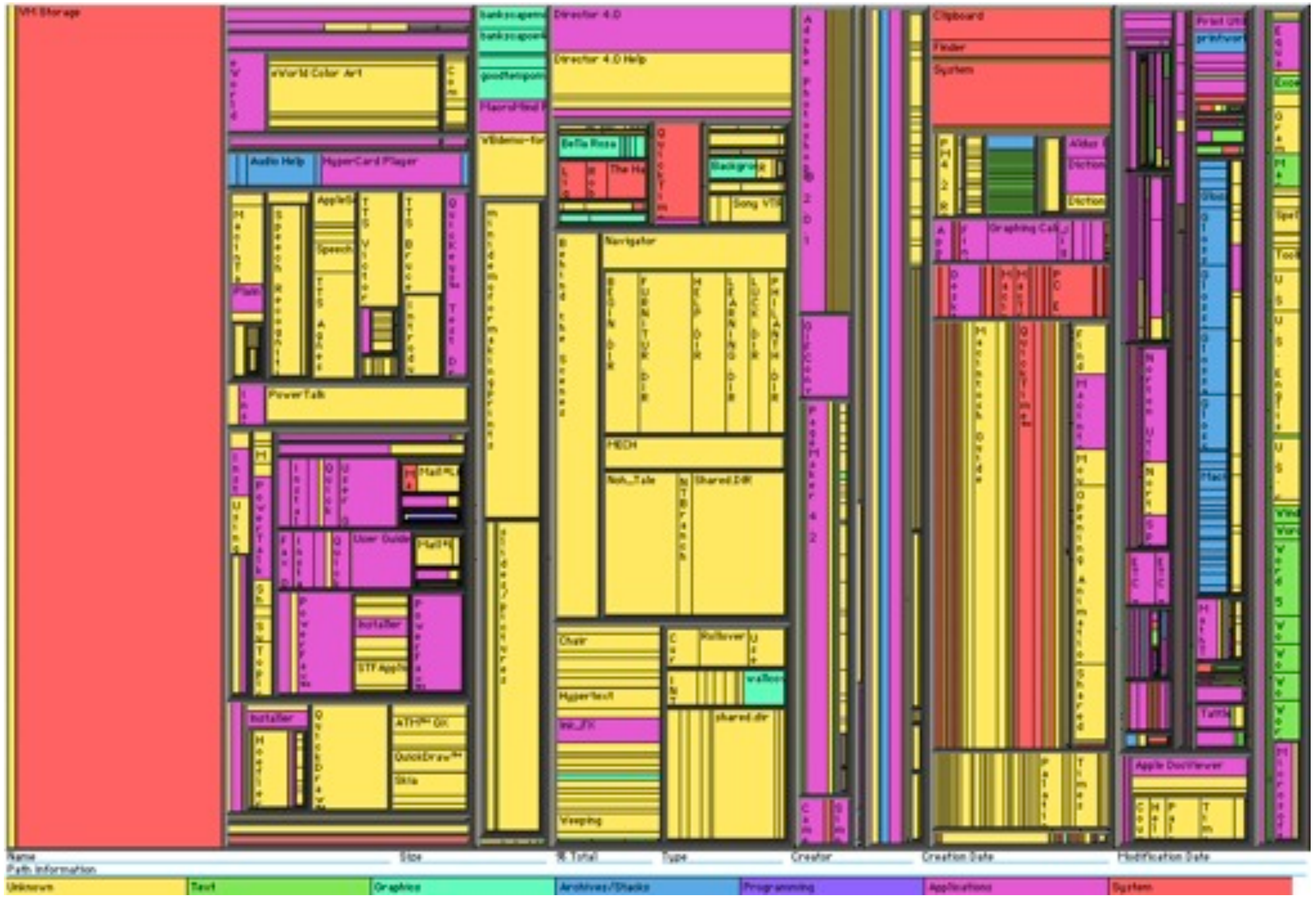




ftp://ftpdim.uqac.ca/pub/ychirico/wvdr2002/nigay.pdf

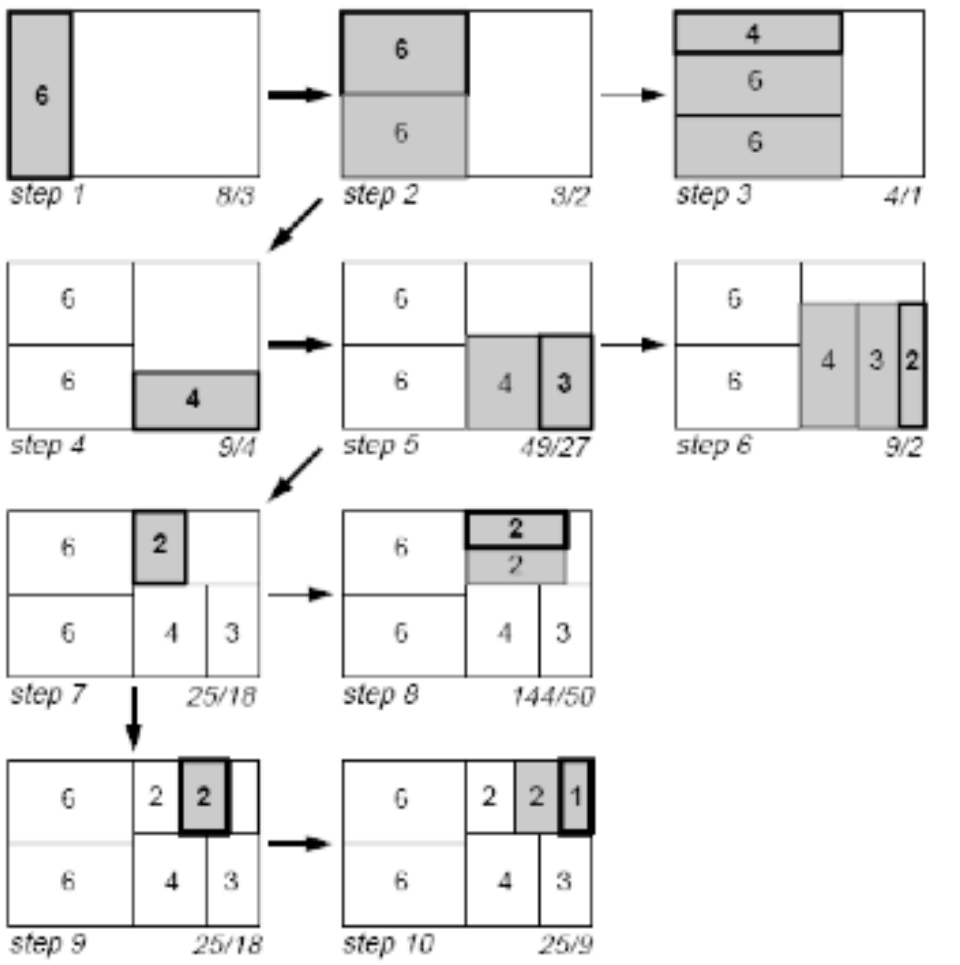
Treemap

- Problems with this layout?
- Creates layouts that contain many rectangles with a high aspect ratio
- Thin rectangles are hard to see, select, label and compare in size
- Which of the blue rectangles is bigger?

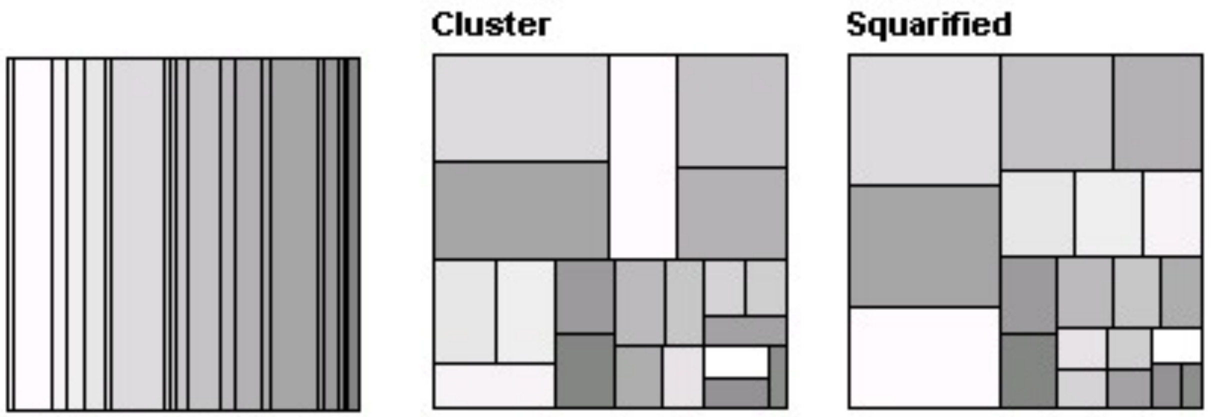


Treemap

- Several algorithms to create more useful tree-maps by reducing the overall aspect ratios of the map rectangles
- Cluster algorithm (Wattenberg1999): employ both vertical and horizontal partitions at each level of the hierarchy
- Squarification algorithm (Bruls et al. 2000)
- Sorts and adds the input rectangles ordered by size
- Problem of both algorithms
  – Changes in the data set can cause dramatic layout changes (hard to track items given dynamic data)
  – Given ordering of items is not preserved (as indicated by shading)

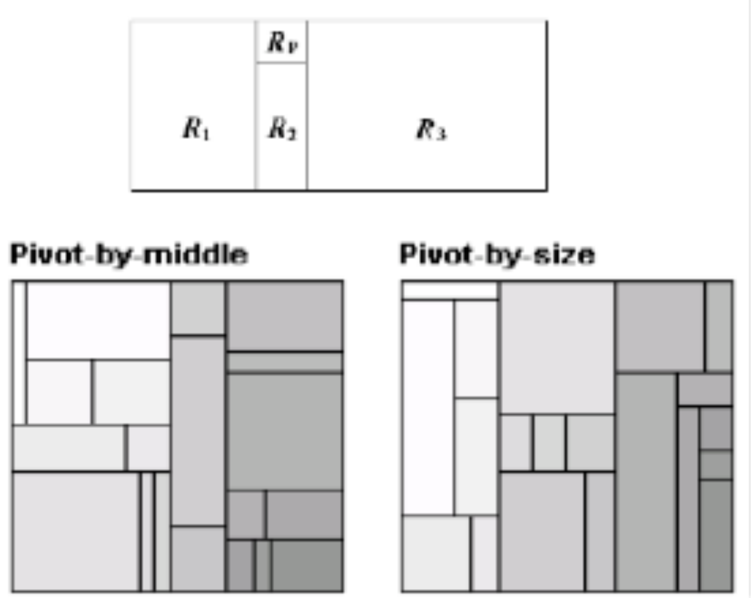


Subdivision algorithm for squarified algorithm (Bruls et al. 2000)



Ordered Treemap

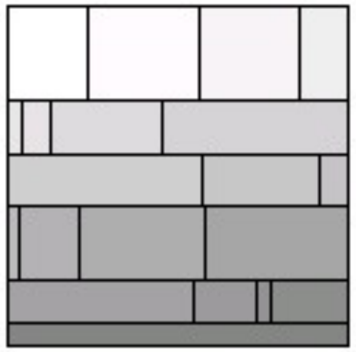
- Seek compromise between smooth updates and low aspect ratios
- Items are given as a list ordered by index and have varied areas
- Items that are next to each other in the given order should be approximately adjacent in the tree-map
- Shneiderman & Wattenberg 2001
- Pivot-by-size & Pivot-by-middle
  - Partition area into 4 regions
  - Pick pivot element Rp
    - Size: largest item
    - Middle: middle item
  - Depending on the aspect ratio of R, place Rp in horizontal oder vertical middle
  - R1: items earlier in the list than pivot (sublist L1)
  - R2: items in list before R3 such that their overall size makes Rp have aspect ratio closest to 1 (sublists L2, and L3)
  - Apply steps recursively for areas R1, R2, and R3



