Hierarchy and Tree Visualization

Fall 2009

Jing Yang

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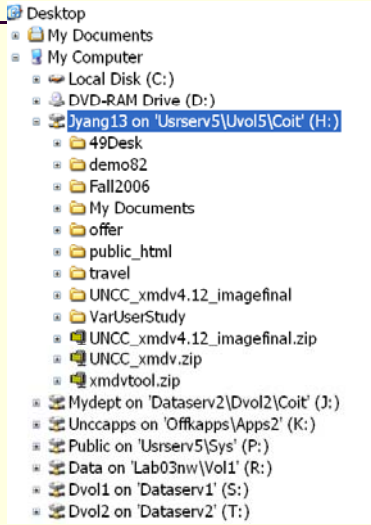
Hierarchies

- Definition
  - An ordering of groups in which larger groups encompass sets of smaller groups.
  - Data repository in which cases are related to subcases

2

Hierarchies in the World

- Family histories, ancestries
- File/directory systems on computers
- Organization charts
- Object-oriented software classes



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Good Hierarchy Visualization

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

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Trees

- Hierarchies are often represented as trees
  - Directed, acyclic graph
- Two major categories of tree visualization techniques:
  - Node-link diagram
    - Visible graphical edge from parents to their children
  - Space-filling

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Node-Link Diagrams

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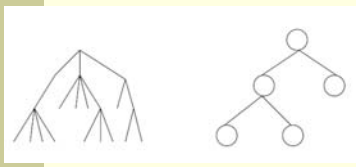
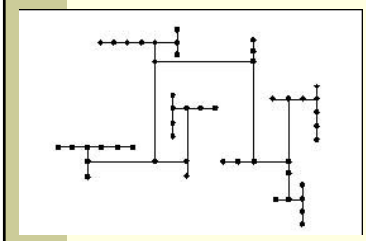
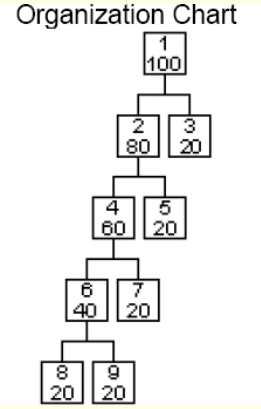
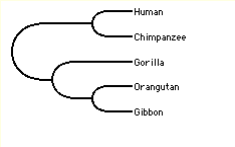
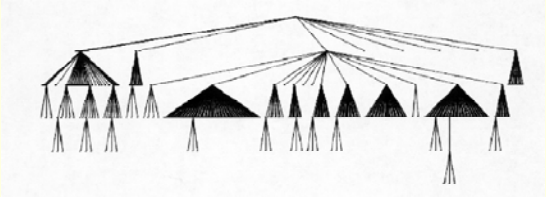
Put Root at Top or Left

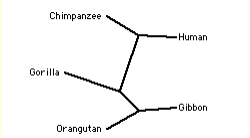




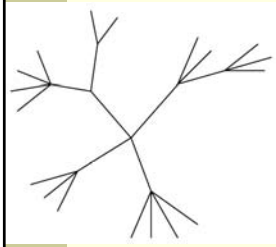


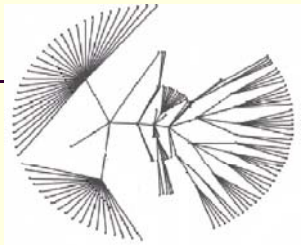


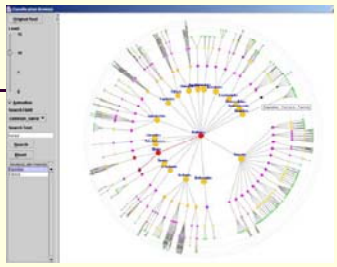




Put Root at Center







Radial View

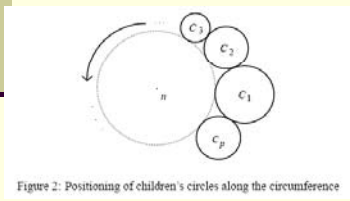
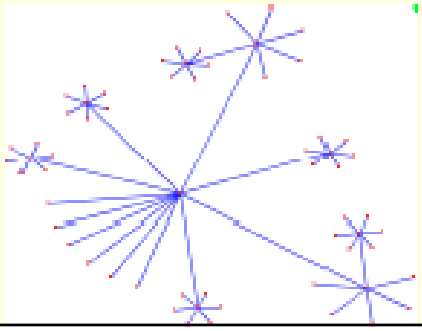


Figure 2: Positioning of children's circles along the circumference



Balloon View

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The Challenges

- Scalability
  - # of nodes increases exponentially
  - Available space increases polynomially (circular case)
- Showing more attributes of data cases in hierarchy or focusing on particular applications of trees
- Interactive exploration

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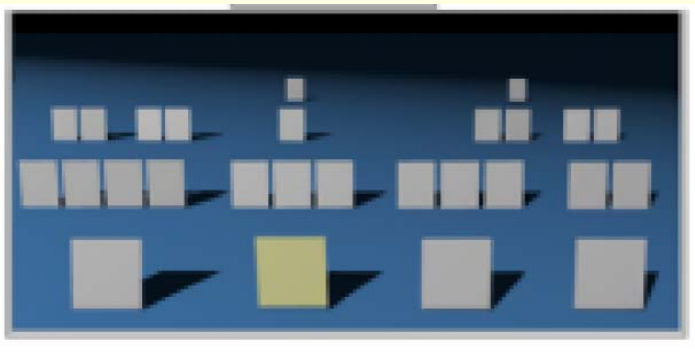
3D Approach 1 - 3D Tree



Tavanti and Lind, InfoVis 01

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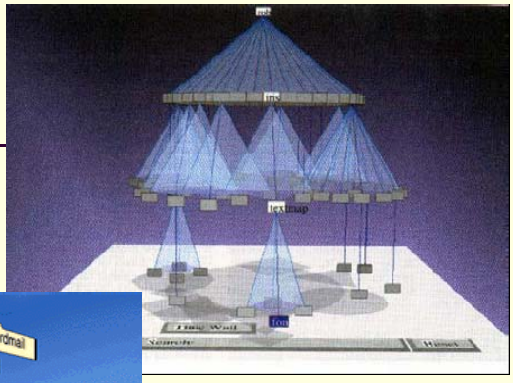
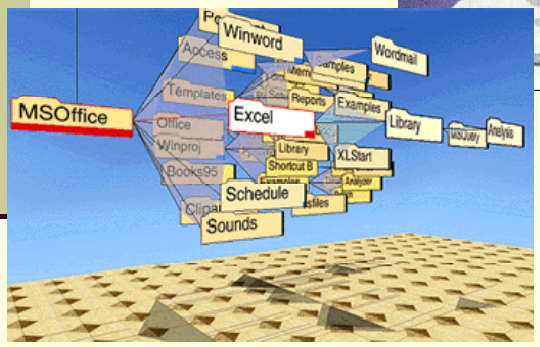
3D Approach 2 - Cone Tree





Robertson, Mackinlay, Card CHI '91

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Advantages vs. Limitations

- Positive
  - More effective area to lay out tree
  - Use of smooth animation to help person track updates
  - Aesthetically pleasing
- Negative
  - As in all 3D, occlusion obscures some nodes
  - Non-trivial to implement and requires some graphics horsepower

J. Stasko's InfoVis class slides

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Hyperbolic Browser

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

J. Lamping and R. Rao, “The Hyperbolic Browser: A Focus + Context Technique for Visualizing Large Hierarchies”, *Journal of Visual Languages and Computing,* vol. 7, no. 1, 1995, pp. 33-55.

