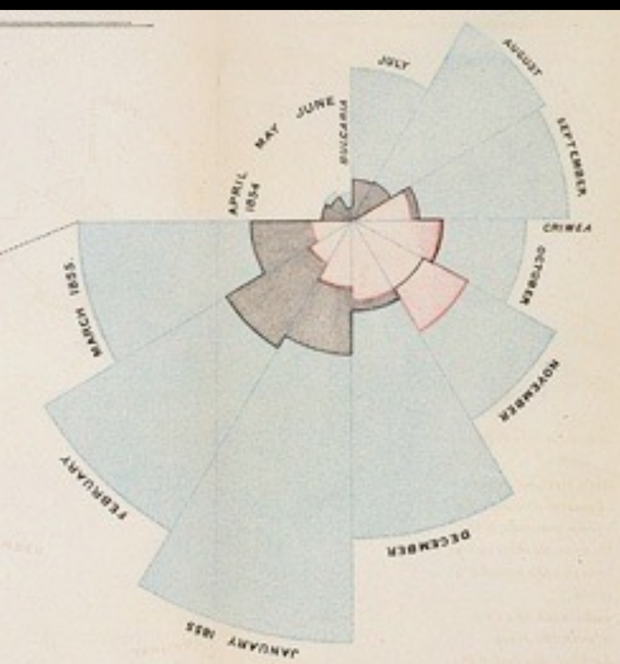
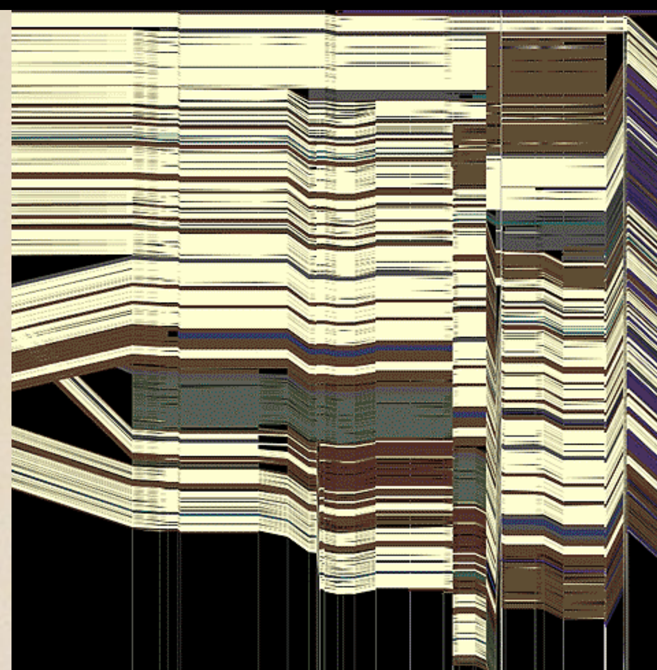
**CSE 442** - Data Visualization

# Hierarchies




Jeffrey Heer University of Washington

# Graphs and Trees

**Today:** Visualizing Hierarchical Data

**Next Time:** Visualizing Network Data

**Goals**

Overview of layout approaches

Assess strengths and weaknesses

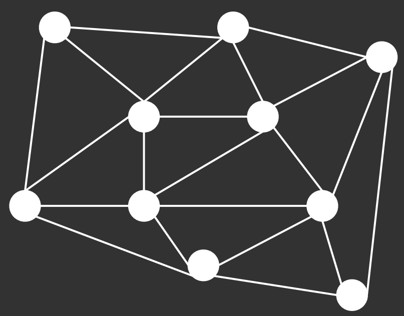
Insight into implementation techniques

# Graphs and Trees

**Graphs**

Model relations among data

*Nodes* and *edges*

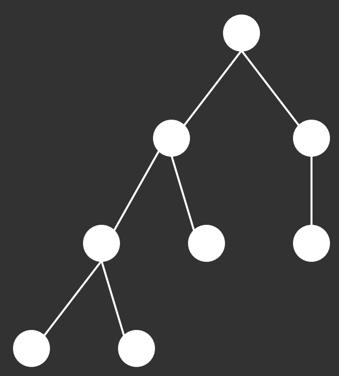


**Trees**

Graphs with hierarchical structure

Connected graph with N-1 edges

Nodes as *parents* and *children*



# Spatial Layout

A primary concern of tree/graph drawing is the spatial arrangement of nodes and edges.

Often (but not always) the goal is to effectively depict the graph structure:

- Connectivity, path-following
- Topological distance
- Clustering / grouping
- Ordering (e.g., hierarchy level)