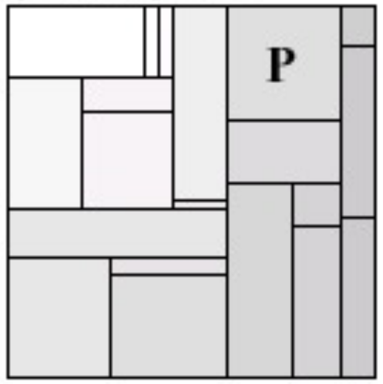
Ordered Treemap

- Strip treemap - Bederson & Shneiderman 2002
- Modification of squarified algorithm
- Produces better readability than basic ordered treemap algorithms and comparable aspect ratios (only slightly worse than unordered squarified algorithm)
- Rectangle is filled stepwise with strips
- Strip is filled stepwise with rectangles as long as the average aspect ratio of the strip decreases or stays the same
- Otherwise a new strip is added

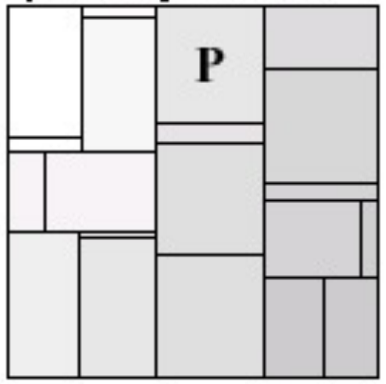
StripTreemap



pivot-by-size



pivot-by-middle



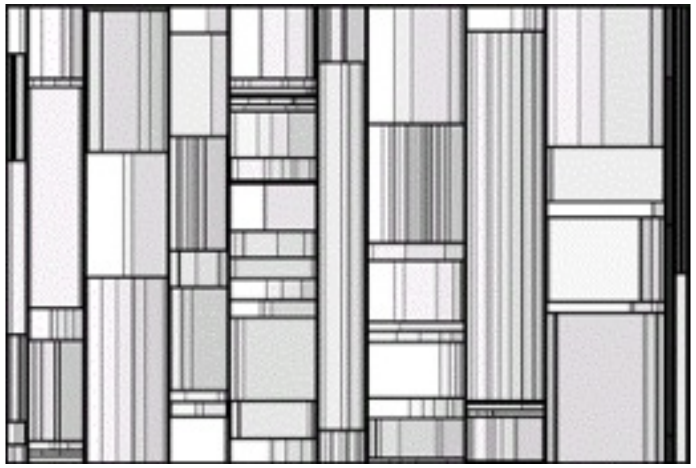
Ordered Treemap

- Test with several generated data sets
- Table shows results for three levels of hierarchy and eight items at each level
- 100 trials of 100 steps each
- Comparing the algorithms by average aspect ratio and average layout distance change (how much do rectangles move as data is updated) and readability (how easy it is to visually scan a layout to find a particular item)
- Tradeoff between low aspect ratios and smooth updates!

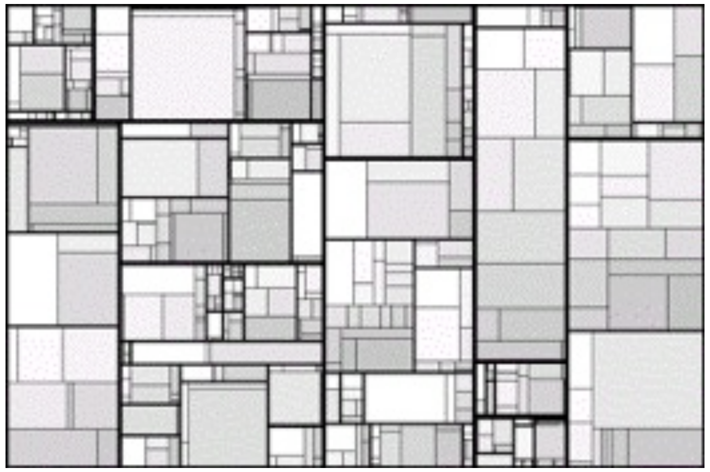
Algorithm	Aspect Ratio	Change	Readability
Slice-and-dice	26.10	0.46	1.0
Pivot-by-middle	3.58	1.21	0.42
Pivot-by-size	3.31	4.14	0.33
Pivot-by-split	3.00	2.37	0.35
Strip	2.83	1.09	0.51
Cluster	1.79	7.67	0.26
Squarified	1.74	8.27	0.26

Ordered Treemap

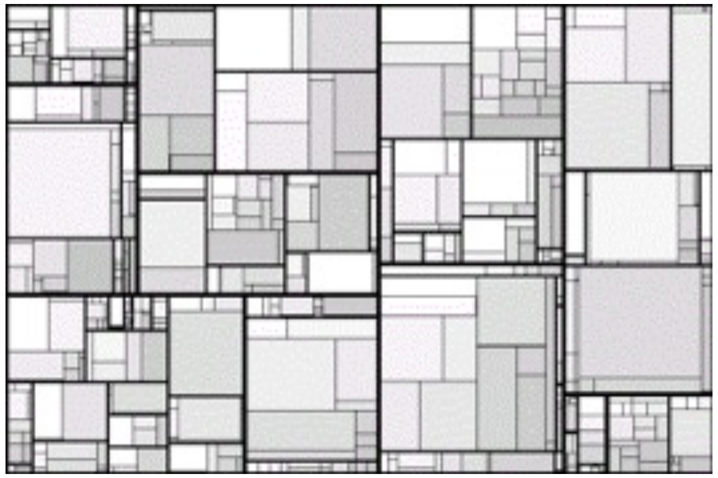
- Applying the algorithms to real-world data - confirmed prior test results
- Set of 535 publicly traded companies, market capitalization as the size attribute
- Gray scale indicates ordering within each industry group that is the last level of hierarchy in this data set



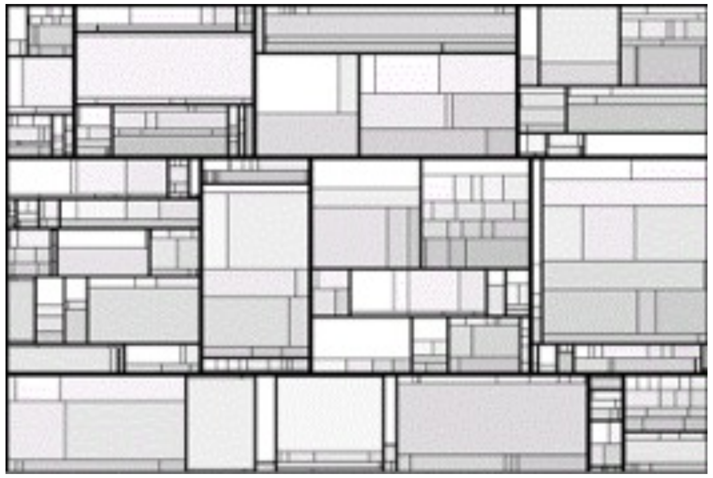
Slice-and-dice layout



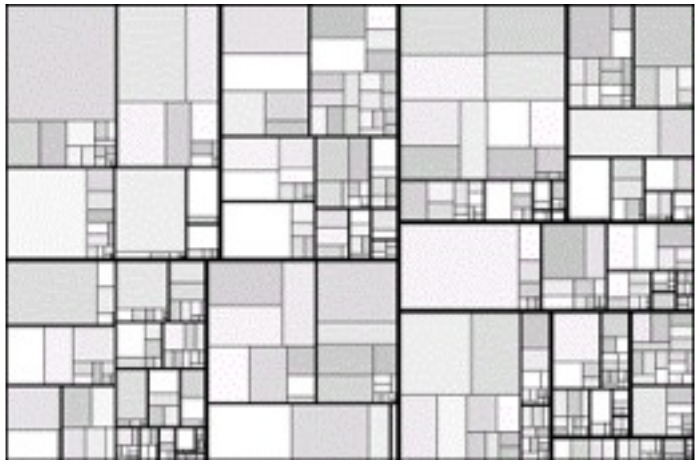
Pivot-by-middle layout.



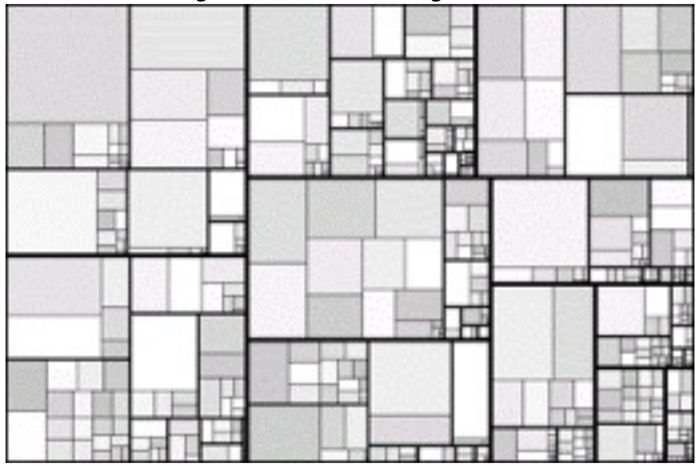
Pivot-by-size layout



Strip layout



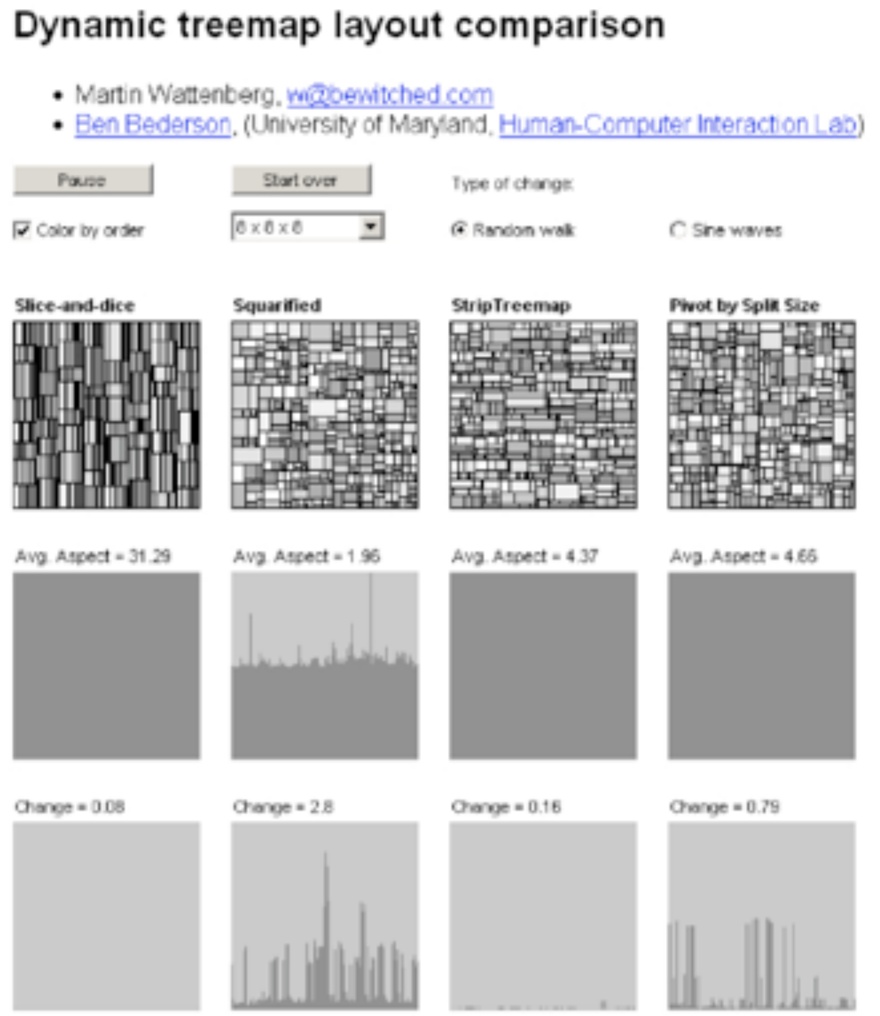
Cluster layout



Squarified layout.

