7. Hierarchies & Trees
Visualizing topological relations

Vorlesung „Informationsvisualisierung”
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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

• 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
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 get 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

Hyperbolic Tree Browser

• Lamping et al. 1995
• Comparable to fisheye distortion
  – 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!

Inspiration:
Circle Limit IV
M.C. Escher
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!
• DOI Tree
  – 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

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 & Shneiderman 1992
- 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

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 (Wattenberg 1999): 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)
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
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!

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Aspect Ratio</th>
<th>Change</th>
<th>Readability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slice-and-dice</td>
<td>26.10</td>
<td>0.46</td>
<td>1.0</td>
</tr>
<tr>
<td>Pivot-by-middle</td>
<td>3.58</td>
<td>1.21</td>
<td>0.42</td>
</tr>
<tr>
<td>Pivot-by-size</td>
<td>3.31</td>
<td>4.14</td>
<td>0.33</td>
</tr>
<tr>
<td>Pivot-by-split</td>
<td>3.00</td>
<td>2.37</td>
<td>0.35</td>
</tr>
<tr>
<td>Strip</td>
<td>2.83</td>
<td>1.09</td>
<td>0.51</td>
</tr>
<tr>
<td>Cluster</td>
<td>1.79</td>
<td>7.67</td>
<td>0.26</td>
</tr>
<tr>
<td>Squarified</td>
<td>1.74</td>
<td>8.27</td>
<td>0.26</td>
</tr>
</tbody>
</table>
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
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
- 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
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)
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

• 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


• Benjamin B. Bederson & Ben Shneiderman, "Ordered and Quantum Treemaps: Making Effective Use of 2D Space to Display Hierarchies", 2002.