# Tree Visualization

**Indentation**

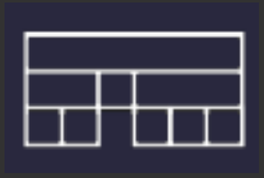
Linear list, indentation encodes depth

**Node-Link diagrams**

Nodes connected by lines/curves

**Enclosure diagrams**

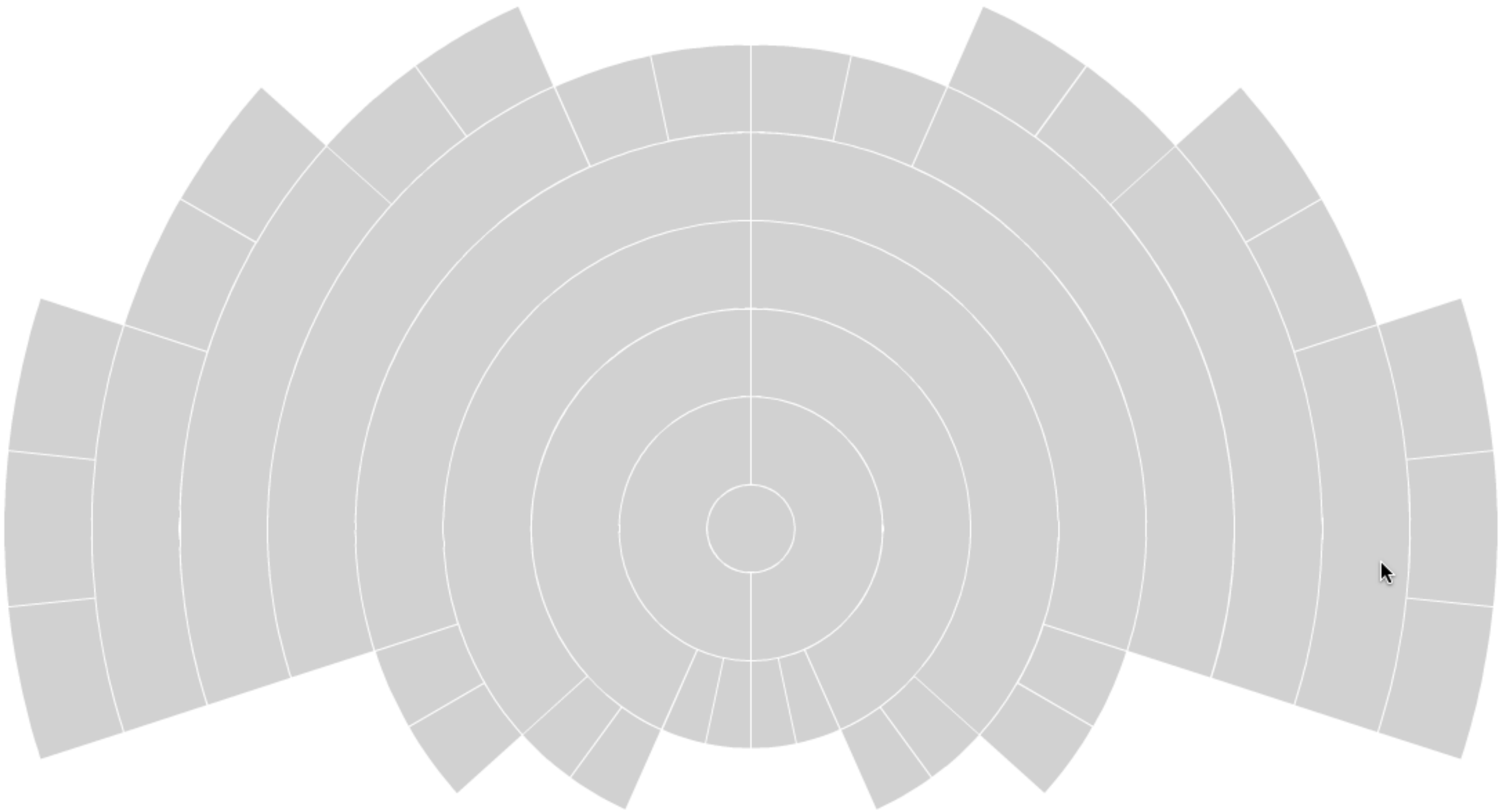
Represent hierarchy by enclosure



**Layering**

Relative position and alignment

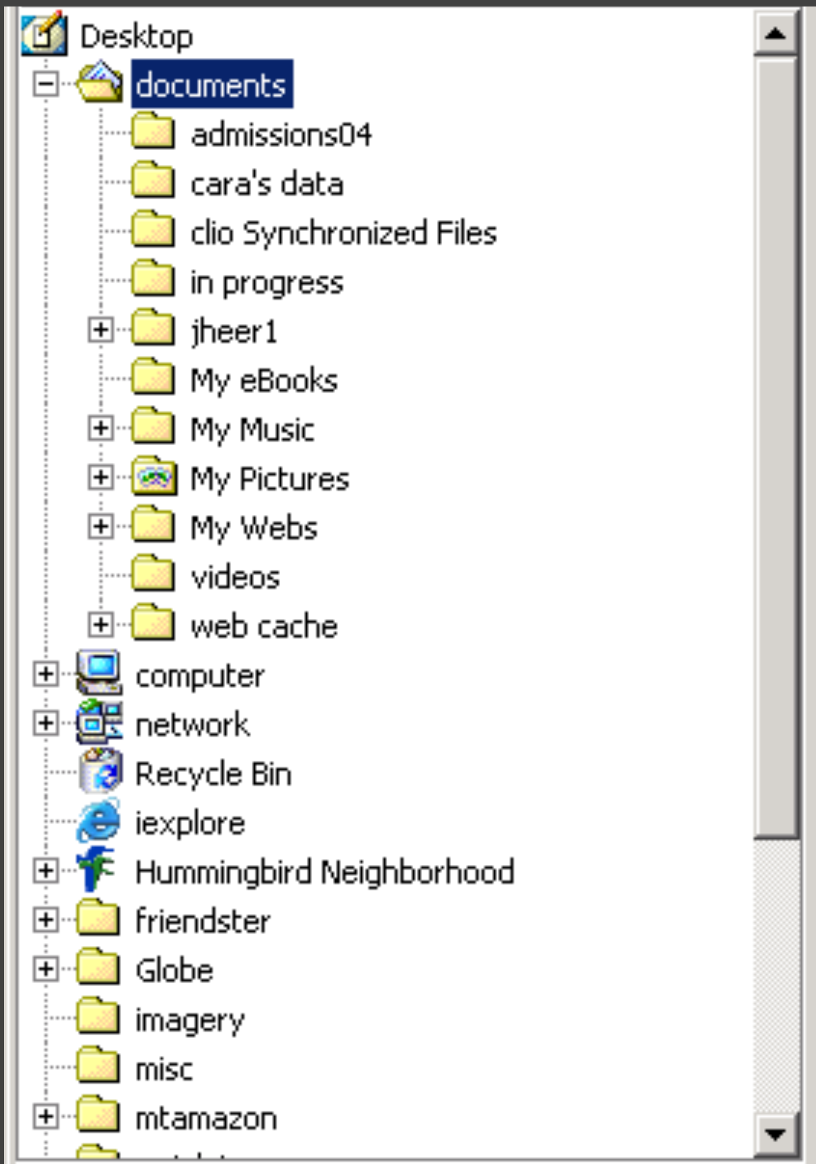
Typically fast: O(n) or O(n log n), interactive layout



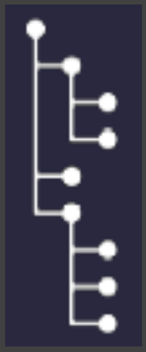
Interactive Layout Demo (requires Flash Player)