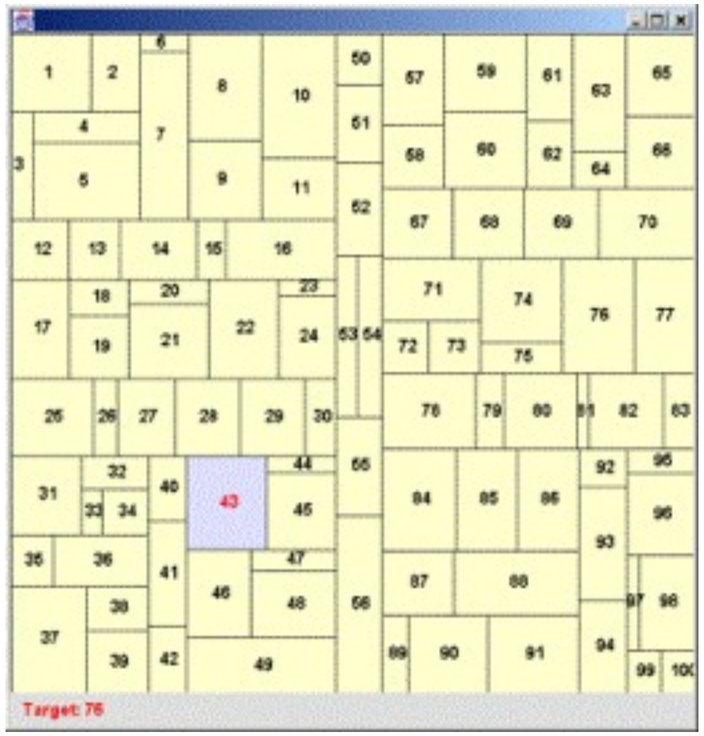
Ordered Treemap

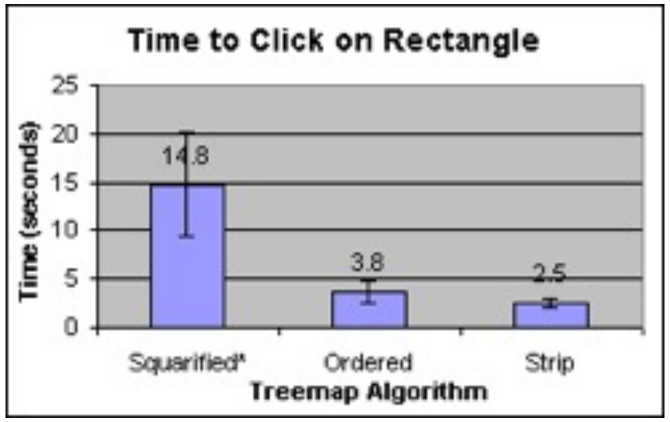
- Compare algorithms
- http://www.cs.umd.edu/hcil/treemap-history/java_algorithms/LayoutApplet.html
- History of treemaps
- http://www.cs.umd.edu/hcil/treemap-history/
- Java 1.1 library for five Tree-map algorithms:
- http://www.cs.umd.edu/hcil/treemap-history/Treemaps-Java-Algorithms.zip

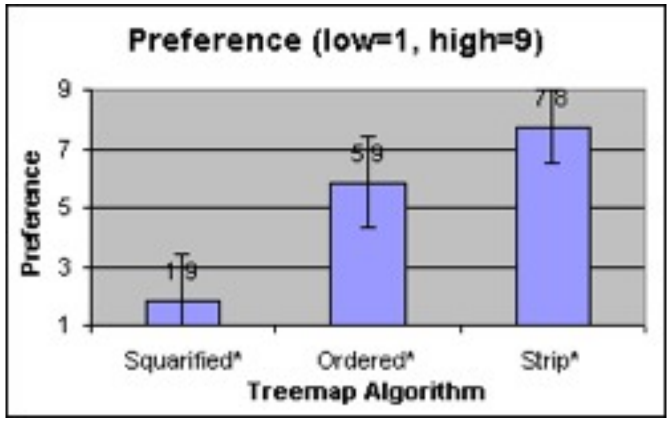


Ordered Treemap

- Bederson et al. 2002
- User study of layout readability
- Compared the squarified, pivot-based, and strip treemap algorithms
- 20 Participants had to identify a specific rectangle by clicking on the rectangle with the requested numerical ID
- Repeated-measures design
- Independent variable: treemap algorithm
- Dependent variable: time, subjective user rating
- Time: significant difference between squarified algorithm and the other two
- Preference: significant difference between all three algorithms
- Validates readability metric used

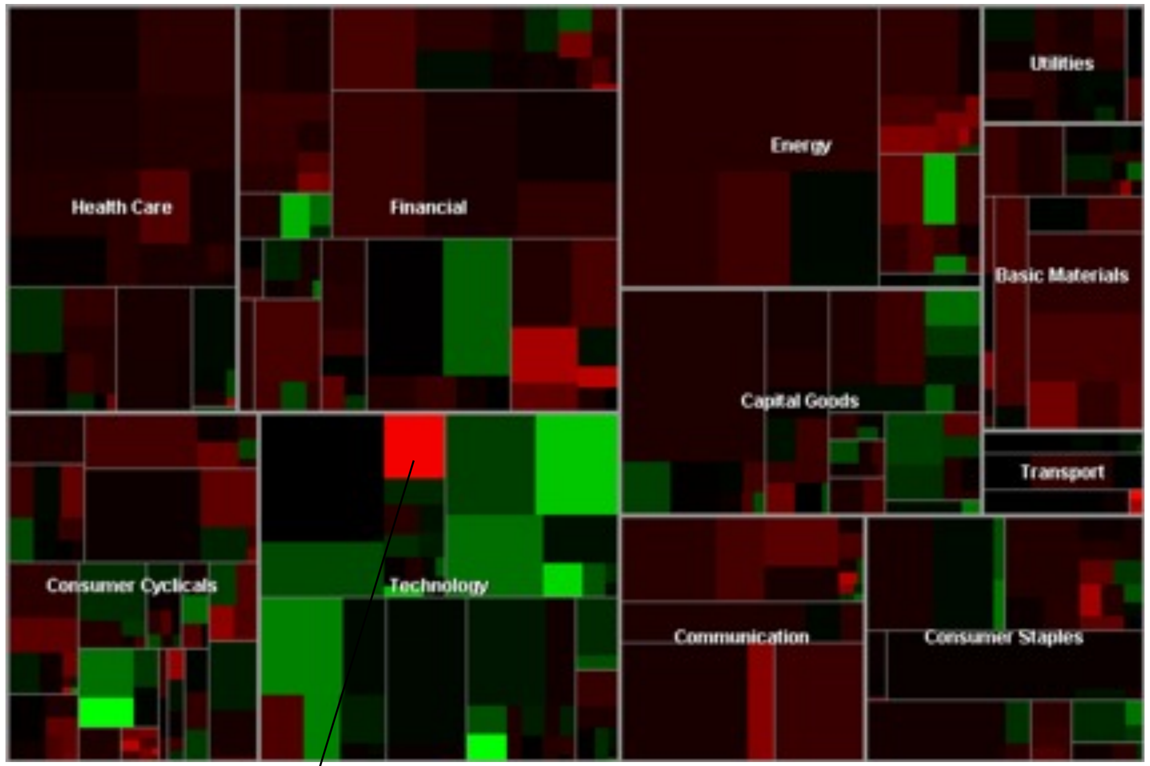






Map of the Market

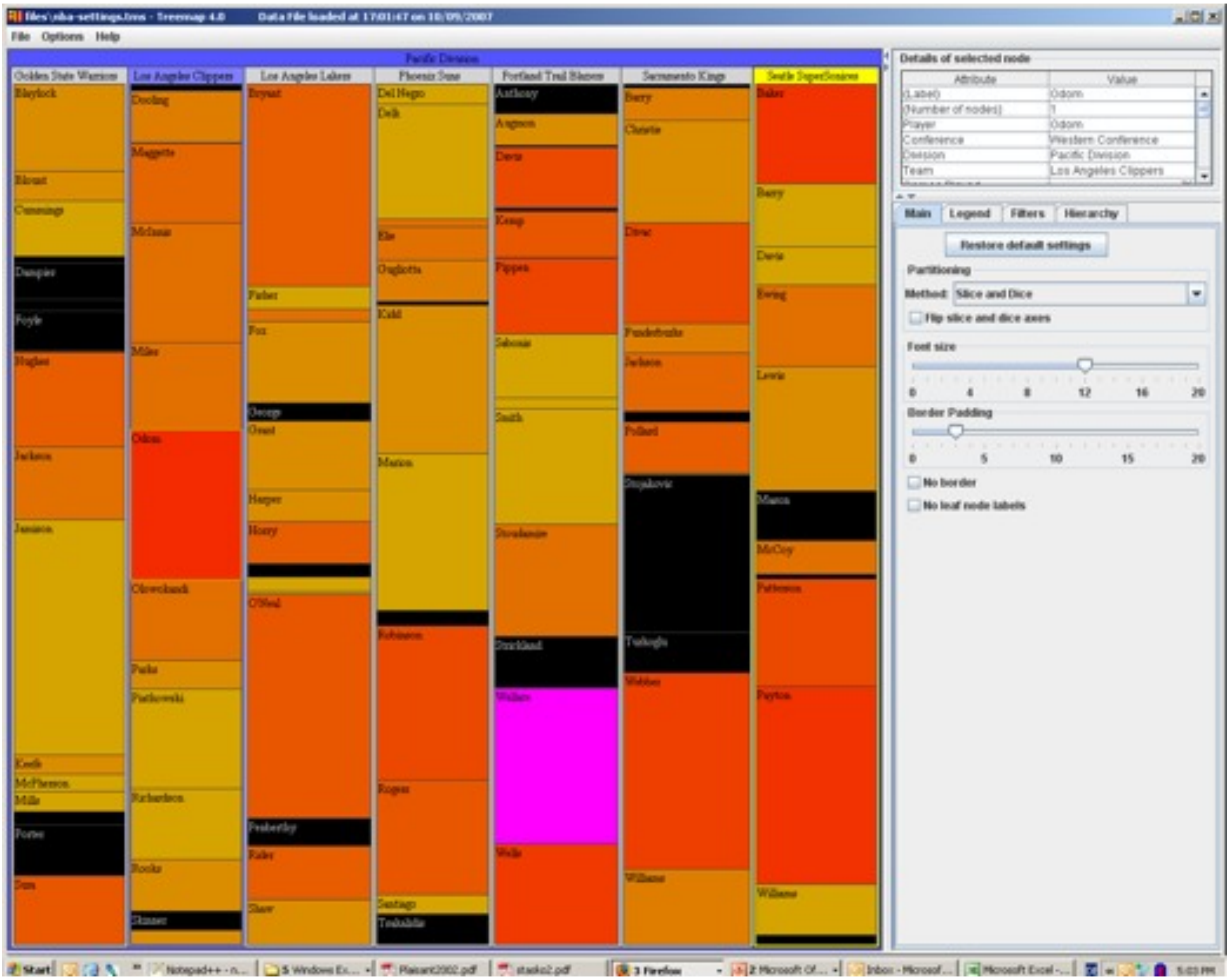
- Wattenberg 1999
- Cluster treemap to reduce overall aspect ratios
- http://www.smartmoney.com/marketmap/
- 500 stocks updated every 15 minutes
- Each rectangle represents a company
  - Size: company's market capitalization
  - Color: price performance
- Double-ended multiple hue color coding
  - Green: stock price is up
  - Red: stock price is down
  - Black: neutral, no change
- Detailed information on-demand
- Demo