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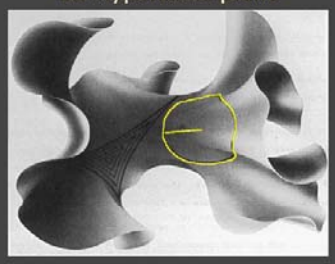
Hyperbolic space background

geometry with exponential "amount of room"

- good match for exponential node count of trees

2D hyperbolic plane



[Thurston and Weeks 84]

hemisphere area

hyperbolic: exponential

$$2\pi \sinh^2(r)$$

euclidean: polynomial

$$2\pi r^2$$

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

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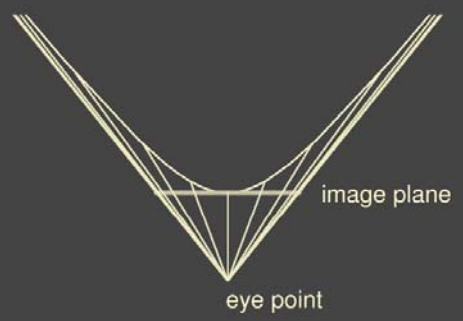
1D hyperbolic space

hyperbola projects to line



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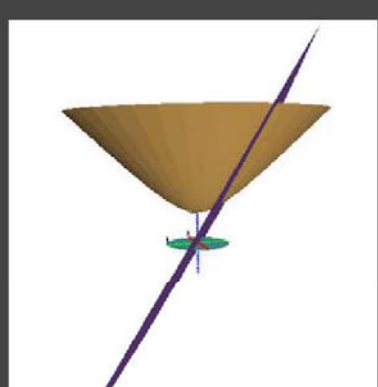
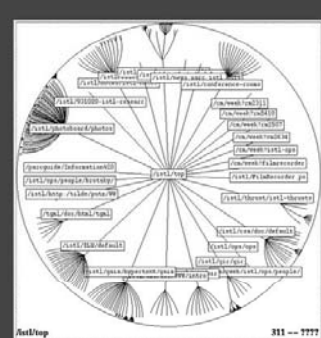
2D hyperbolic space

hyperboloid projects to disk





[Lamping et al 95]

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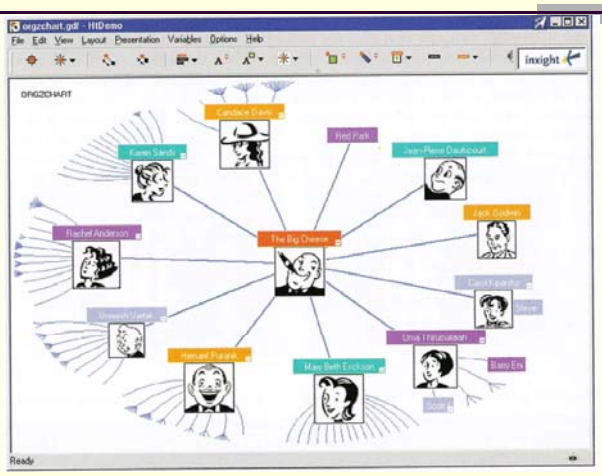
Hyperbolic Browser



R. Spence. Information Visualization

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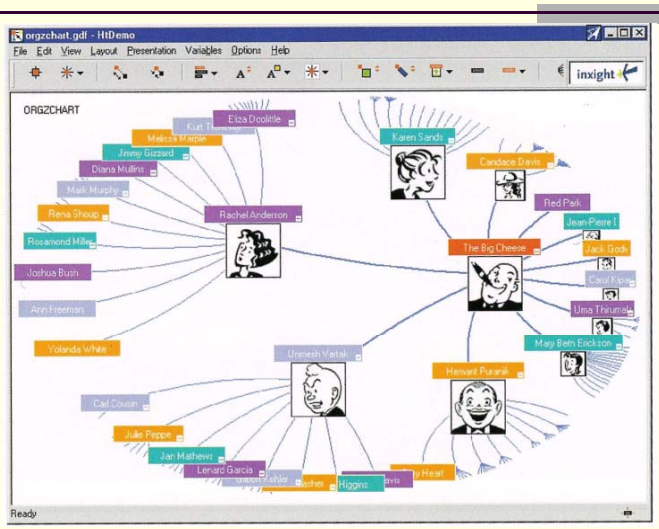
Change Focus



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Key Attributes

- 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)

J. Stasko's InfoVis class slides

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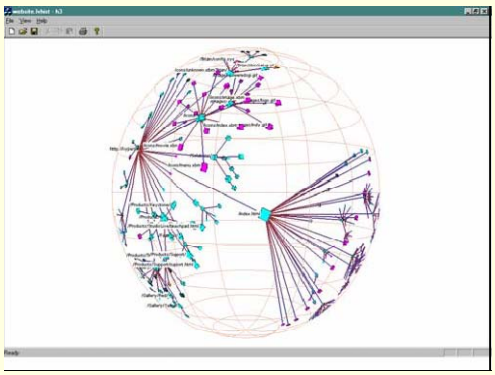
H3 Browser

- Use hyperbolic transformation in 3D space



Demo: http://www-graphics.stanford.edu/videos/h3/

Tamara Munzner: H3: laying out large directed graphs in 3D hyperbolic space. INFOVIS 1997: 2-10

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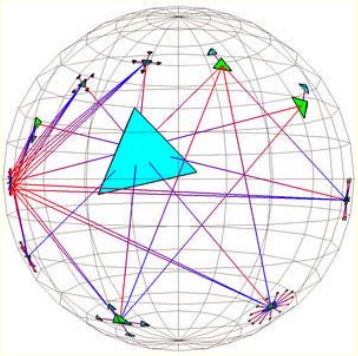
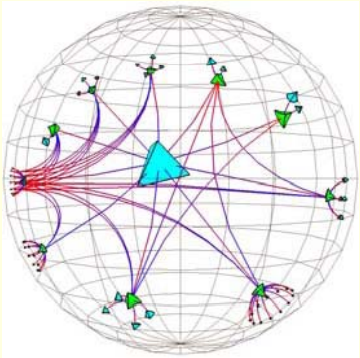
Scalability - Model Selection (1)



Projective model: keeps lines straight but distorts angles.