# Tree Layout

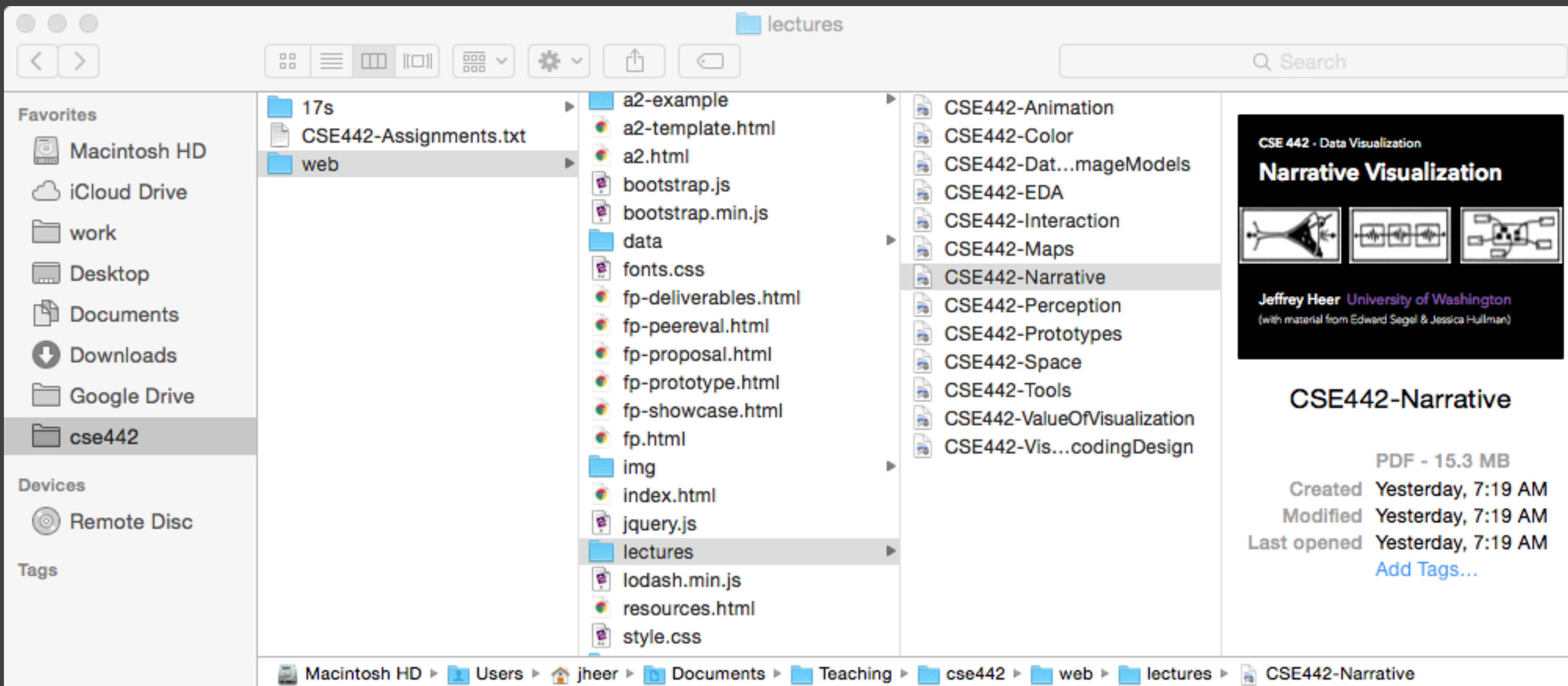
# Indentation




- Places all items along vertically spaced rows
- Indentation used to show parent/child relationships
- Commonly used as a component in an interface
- Breadth and depth contend for space
- Often requires a great deal of scrolling



# Single-Focus (Accordion) List




Separate breadth & depth along 2D.
Focus on a single path at a time.

# Node-Link Diagrams

Nodes are distributed in space, connected by straight or curved lines

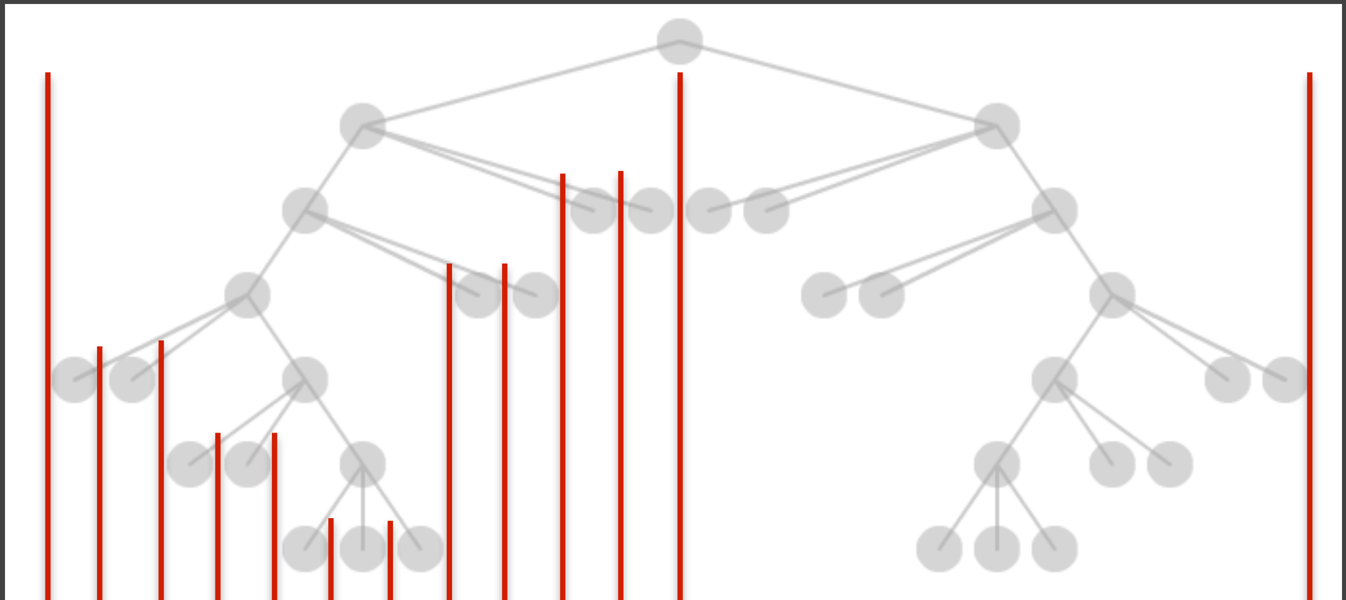
Typical approach is to use 2D space to break apart breadth and depth