SAP Pays $6.8 Billion for Business Objects

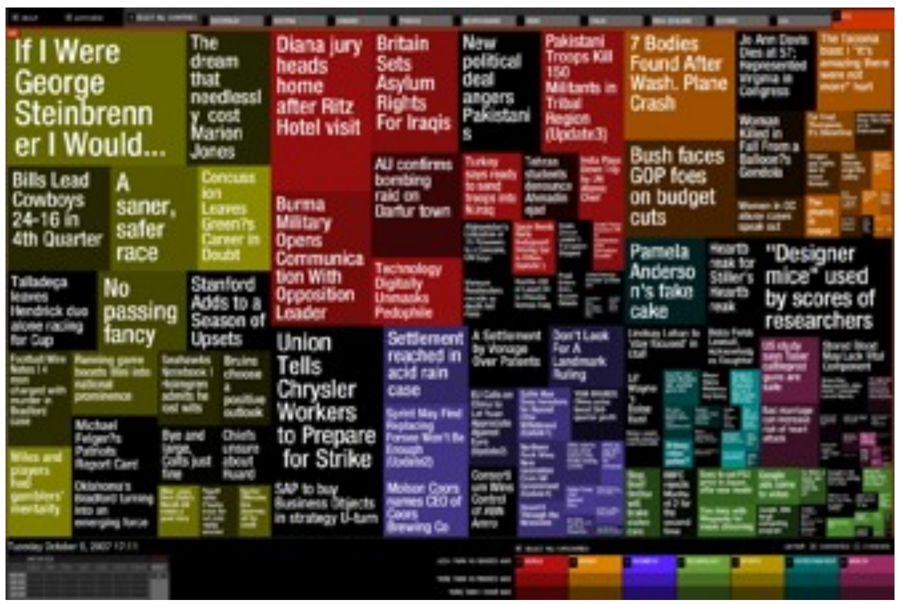
Treemap 4.1

- Human-Computer Interaction Lab – University of Maryland
- Applet: http://www.cs.umd.edu/hcil/treemap/index.shtml
- Demo



Some Treemaps Online

NewsMap



Peet's Coffee: Coffee Selector

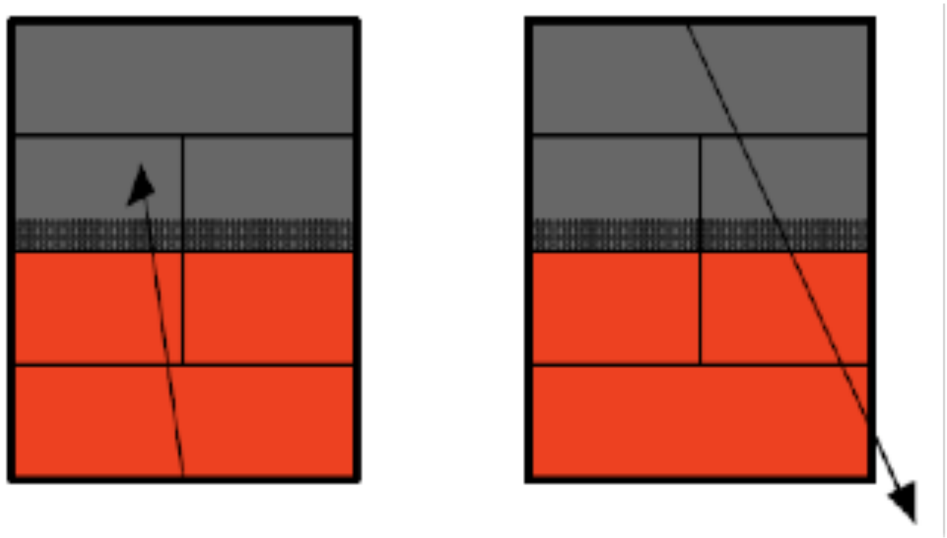
iTunes Top 100

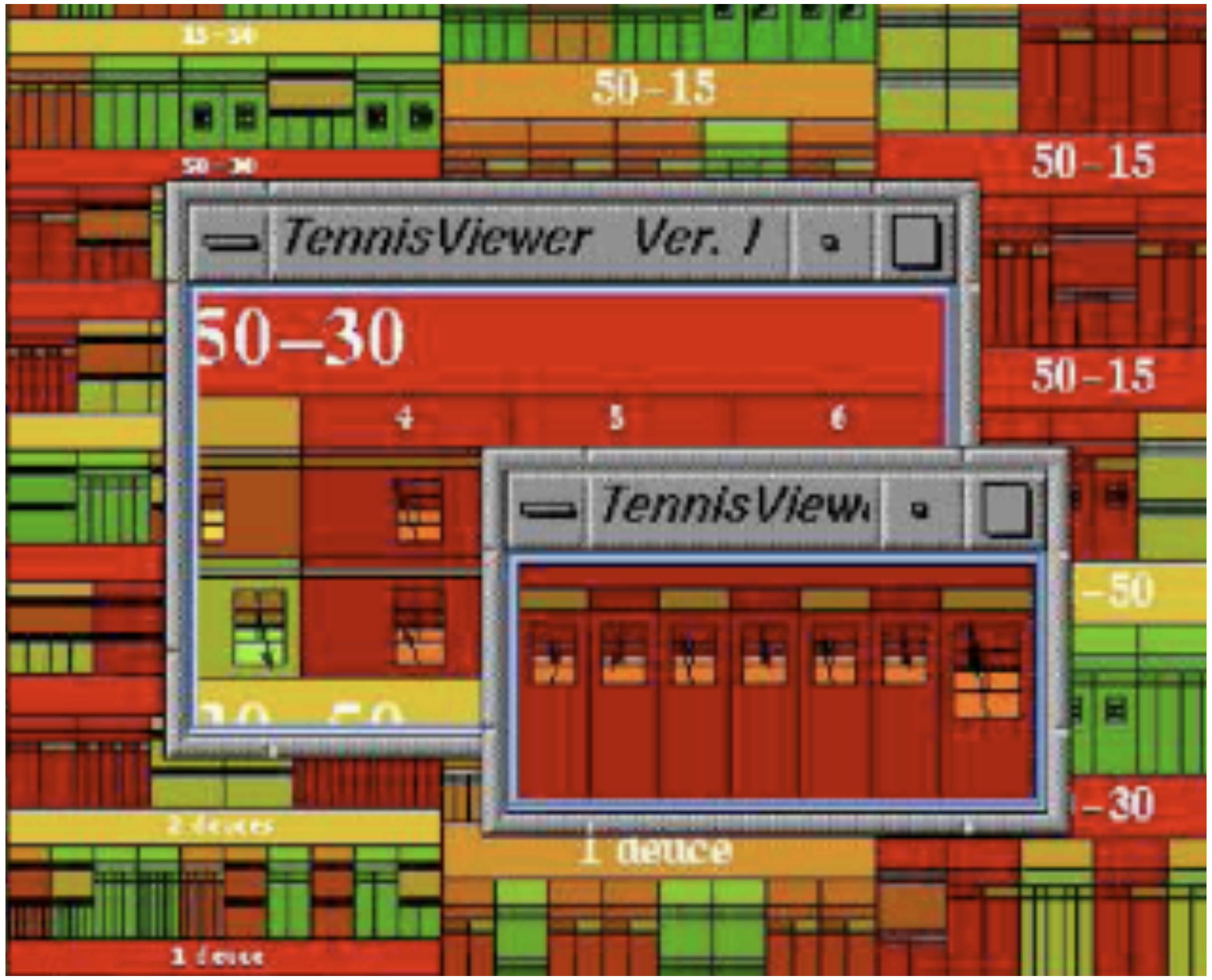
TennisViewer

- Jin & Banks 1997
- Visualize a tennis match using a treemap
- Match tree
  - Root node – the tennis match
  - Match node subdivides horizontally into sets
  - A set subdivides vertically into games
  - A game subdivides horizontally into points
- Color mapping of rectangles show node ownership (who won what?)
- Translucent child rectangles are layered over parent rectangles

TennisViewer

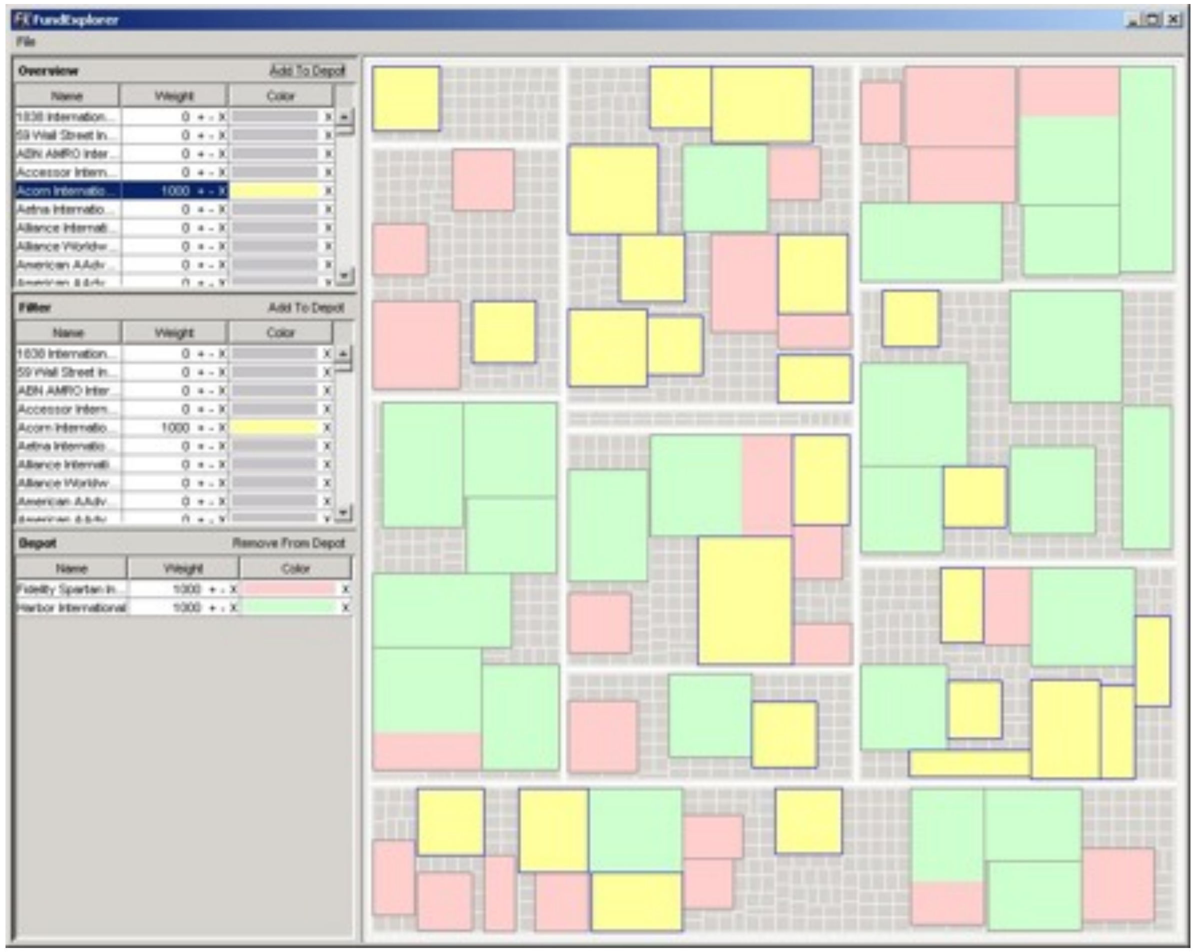
- Magic Lens to explore ball traces
- Example: the return of a service goes out of bounds