Conformal model: preserves angles but maps straight lines to circular arcs.

From Tamara Munzner's Ph.D. dissertation

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Scalability - Model Selection (1)

Projective vs. Conformal Model

- Projective model
  - Less aesthetically pleasing ☹
  - Transformation: 4X4 matrices ☺
  - Straight lines ☺
- Conformal model
  - More aesthetically pleasing ☺
  - Transformation: 2X2 complex matrices ☹
  - Curves ☹

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Scalability - Layout (1)

- Find a spanning tree from an input graph
  - Use domain-specific knowledge
- Layout algorithm
  - Nodes are laid out on the surface of hemispheres
  - A bottom-up pass to estimate the radius needed for each hemisphere
  - A top-down pass to place each child node on its parental hemisphere's surface

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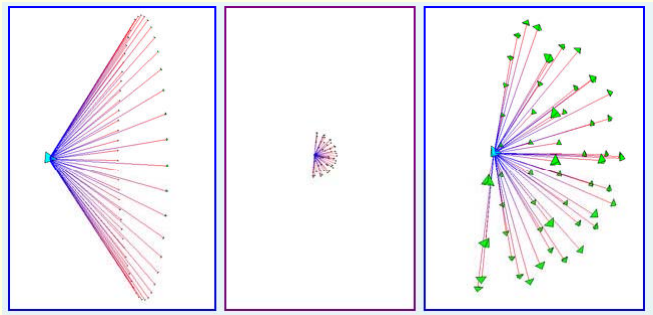
Scalability - Layout (2)

- Lays out child nodes on the surface of a hemisphere like sprinkles on an ice cream cone.



Left: cone tree approach Middle and right: H3 approach

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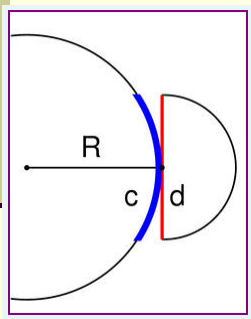
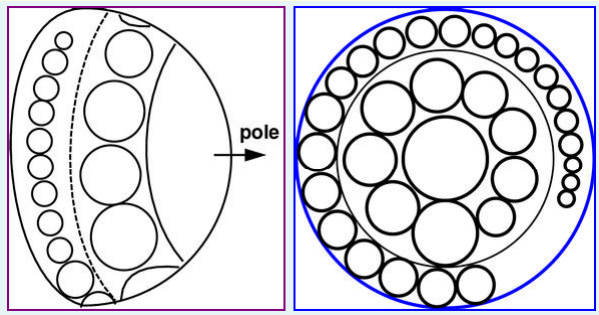
Scalability - Layout (3)

- An approximate layout is fine, whereas a perfect but slow iterative solution would be inappropriate



Bottom-up pass



Top-down pass

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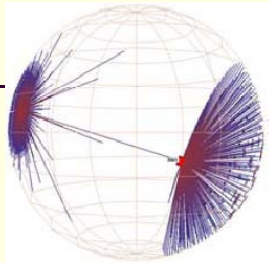
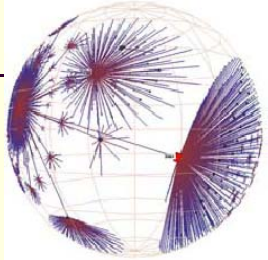
Scalability - Adaptive Drawing (1)





- Maintain a target frame rate (movie 3)
  - Draw only as much of the neighborhood around a center point as is possible in the allotted time
    - Unterminated links
  - Fill in scene fringe using several bounded idle frames when the user is idle

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Scalability - Adaptive Drawing (2)

Active mode - when the user is active dragging the mouse, or during animated transitions.

- **Initialization:** Initialize ActionQueue with a single node with the largest projected screen area in the previous frame (it is close to the ball's center)
- **Draw Loop**
  - Current node is popped off the ActionQueue.
  - Handle the current node.
  - Handle the nodes one hop away from the current one in the spanning tree: the parent node and the children nodes.
  - If the projected screen area of any of these neighboring nodes is at least one pixel, insert it into the ActionQueue, maintaining sorted order.
  - Terminate if: No more time left, or ActionQueue is empty.

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Scalability - Adaptive Drawing (3)

Idle mode - when the user stops dragging the mouse, or an animated transition ends

- **Initialization:** ActionQueue from the previous frame is left untouched.
- **Draw Loop Termination:** Terminate if either: No more time left, or ActionQueue is empty.
- Several idle frames can be drawn back to back if no input is found
  - Why?

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Scalability - Other Tricks

- Only draw a local neighborhood of nodes
  - Nodes sufficiently far from the center will project to less than a single pixel – terminate drawing when features project to subpixel areas
- Use front buffer for highlighting

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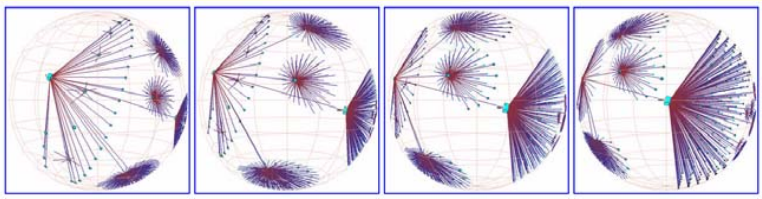
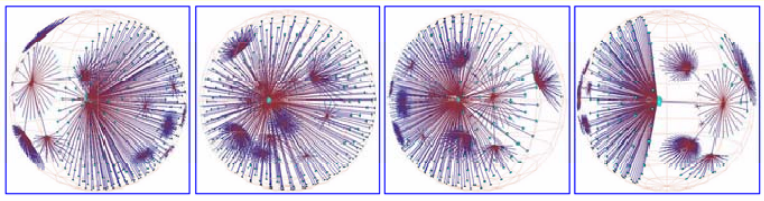
Navigation



Translation of a node to the center



Rotation around the same node (Movie 0)