Often space is used to communicate hierarchical orientation (e.g., towards authority or generality)

# Naïve Recursive Layout

Repeatedly divide space for subtrees by leaf count

- Breadth of tree along one dimension
- Depth along the other dimension

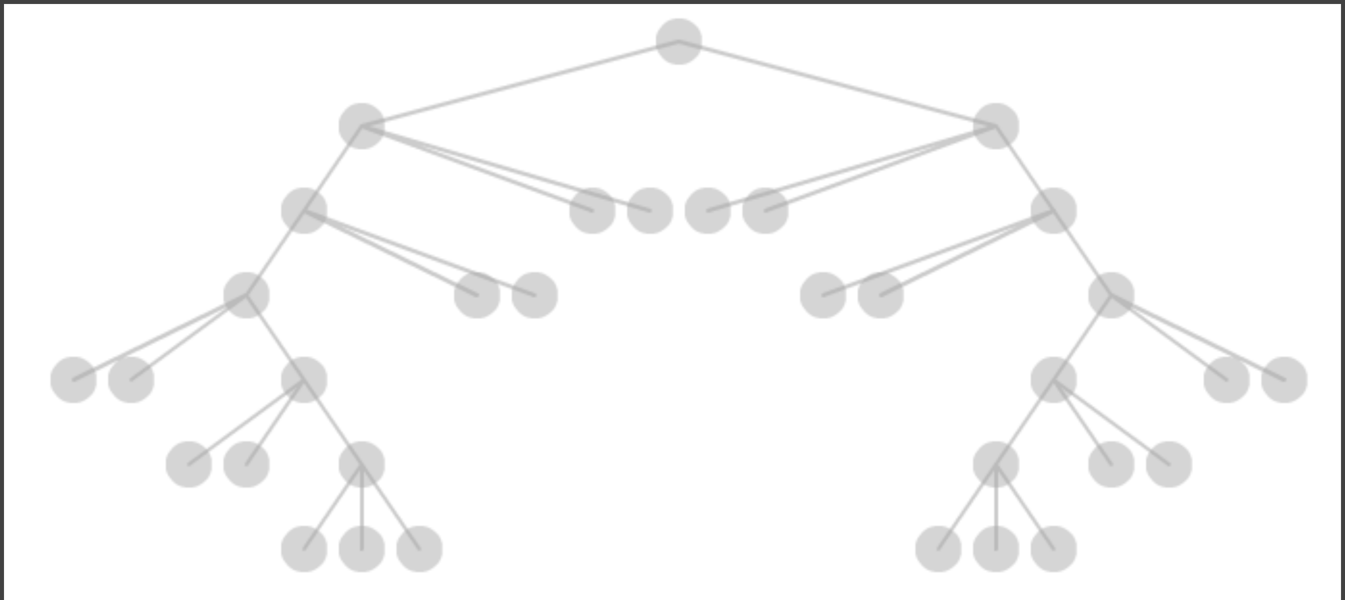


# Naïve Recursive Layout

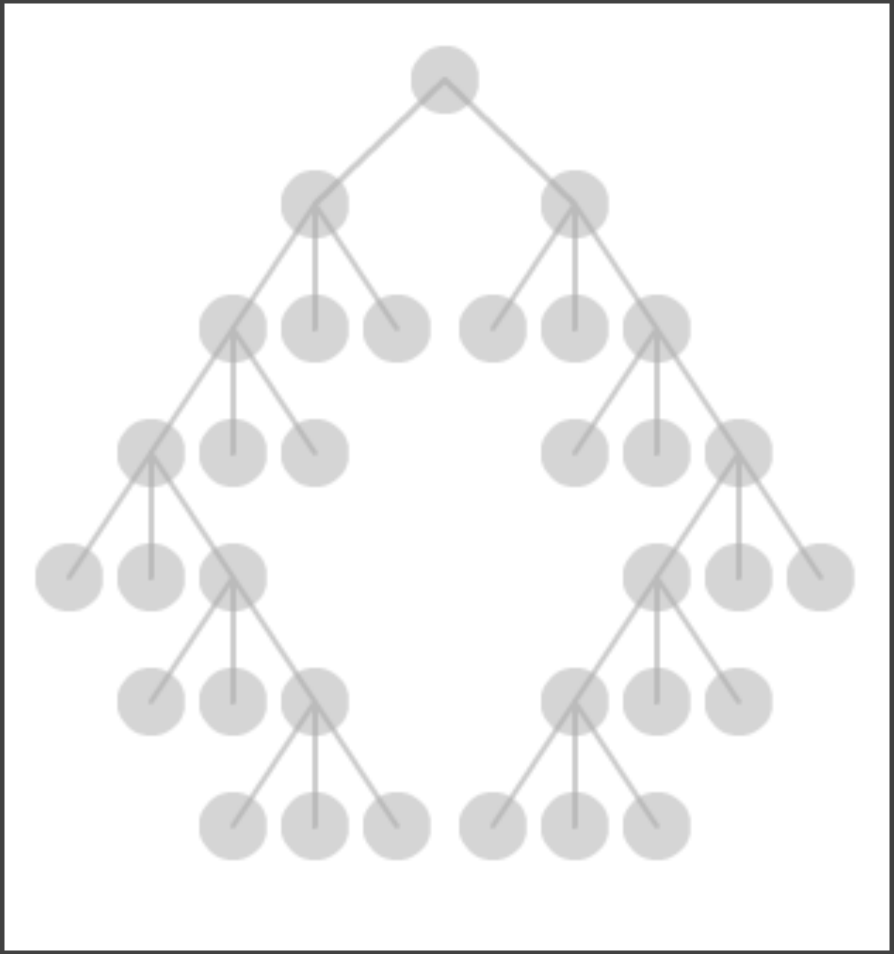
Repeatedly divide space for subtrees by leaf count

- Breadth of tree along one dimension
- Depth along the other dimension

Problem: exponential growth of breadth



# Reingold & Tilford's "Tidy" Layout



Goal: make smarter use of space, maximize density and symmetry.