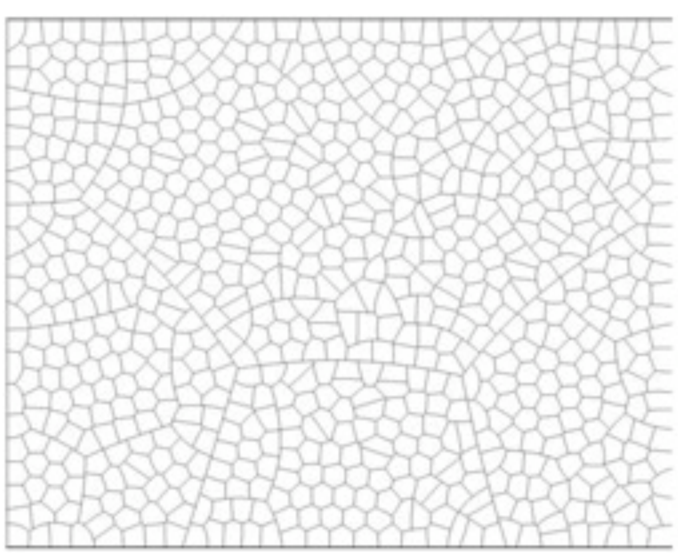
FundExplorer

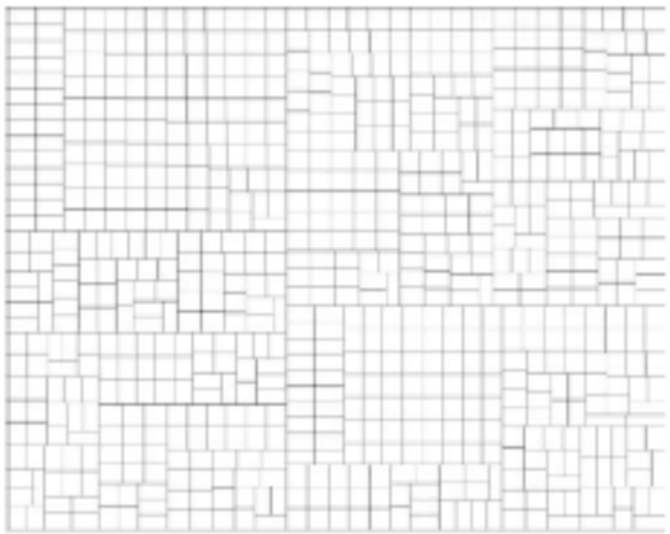
- Csallner et al. 2003
- To support the diversification of mutual fund portfolios, i.e. how to find funds with little overlap in their investments
- Also show stocks with zero investment
- Movie

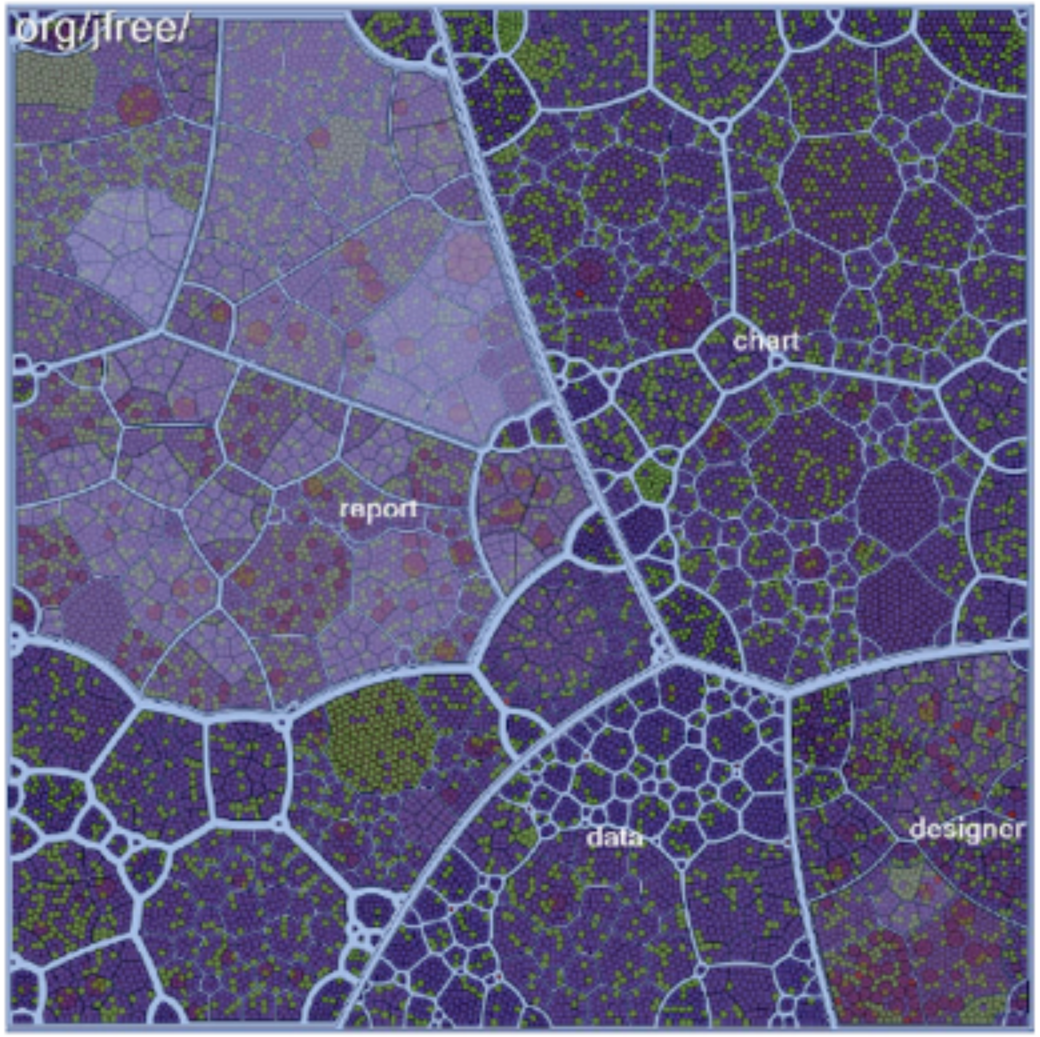


Voronoi Treemap

- Balzer et al. 2005
- Treemap consisting of arbitrary polygons instead of rectangles
  - Aspect ratio of polygons converges to 1
  - Polygons are distinguishable due to the irregular shapes
  - Avoid that edges of different objects run into each other



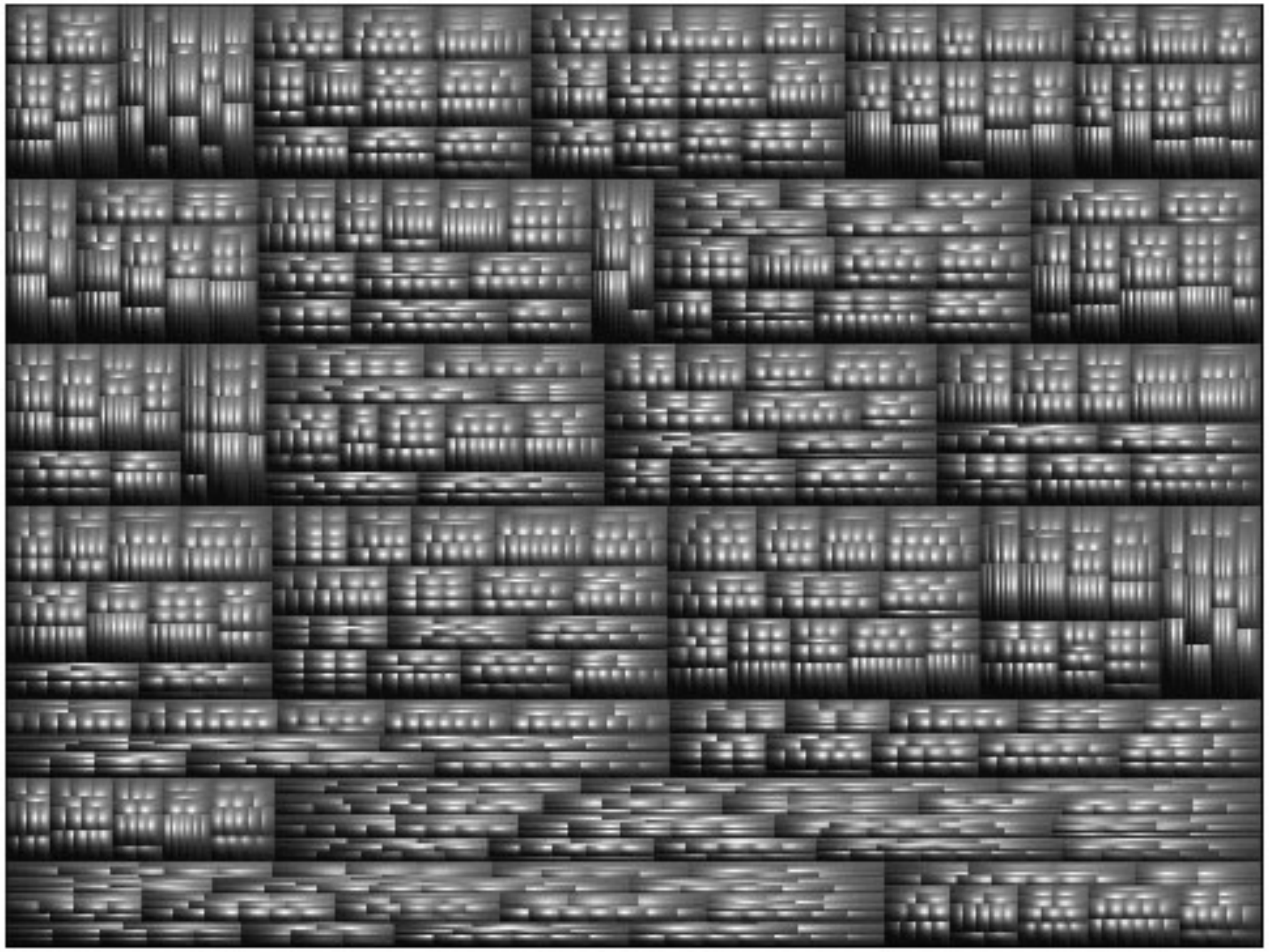


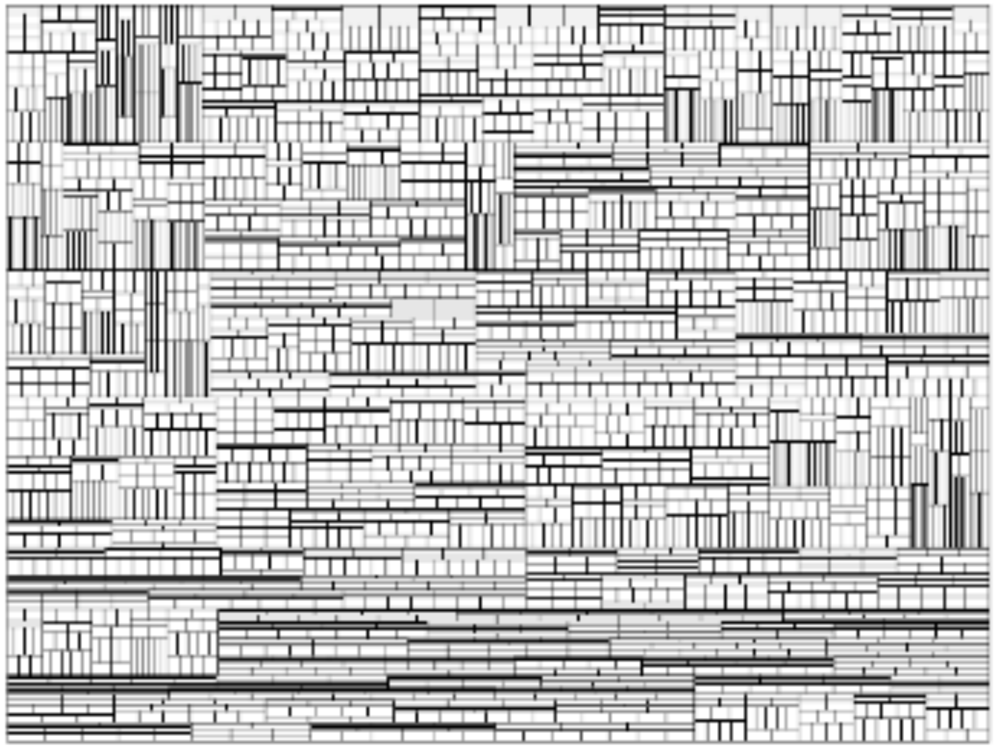


Cushion Treemap

- Wijk & van de Wetering 1999
- Treemaps usually fall short to visualize the structure of the tree
- Worst case: a balanced tree, where each parent has the same number of children and each leaf has the same size
- Outcome: regular grid
- Nested treemap may reduce this problem, but:
  - Margins require screen space
  - Deeply nested trees are difficult to read
- Idea: add shading and texture to help convey the structure of the tree