From Tamara Munzner's Ph.D. dissertation

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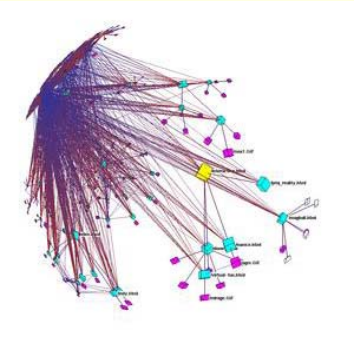
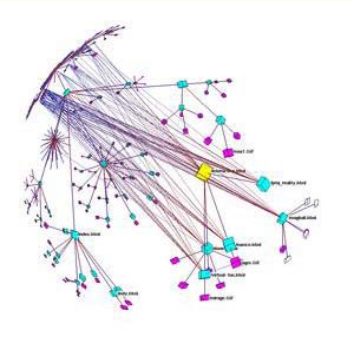
Non-Tree Links



Drawing all the non-tree links



Drawing the outgoing non-tree links for the entire subtree beneath the highlighted yellow node

From Tamara Munzner's Ph.D. dissertation

Movie1

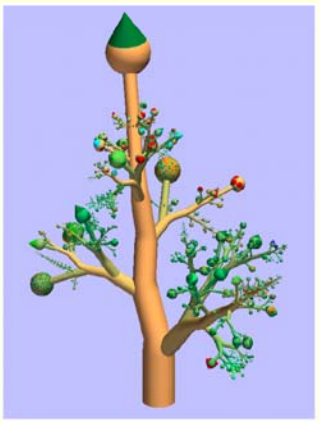
Problems

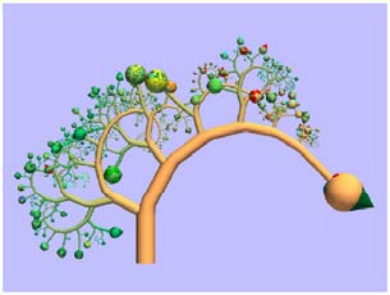
- Orientation
  - Watching the view can be disorienting
  - When a node is moved, its children don't keep their relative orientation to it as in Euclidean plane. They rotate
- Not as symmetric and regular as Euclidean techniques, two important attributes in aesthetics

J. Stasko's InfoVis class slides

Botanical Tree [E. Kleiberg et. al. InfoVis 2001]

- Botanical tree:





The same directory with different settings

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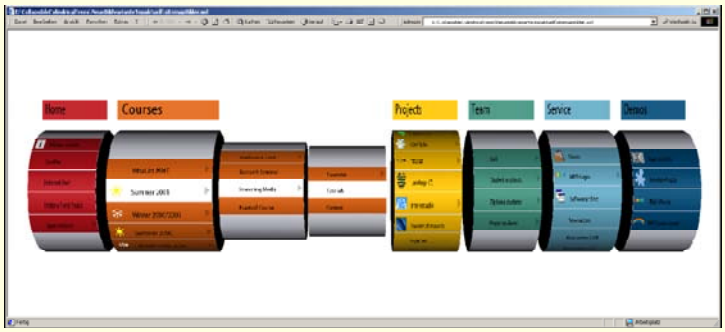
Collapsible Cylindrical Tree [Dachselt & Ebert Infovis 01]

- 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



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Space-Filling Techniques

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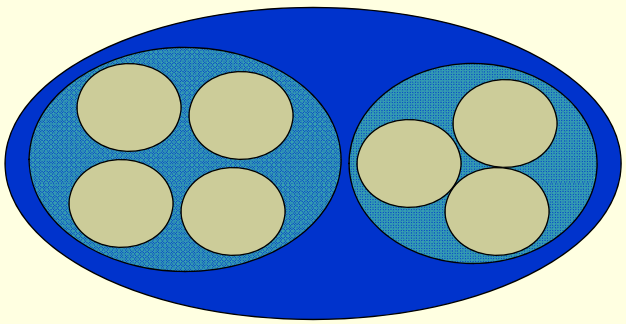
Space-Filling Techniques

- Each item occupies an area
- Children are “contained” within parent



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Visualization of Large Hierarchical Data by Circle Packing W.Wang et al. CHI 2006

- Key ideas:
  - tree visualization using nested circles
  - brother nodes represented by externally tangent circles
  - nodes at different levels displayed by using 2D nested circles or 3D nested cylinders

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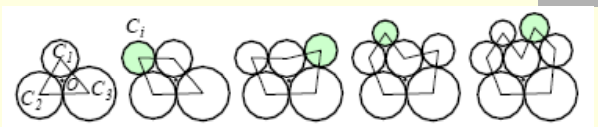
Visualization of Large Hierarchical Data by Circle Packing W.Wang et al. CHI 2006



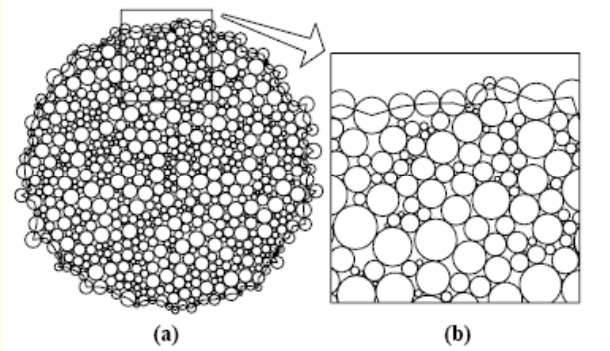


Figure 4. Packing 1000 circles with random radii

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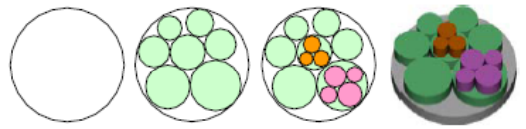
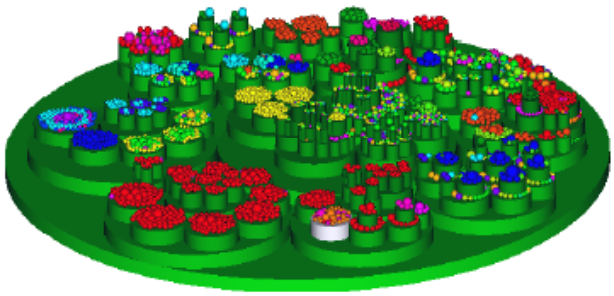
Visualization of Large Hierarchical Data by Circle Packing W.Wang et al. CHI 2006