Originally binary trees, extended by Walker to cover general case.

Corrected by Buchheim et al. to achieve a linear time algorithm.

# Reingold-Tilford Layout

**Design Considerations**

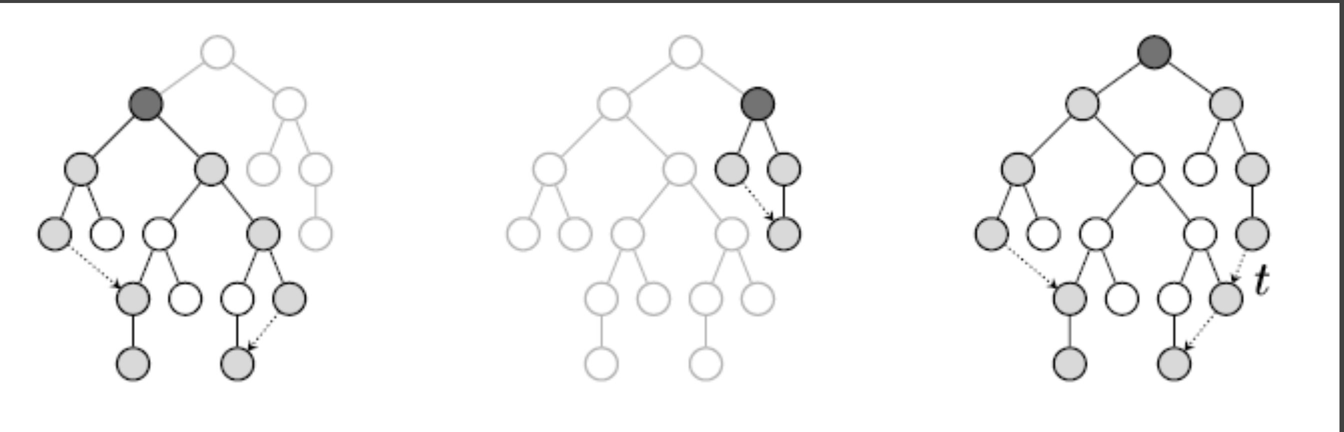
Clearly encode depth level

No edge crossings

Isomorphic subtrees drawn identically

Ordering and symmetry preserved

*Compact layout (don't waste space)*



# Reingold-Tilford Layout

**Initial bottom-up (post-order) traversal of the tree**

- Y-coordinates based on tree depth
- X-coordinates set piecemeal via “shifts” at each depth

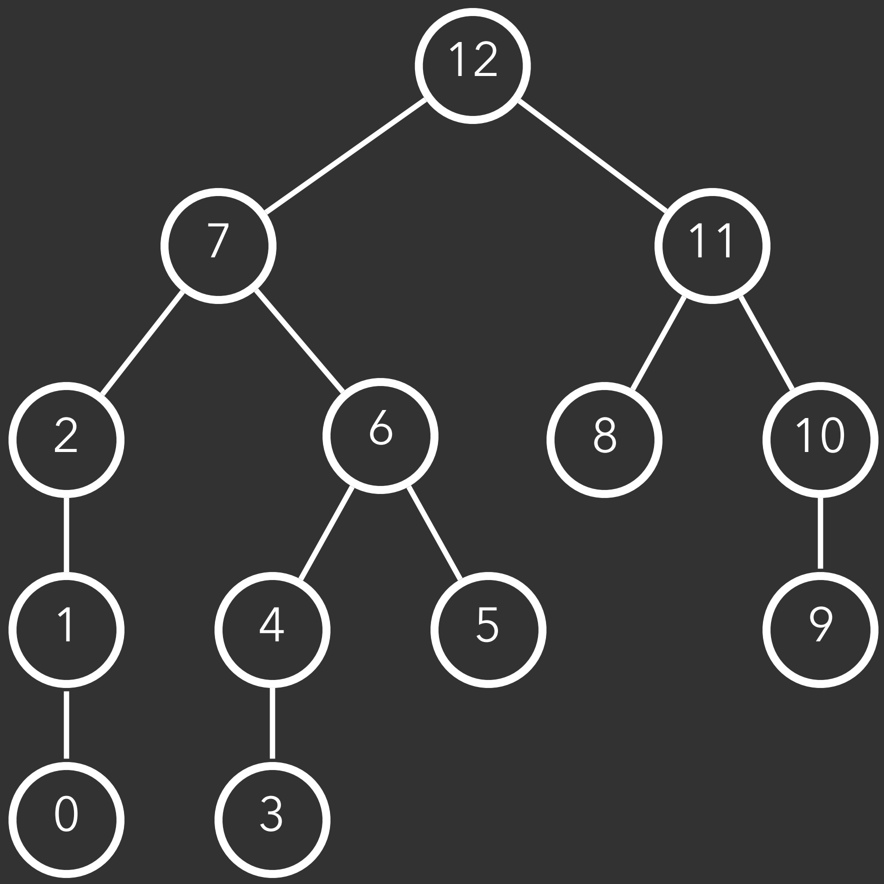
**At each parent node: merge left and right subtrees**

- Shift right subtree as close as possible to the left
- Computed efficiently by maintaining subtree contours
- “Shifts” in position saved for each node
- Parent nodes centered above children

**Final top-down (pre-order) traversal to set X-coordinates**

- Sum initial layout and aggregated shifts

# Reingold-Tilford Layout



# Reingold-Tilford Layout

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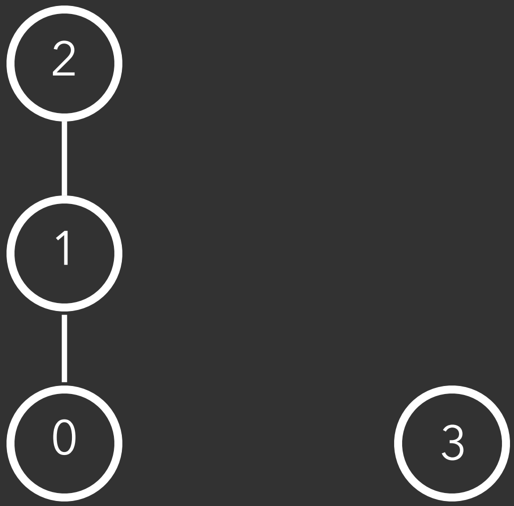