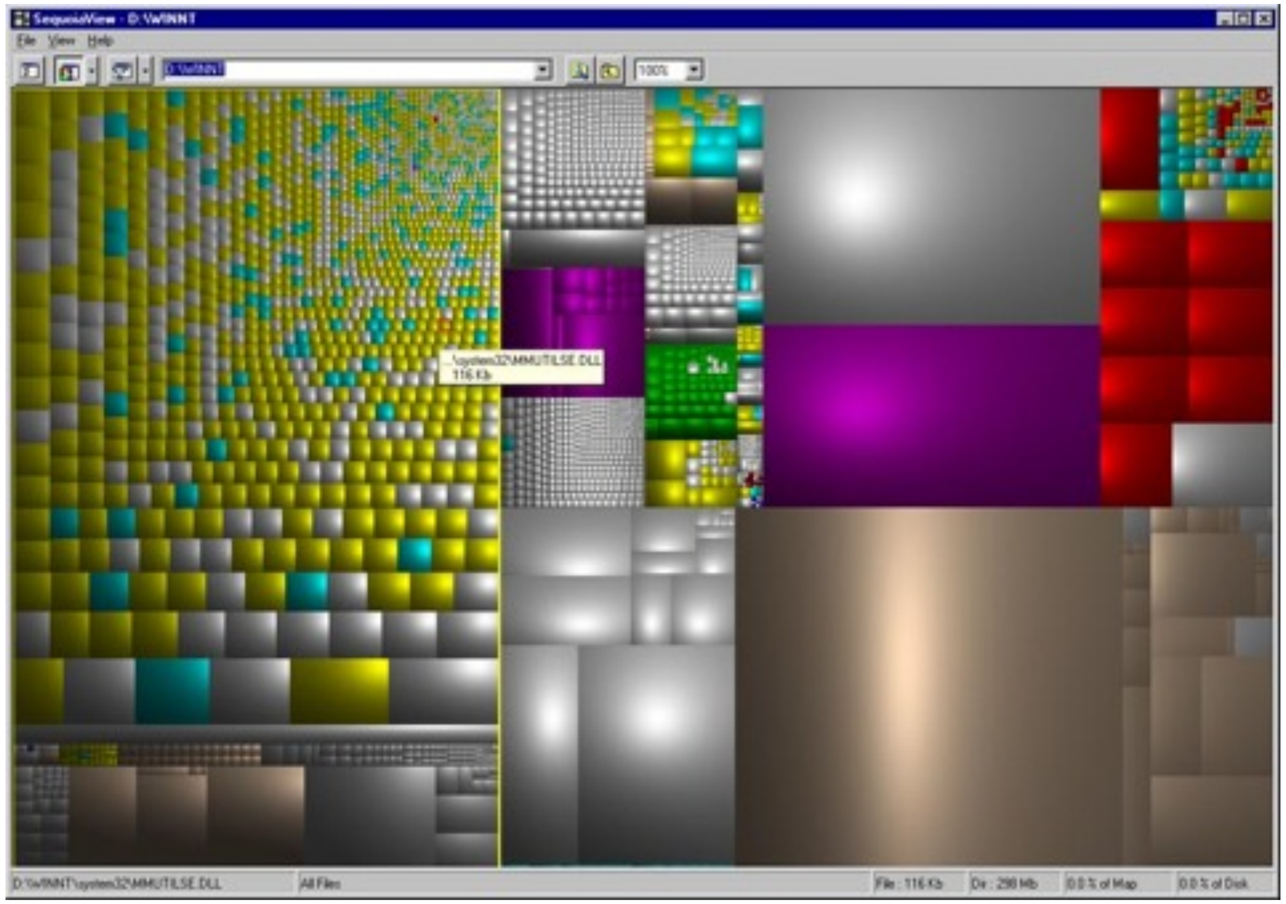
Cushion Treemap





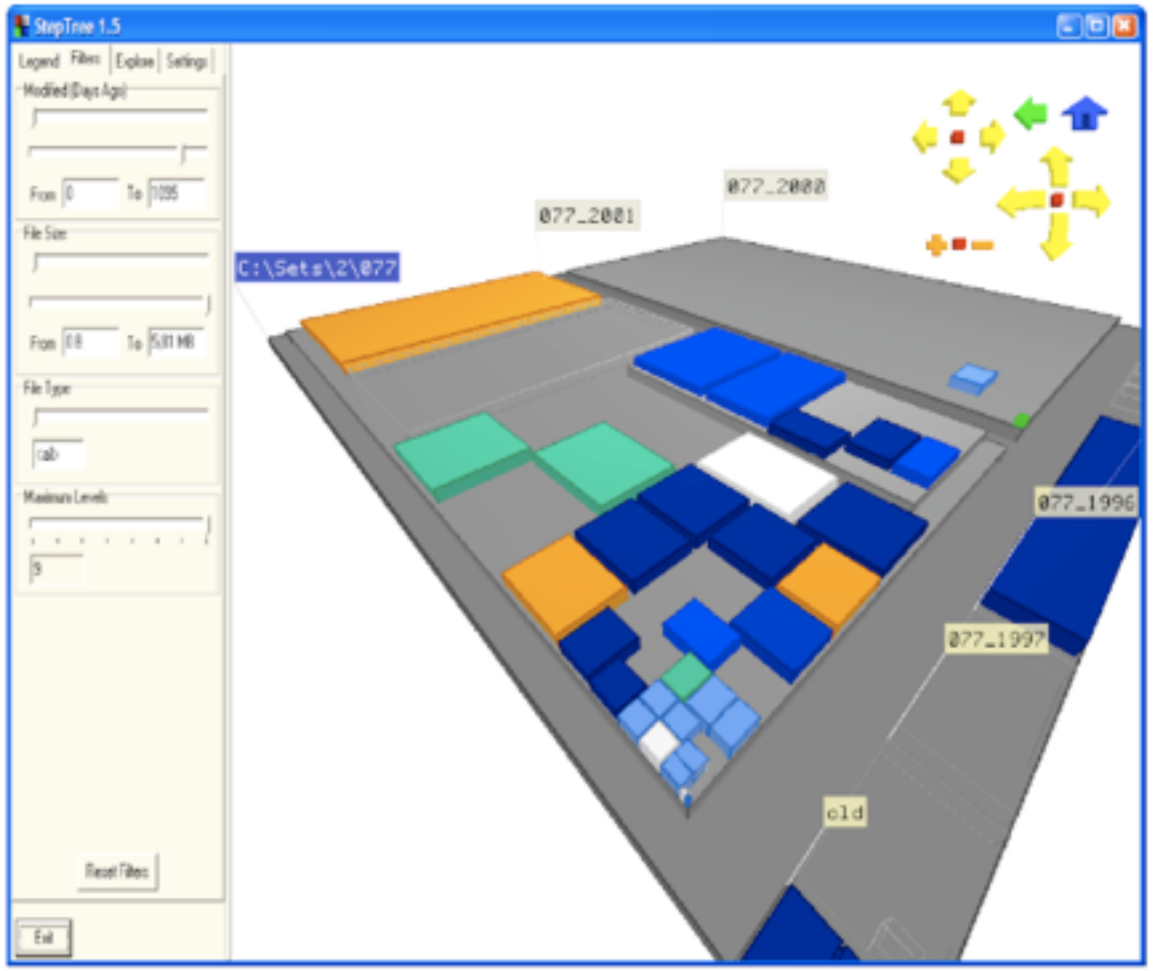
Cushion Treemap

- SequoiaView
- http://w3.win.tue.nl/nl/onderzoek/onderzoek_informatica/visualization/sequoiaview//
- Visualizes the contents of your hard drive



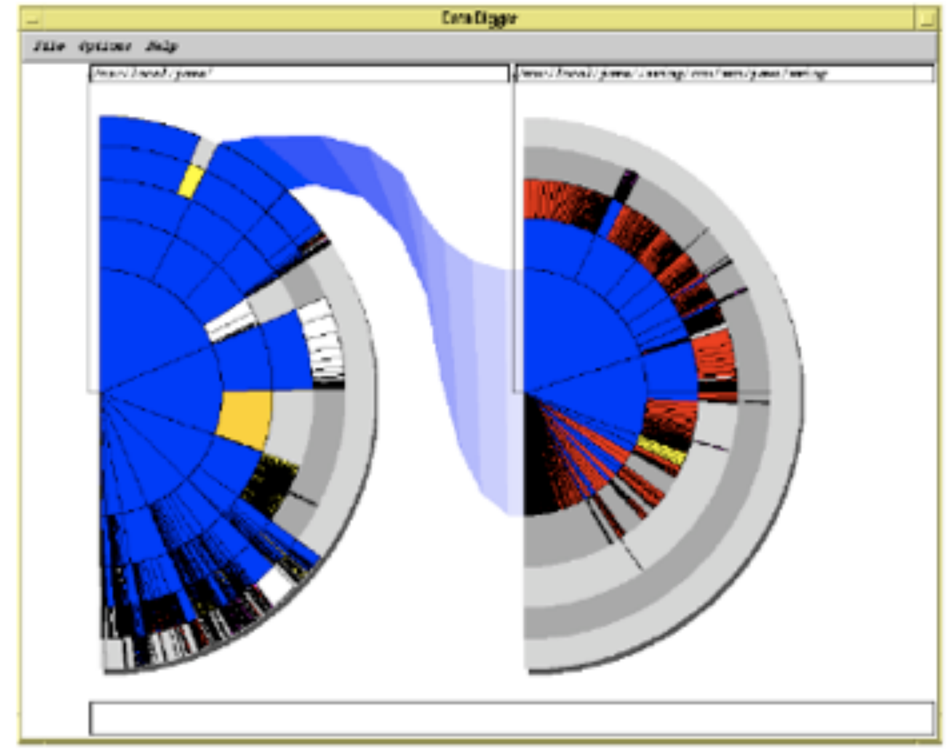
StepTree

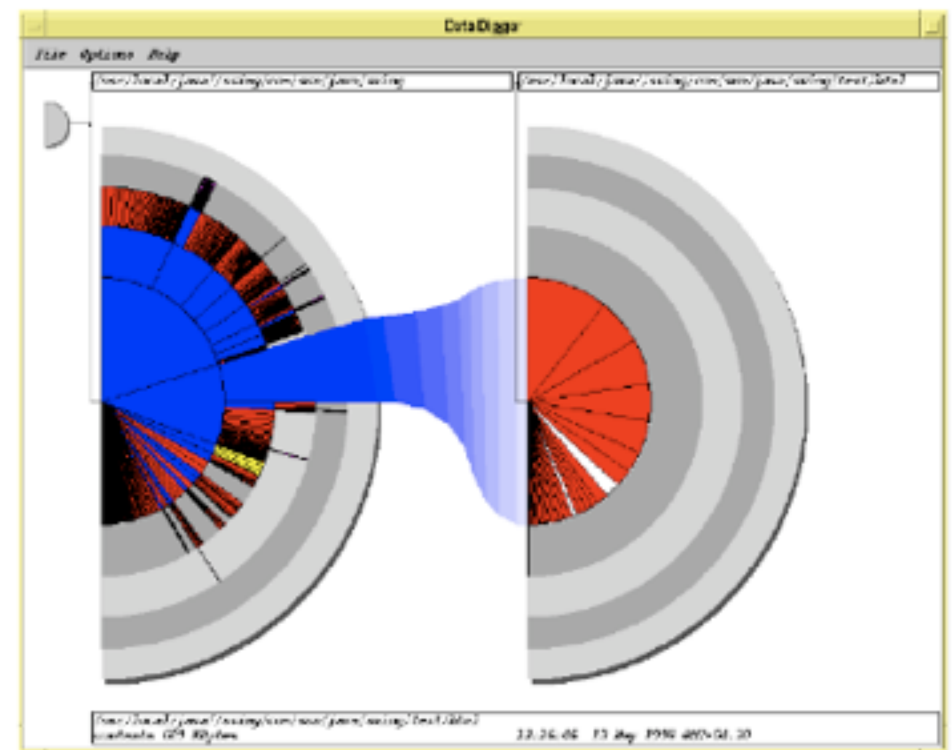
- Bladh et al. 2004
- Convey tree structure via third dimension
- http://www.sm.luth.se/csee/csn/visualization/filesysvis.php