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



(c) 3D nested cylinders and spheres

Figure 6. The visualization of a file system

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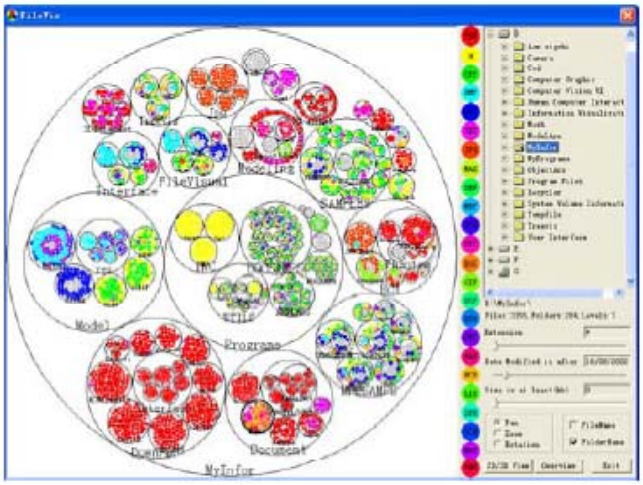
Visualization of Large Hierarchical Data by Circle Packing W.Wang et al. CHI 2006



(a) User interface and the overview of "D:\MyInfor"

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Treemap

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

B. Johnson, Ben Shneiderman: Tree maps: A Space-Filling Approach to the Visualization of Hierarchical Information Structures. IEEE Visualization 1991: 284-291

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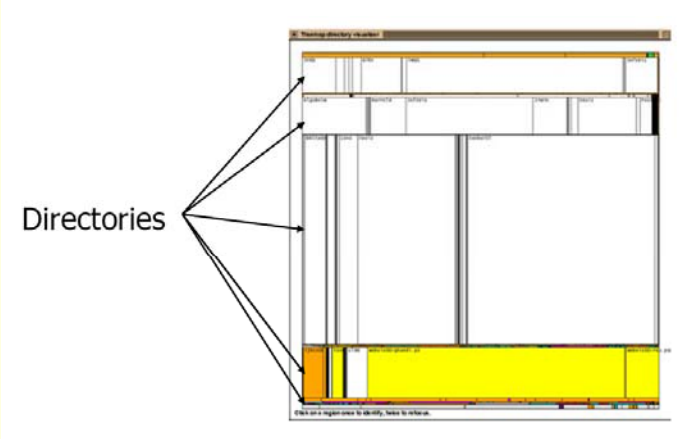
Treemap

- Example



J. Stasko's InfoVis class slides

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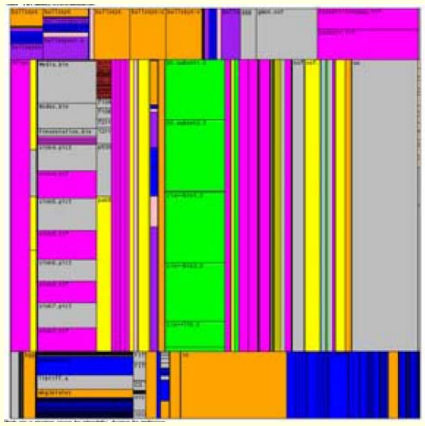
Treemap

- Example



J. Stasko's InfoVis class slides

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Treemap Affordances

- It is rectangular! It makes better use of space
- Good representation of two attributes beyond node-link: color and area
- Not as good at representing structure
  - Can get long-thin aspect ratios
  - What happens if it's a perfectly balanced tree of items all the same size?

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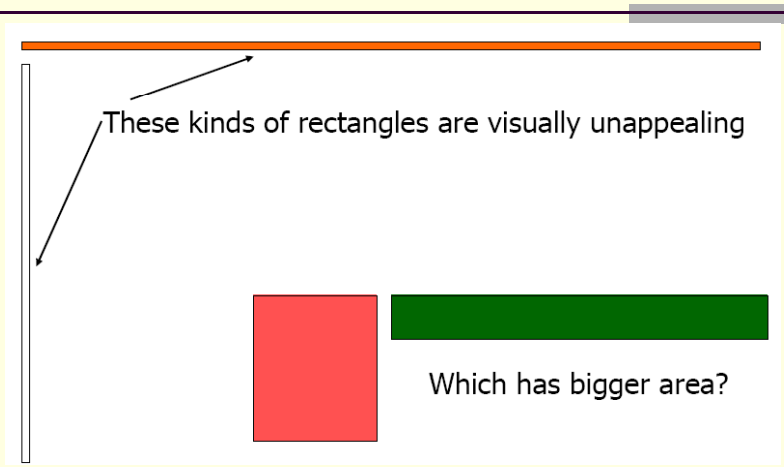
Aspect ratios



J. Stasko's InfoVis class slides

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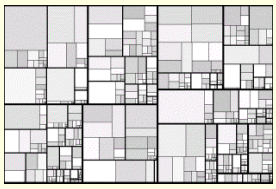
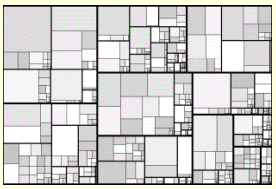
Treemap Variation

- Make rectangles more square

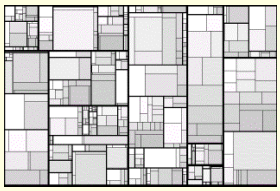
Slice-and-dice



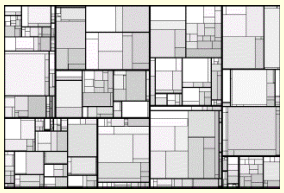
Cluster



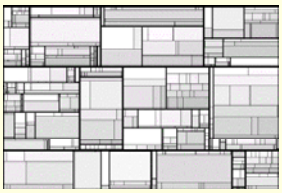
Squarified



Pivot-by-middle



Pivot-by-size



Strip

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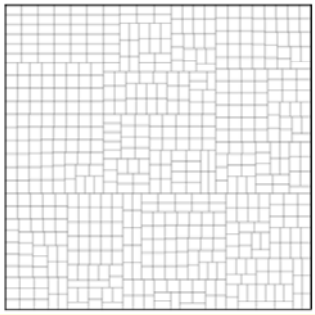
Showing Structure



A tree with 698 node (from [Balzer:infovis2005]

How about a perfectly balanced binary tree?