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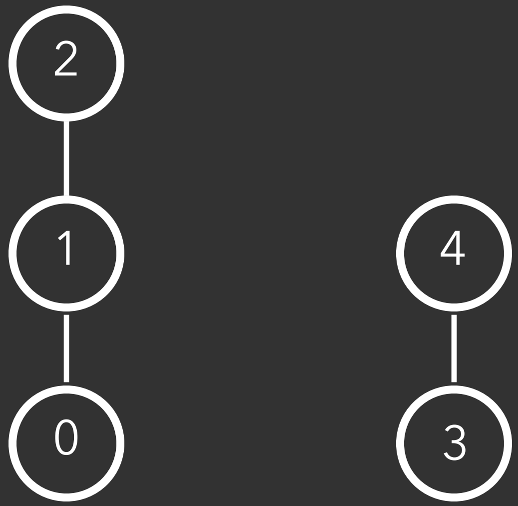

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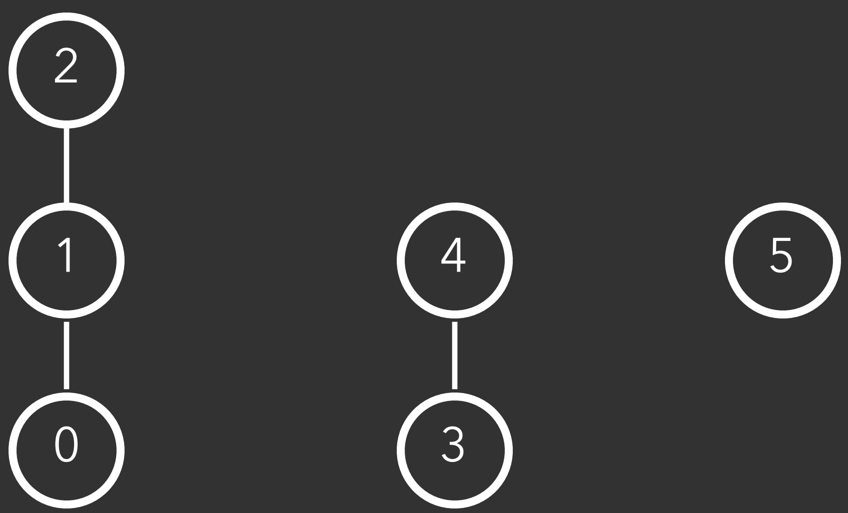

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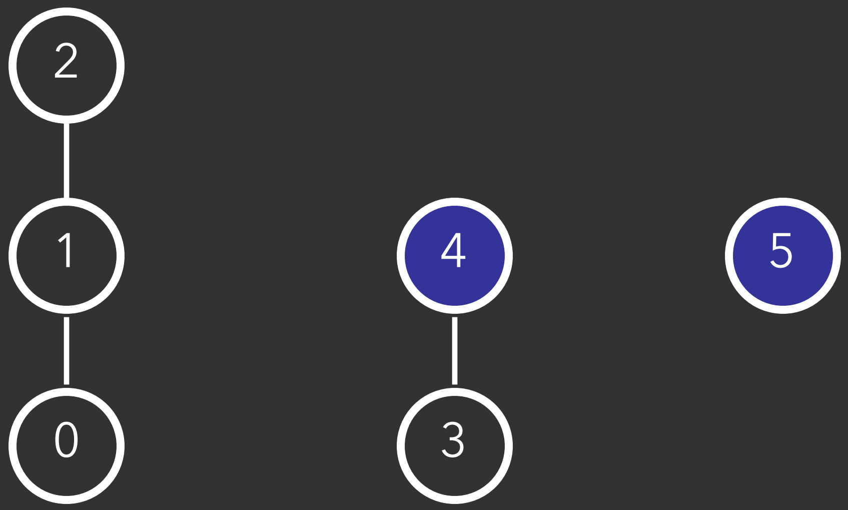

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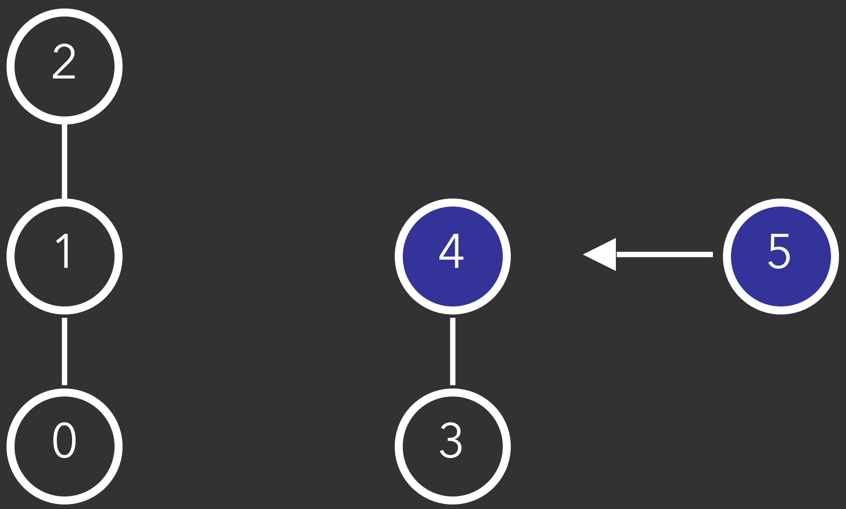

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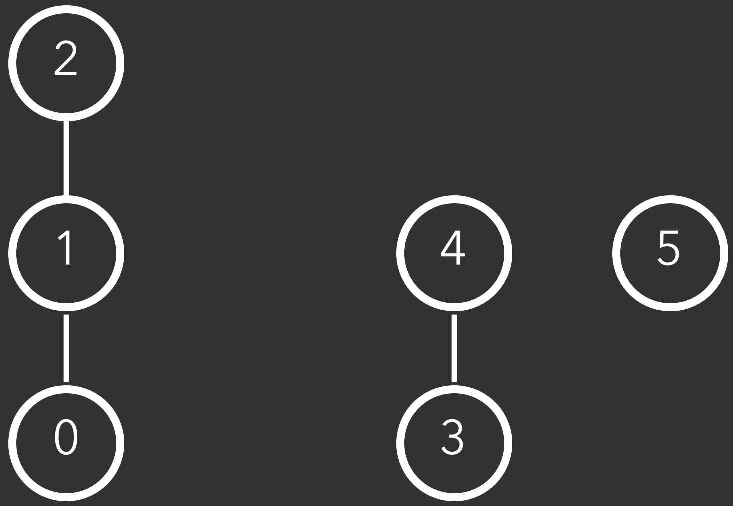