Information Slices

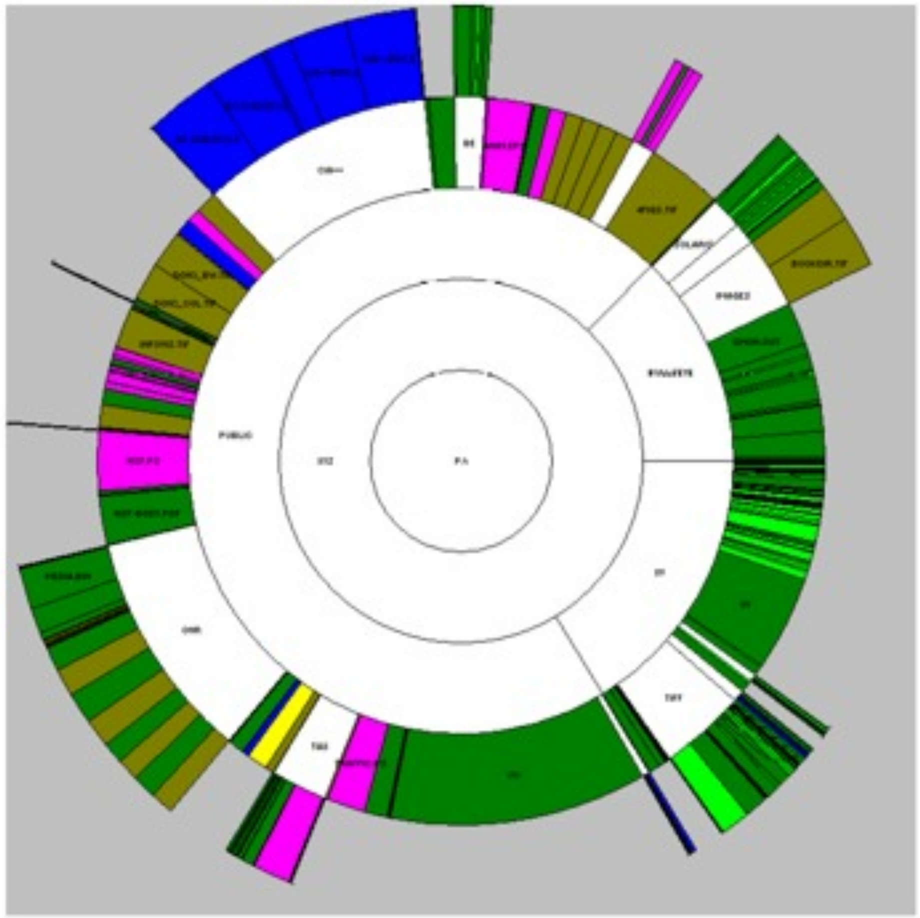
- Andrews & Heidegger 1998
- Visualization is based on one or more semi-circular discs
- Each disc represents multiple levels (5 to 10, configurable) of a hierarchy
- Files and directories deeper in the hierarchy are drawn further from the center
- Child nodes are drawn within the arc subtended by their parents
- For deeper hierarchies multiple discs are cascaded
- Example shows Solaris JDK, 6158 files in 502 directories, maximum depth of 9 levels
- Blue: directories, other colors: file type





Sunburst

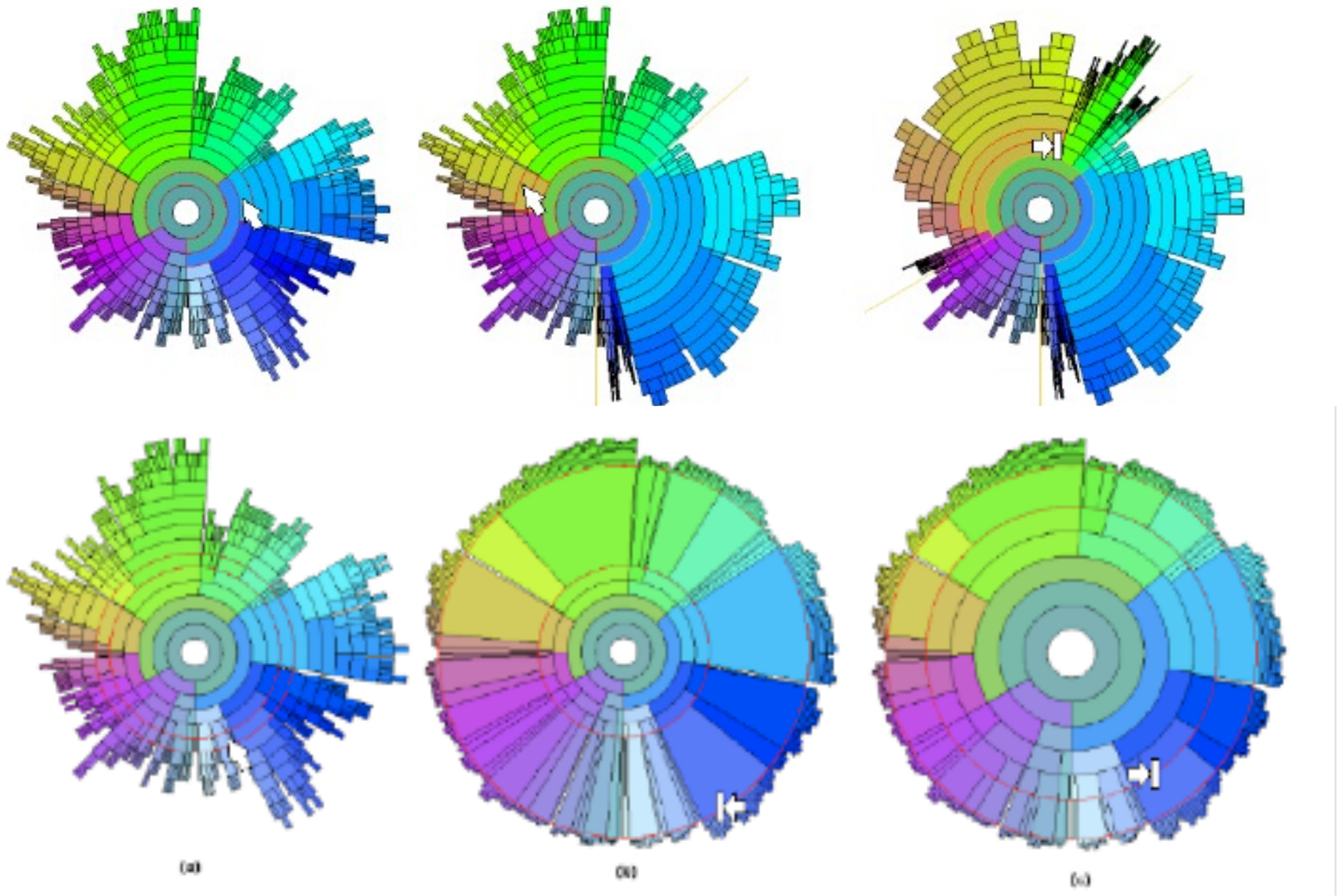
- Stasko & Zhang 2000
- Full circular visualization to give each element more space
- Navigating the tree should not lead to significant node position changes (e.g. hyperbolic browser)
- Three animated approaches to provide a focus area while maintaining context
  - Angular detail method
  - Detail outside method
  - Detail inside method
- Comparative evaluation of sunburst vs. treemap did not show significant differences in task completion times, but participants strongly preferred sunburst (Stasko et al. 2000)
- Radial visualizations may better depict the structure of the tree, but are not as space-efficient as treemaps (Movie)



Sunburst visualizing file structure

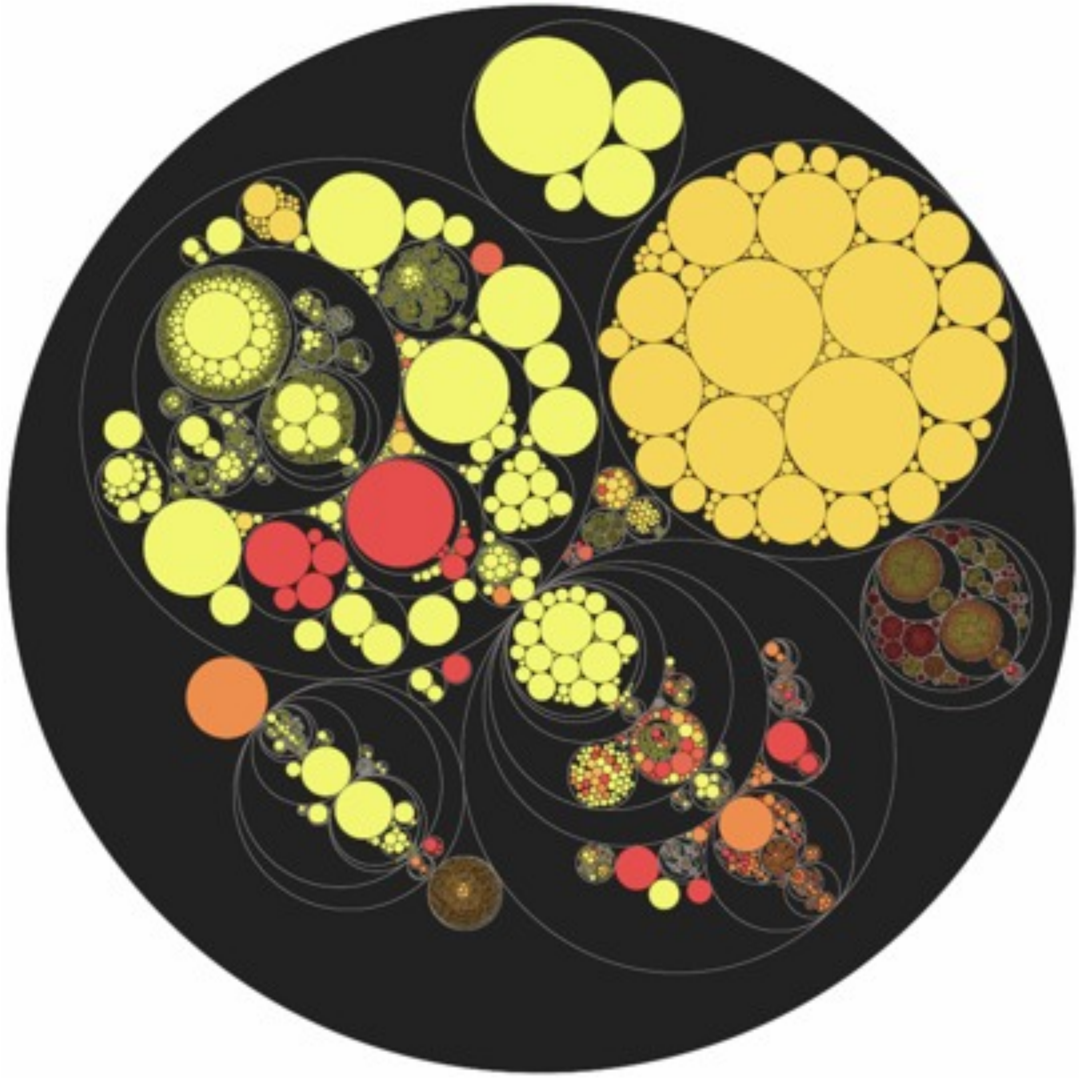
Interring

- Yang et al. 2002
- Multiple foci (circular distortion + radial distortion)