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Showing Structure

- Borderless treemap: hard to discern structure of hierarchy
  - What happens if it's a perfectly balanced tree of items all the same size?
- Variations:
  - Use border
  - Change rectangles to other forms

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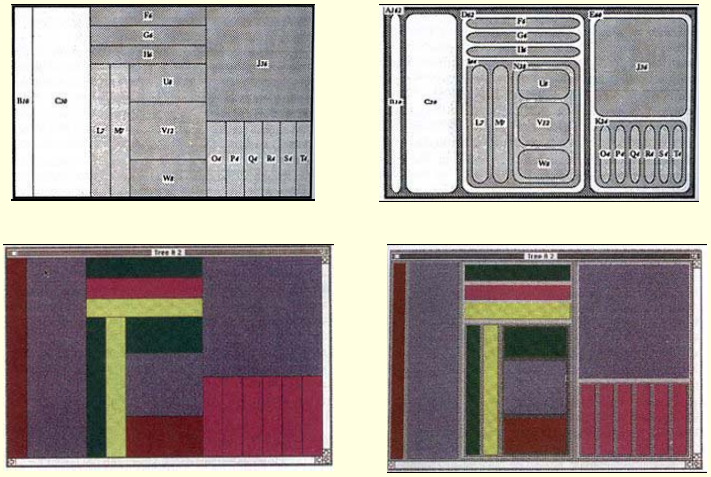
Nested vs. Non-nested



Non-nested Treemap Nested Treemap

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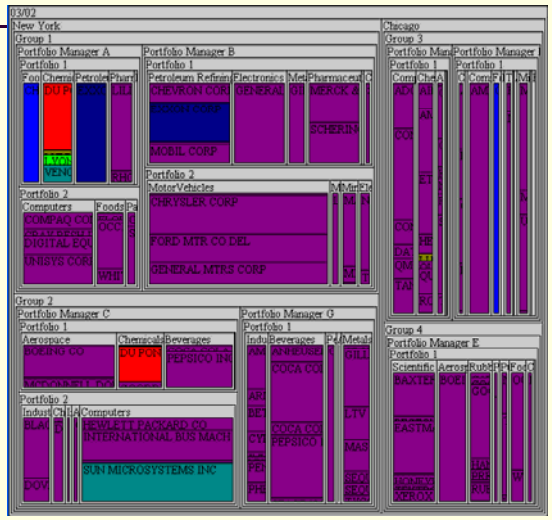
Nested Treemap

- Borders help on small trees, but take up too much area on large, deep ones



http://www.cs.umd.edu/hcil/treemap-history/treemap97.shtml

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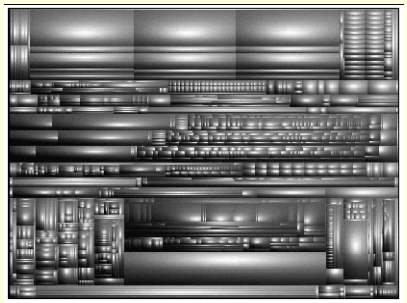
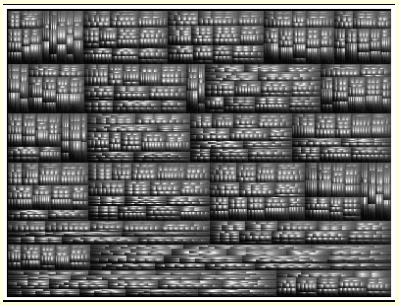
Cushion Treemap

- Add shading and texture (Van Wijk and Van de Wetering InfoVis'99)





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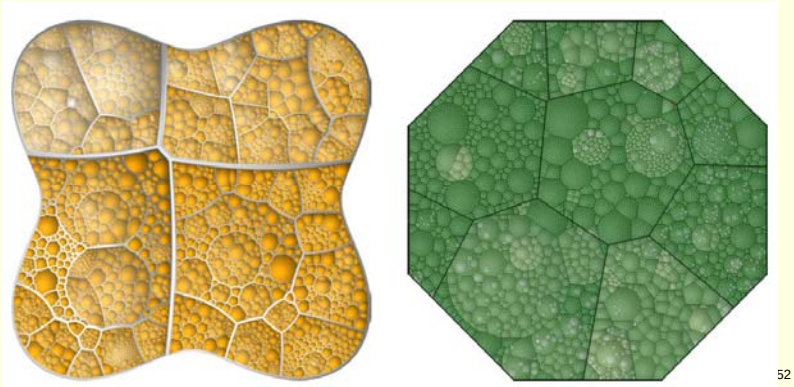
Voronoi Treemaps [balzer:infovis05]

- Enable subdivisions of and in polygons
- Fit into areas of arbitrary shape



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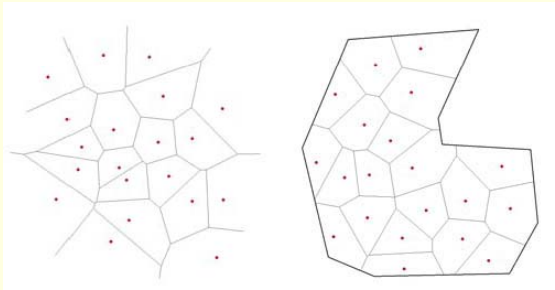
Basic Voronoi Tessellations

- Enable partitioning of m-dimensional space without holes or overlappings
- Planar VT in 2D:
  - P: = {p1, ..pn} a set of n distinct points –generators
  - Divide 2D space into n Voronoi regions V(Pi):
    - Any point q lies in the region V(Pi) if and only if
    - distance(pi, q) < distance(pj,q) for any j != i



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Weighted Voronoi Tessellations

- Basic VT: $distance_{\varepsilon}(p_i, q) := \|p_i - q\| = \sqrt{(x_i - x)^2 + (y_i - y)^2}$
- Additively weighted Voronoi (AW VT):

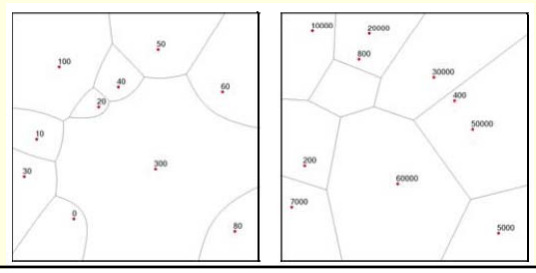
$$distance_{aw}(p_i, w_i, q) := \|p_i - q\| - w_i$$

- Additively weighted power voronoi (PW VT):

$$distance_{pw}(p_i, w_i, q) := \|p_i - q\|^2 - w_i$$

Left: AW VT

Right: PW VT



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Centroidal Voronoi Tessellations (CVT)

- Property of CVT: Each generator is itself center of mass(centroid) of corresponding voronoi region

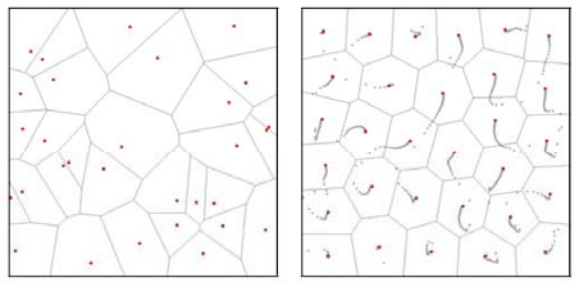

Figure 6: Voronoi tessellation of 20 random points and an associated CVT—traces illustrate the movements of the points during the computation of the CVT

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Centroidal Voronoi Tessellations (CVT)