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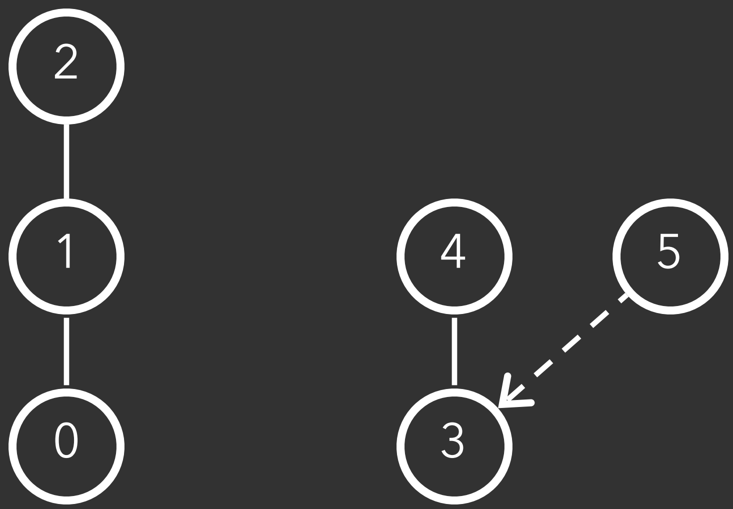

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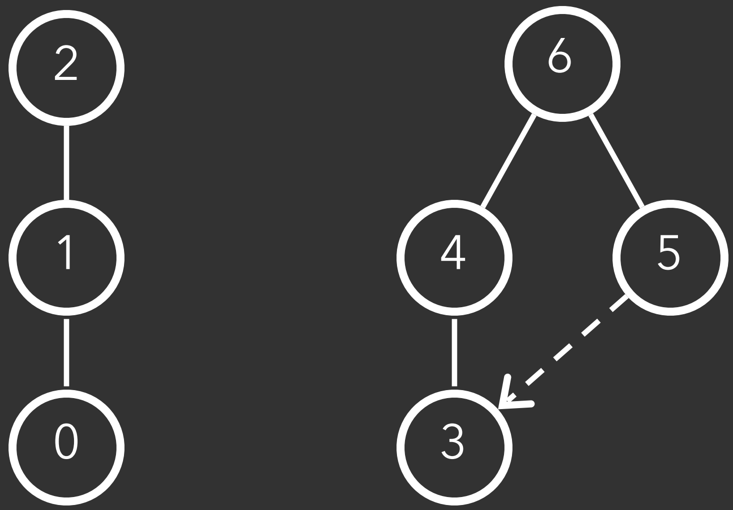

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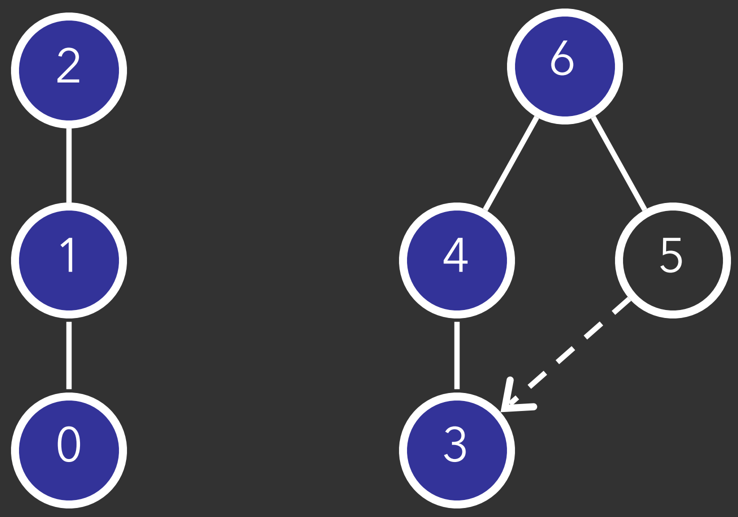

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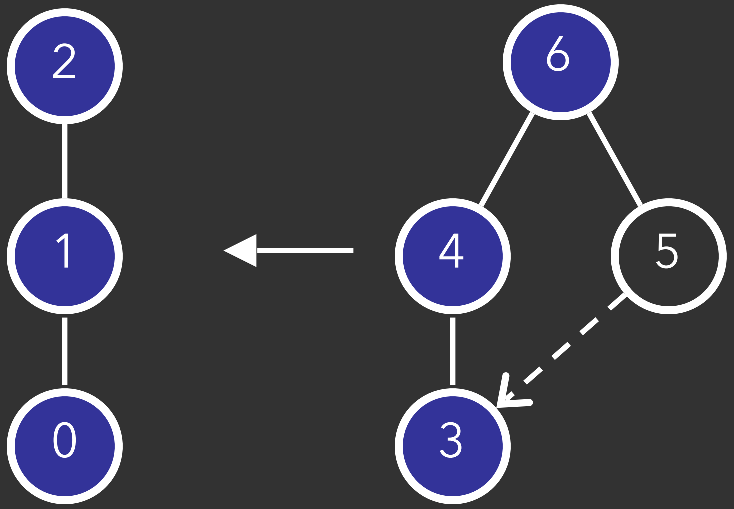

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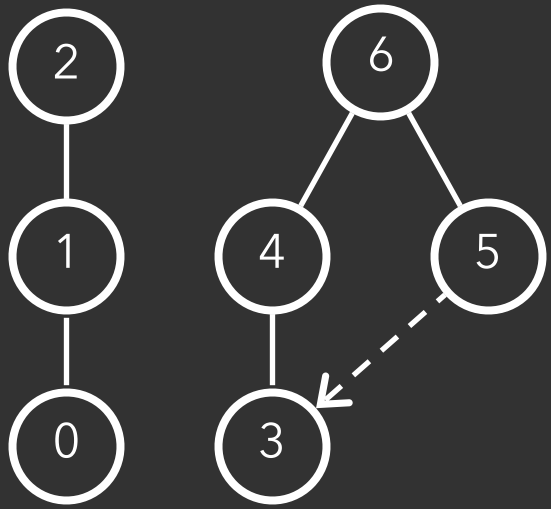