Circular Treemaps

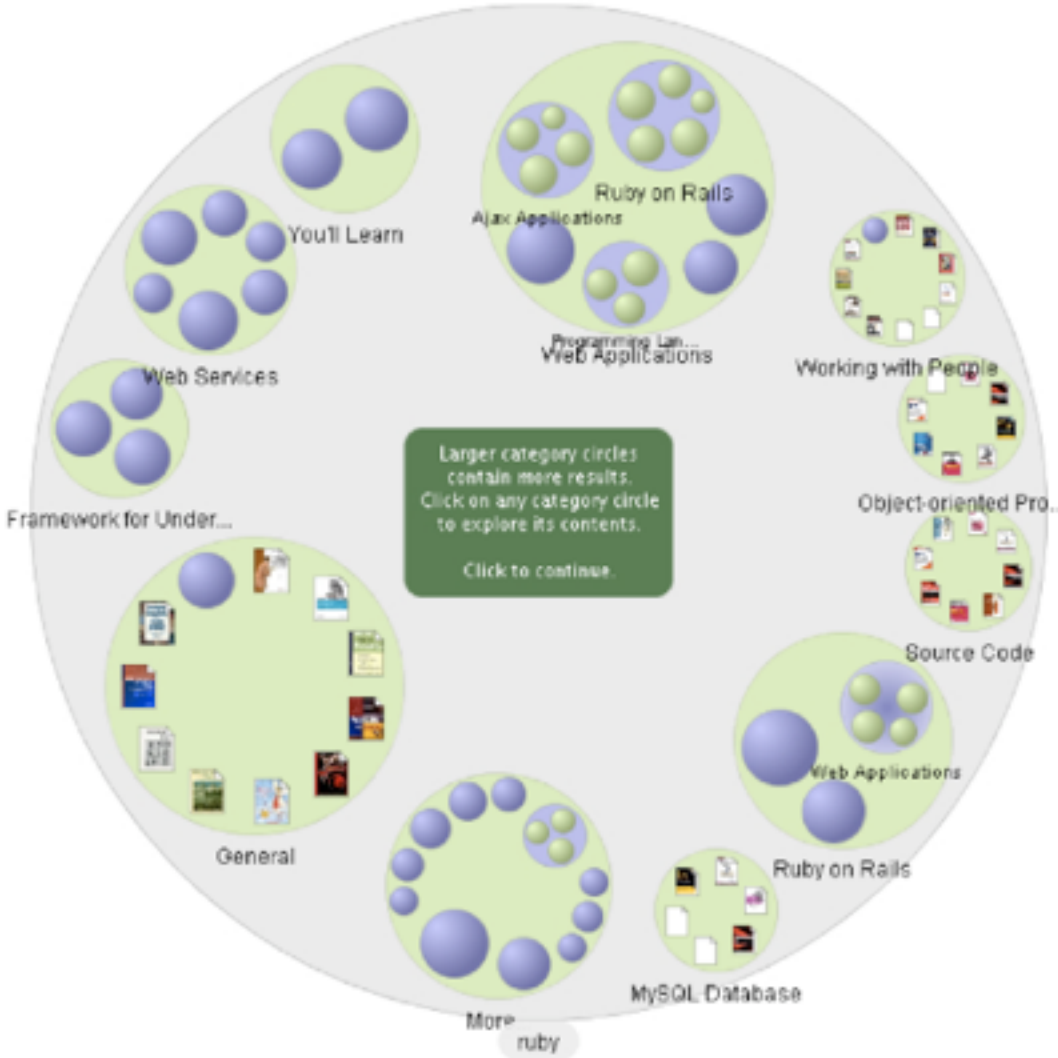
- Kay Wetzel
- Do not fill space completely,
- but...
  - Aspect ratio stays the same for all elements – easy comparison of sizes
  - Good visibility of nesting (though at the cost of unused space)
  - Rather beautiful layout!

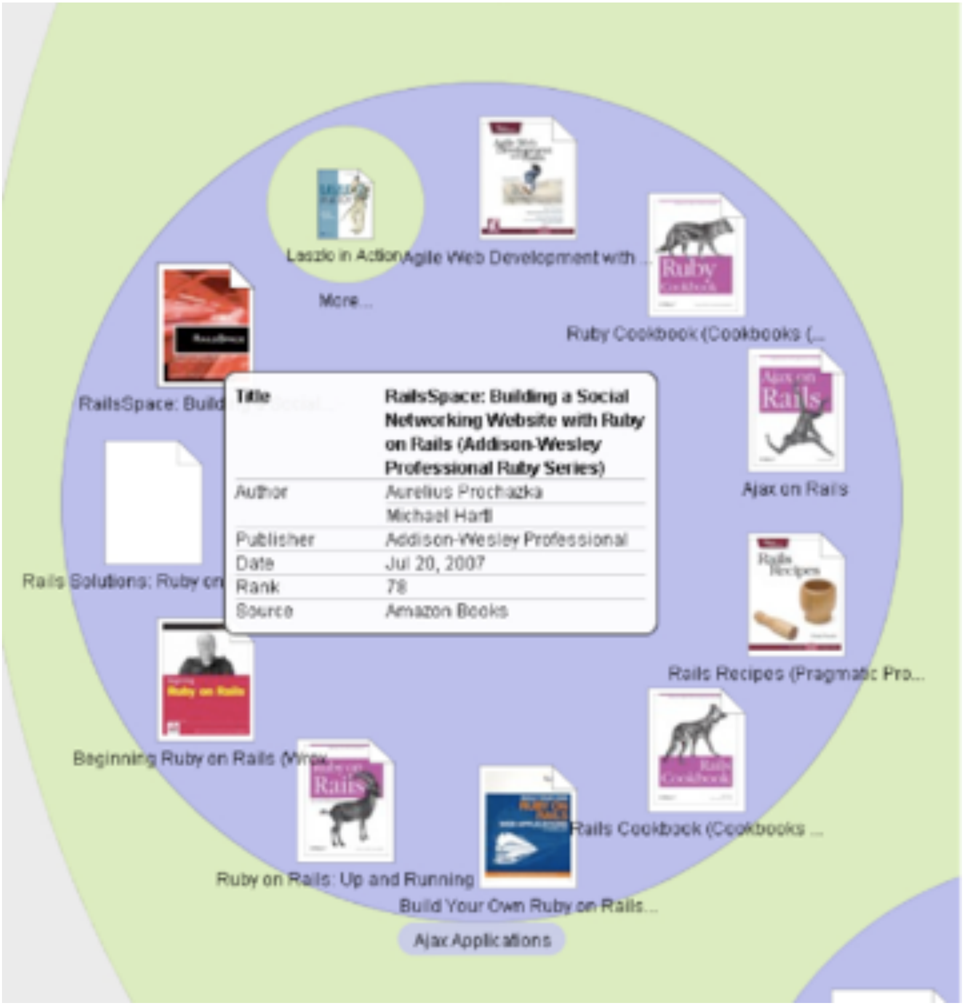


Visualization of a file system with color mapping for creation data

Circular Treemaps

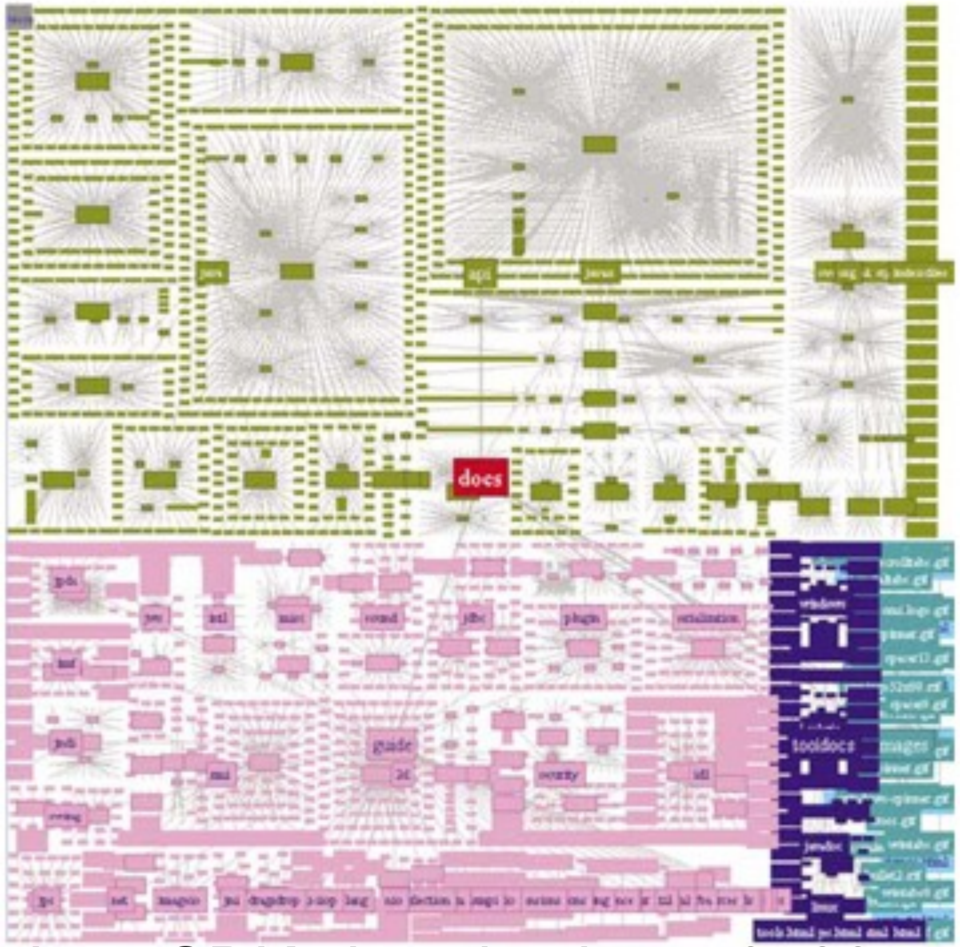
- Grokker - http://live.grokker.com/ (formerly)
- Clustering search results as nested circles





Enclosure + Connection

- EncCON: Nguyen & Huang 2005
- Connection (node-link)
  - Gives immediate perception of data relationships and the tree structure
  - Not efficient regarding display space utilization: most pixels are wasted as background
- Enclosure (e.g. treemaps)
  - Space-filling approach allows the display large trees on a single glance
  - Focus on the leaf nodes but hardly conveys the tree structure
- Idea: combine enclosure and connection approach
- Child nodes are not embedded but placed around parent nodes using a circular, space-filling division method
- Focus+context navigation



Java SDK visualization – 9500 directories and files

Recommended Literature

- N. Henry, J.-D. Fekete, and M. J. McGuffin: ”NodeTrix: A Hybrid Visualization of Social Networks”, 2007.
- Benjamin B. Bederson & Ben Shneiderman , "Ordered and Quantum Treemaps: Making Effective Use of 2D Space to Display Hierarchies“, 2002.