- CVT minimize the energy function:

$$\mathscr{K}(P, \mathscr{V}(P)) = \sum_i \int_{V(p_i)} \|x - p_i\|^2 dx$$

- The energy of the CVT is equivalent to the overall aspect ratio of the subareas of the treemap layout

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Voronoi Treemap Algorithm

- Size of each Voronoi region should reflect size of the tree node
- Area size is not observed in CVT computation
- Extension:
  - Use iteration
  - In each iteration, adjust the area of regions by their weights
  - Weights are adjusted according to the size of the node
  - Iterate until the relative size error is under a threshold
- Video

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Treemap Applications

- Software visualization
- Multimedia visualization
- Tennis matches
- File/directory structures
- Basketball statistics
- Stocks and portfolios

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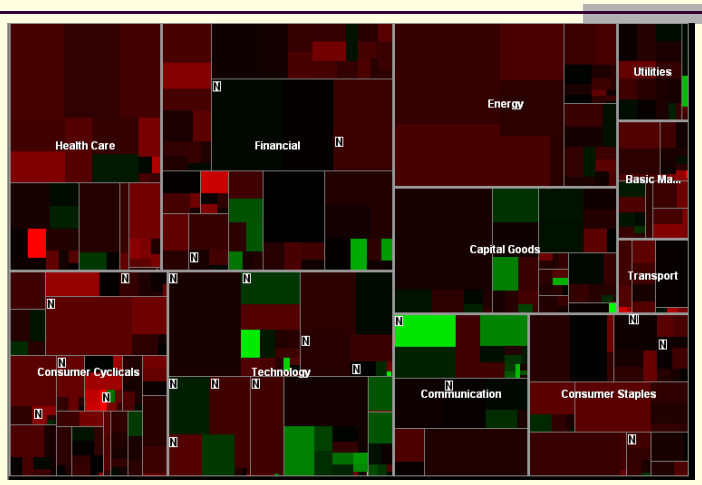
Marketmap



http://www.smartmoney.com/marketmap/

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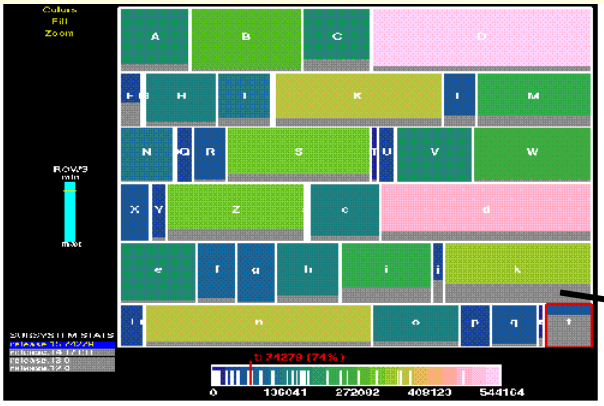
Software Visualization

- SeeSys (Baker & Eick, AT&T Bell Labs)



New code in this release

Figure 2: NCSL and new development by subsystem in a recent release.

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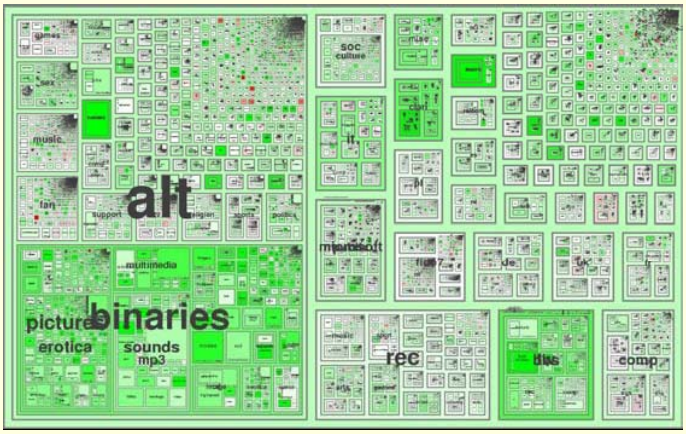
Internet News Groups

- Netscan (Fiore & Smith Microsoft)



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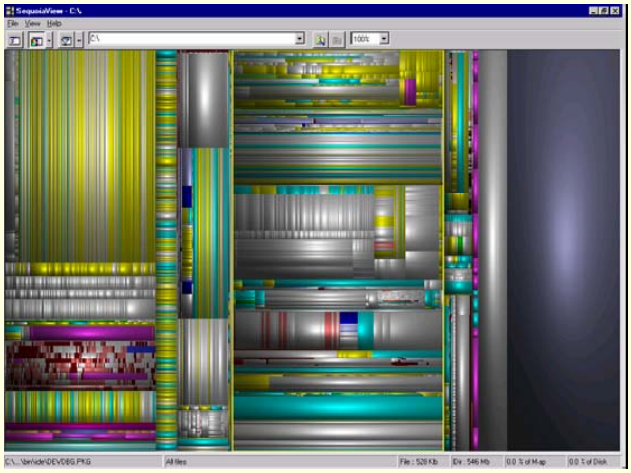
SequoiaView

- File visualizater www.win.tue.nl/sequoiaview/



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Photomesa

- Image browser (quantum and bubble treemap) http://www.cs.umd.edu/hcil/photomesa/

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Space-Filling Techniques

- Each item occupies an area
- Children are “contained” within (under) parent

One Example

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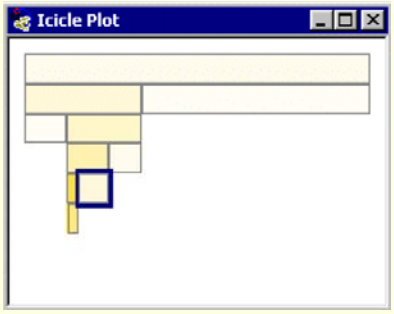
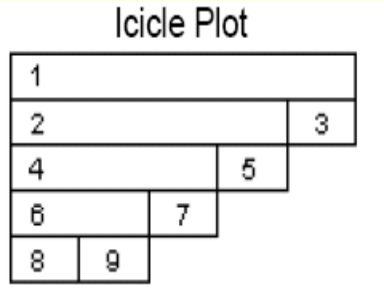
Icicle Plot

- Icicle plot (similar to Kleiner and Hartigan's concept of castles)
  - Node size is proportional to node width





Barlow and Neville InfoVis 2001

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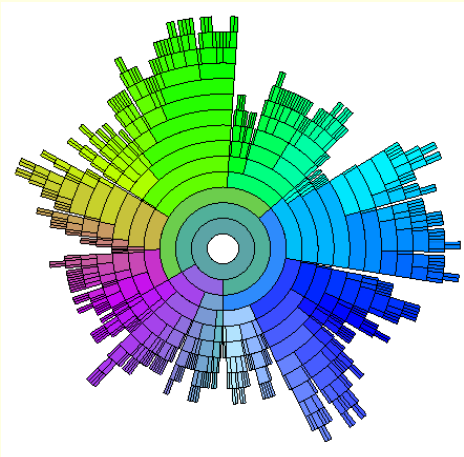
Radial Space Filing Techniques

- InterRing [Yang02]



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Node Link + Space Filling Techniques

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Elastic Hierarchies: Combining Treemaps and Node-Link Diagrams [zhao:infovis 05]

- A hybrid approach
- Dynamic

- Video

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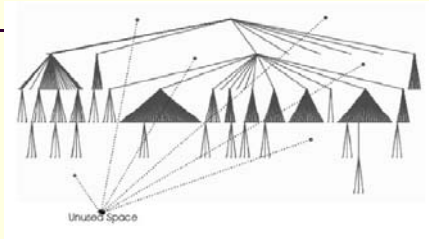
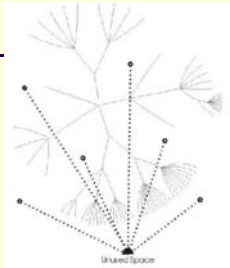
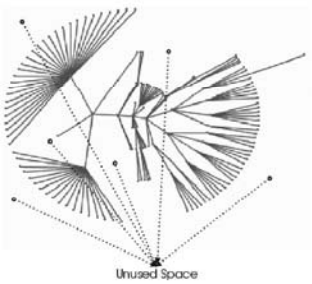
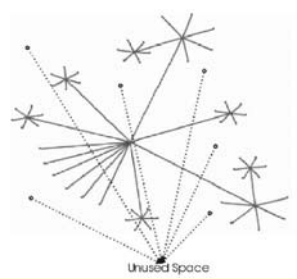
Space-Optimized Tree - Motivation









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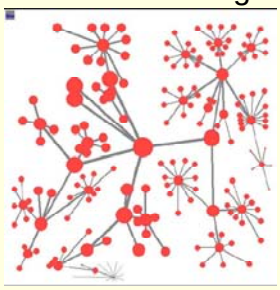
Q. Nguyen and M. Huang Infovis 02

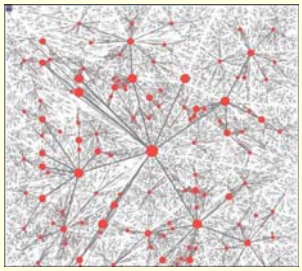
Space-Optimized Tree [Q. Nguyen and M. Huang Infovis 02]

Key idea:

- Partition display space into a collection of geometrical areas for all nodes
- Use node-link diagrams to show relational structure



Example: Tree with 150 nodes



Example: Tree with approximately 55000 nodes

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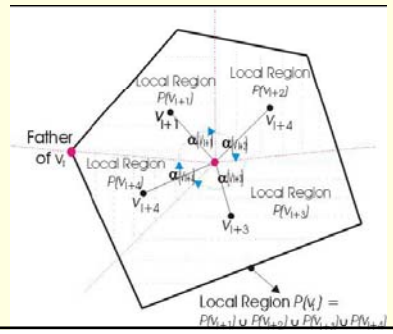
Space-Optimized Tree [Q. Nguyen and M. Huang Infovis 02]

Algorithm for dividing a region:

1. weight calculation for each direct child
2. wedge calculation for each direct child
3. vertex position calculation for each direct child



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Weight Calculation

$$w(v_i) = 1 + C\sum_{j=0}^{k-1} w(v_{l+j})$$

- V_i: the direct child
- V_l – V_{l+k} : Direct children of V_i
- Constant *C:* decide difference between vertexes with more descendants and vertexes with fewer descendants.

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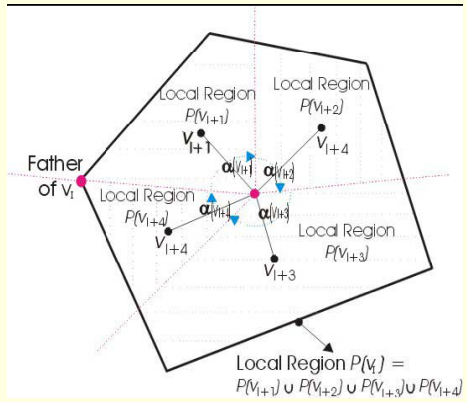
Wedge Calculation

$$\alpha(v_{l+m}) = A \frac{w(v_{l+m})}{\sum_{j=0}^{k} w(v_{l+j})}$$



Example of dividing the local region of one node

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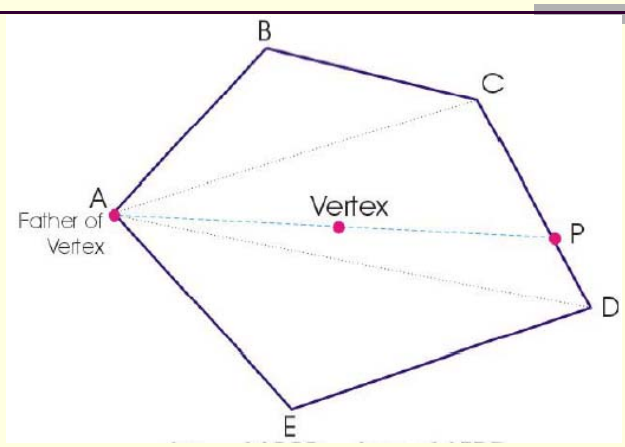
Vertex Position Calculation



Area ABCP = Area AEDP

Vertex is the midpoint of line AP

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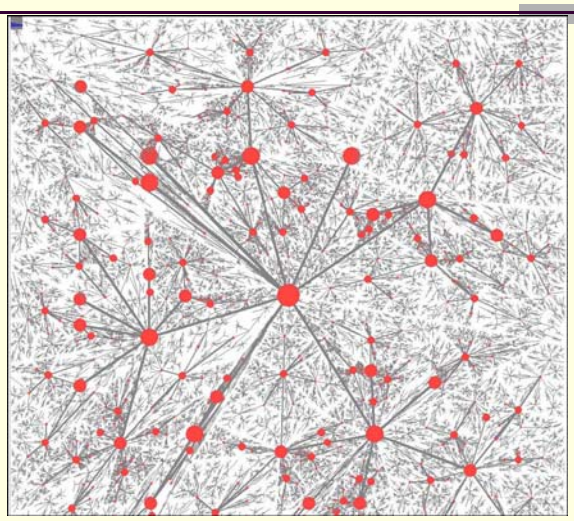
Space-Optimized Tree



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Example: Tree with approximately 55000 nodes