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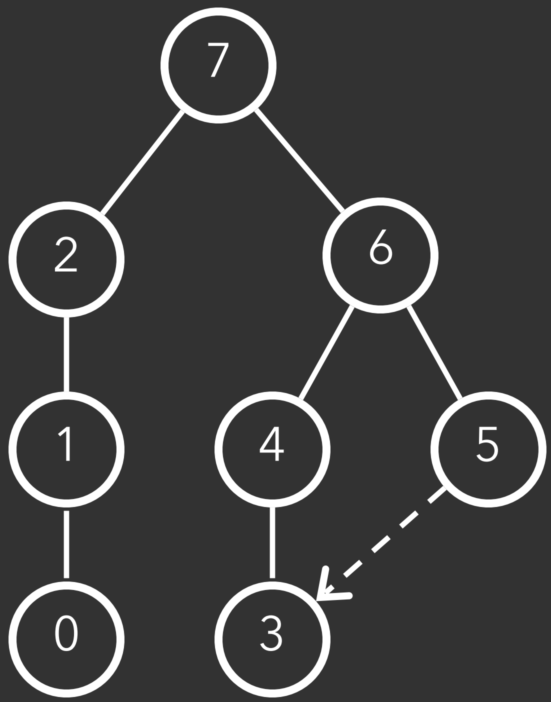

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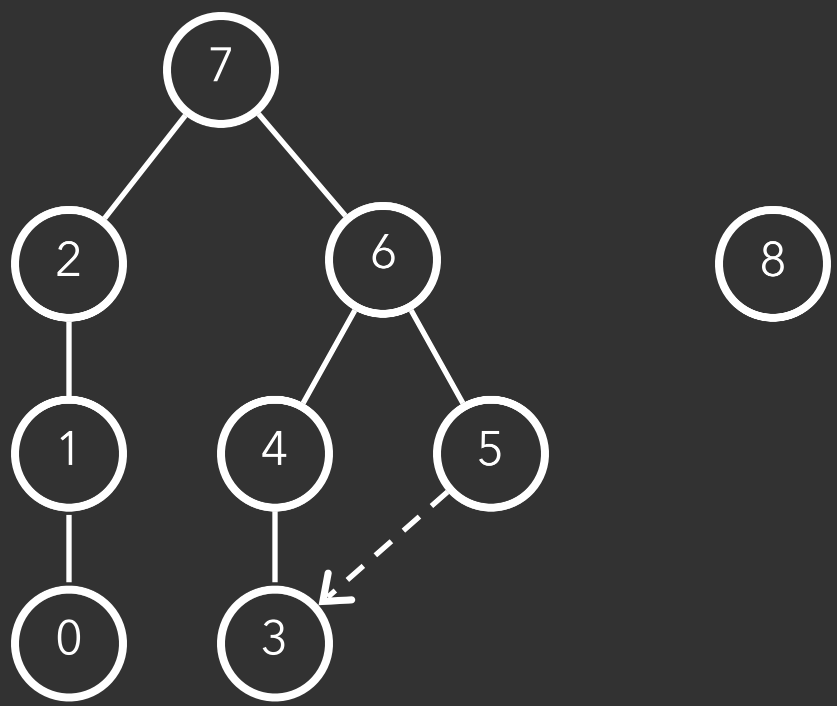

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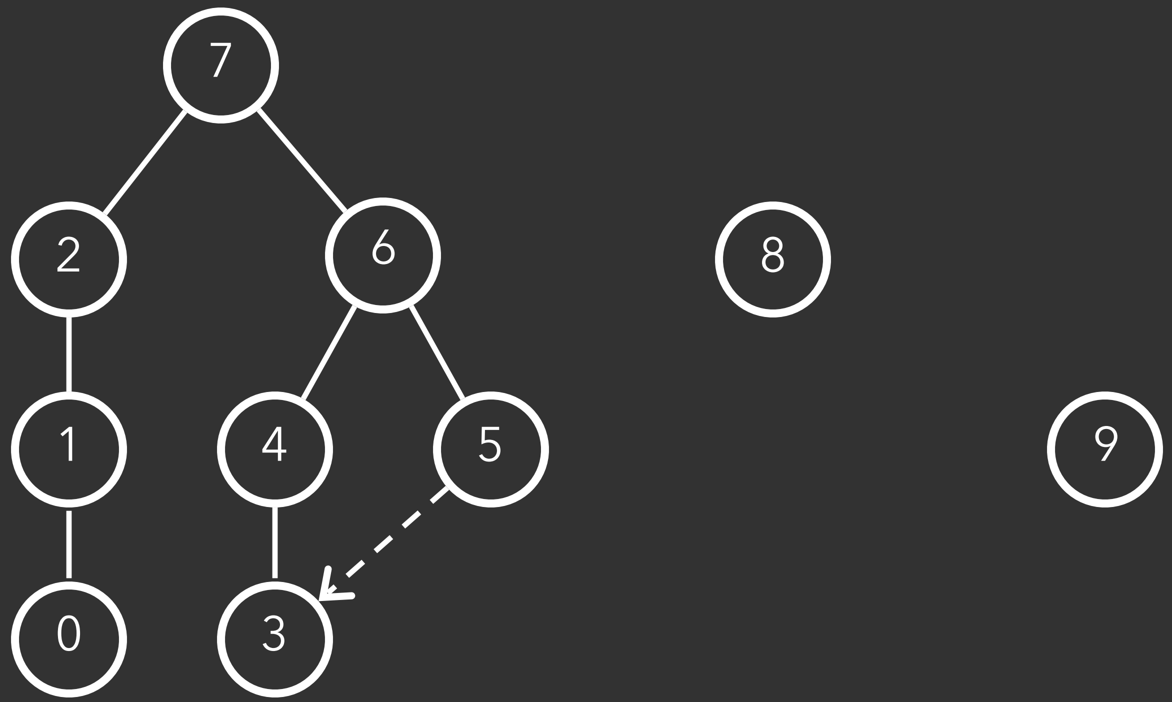

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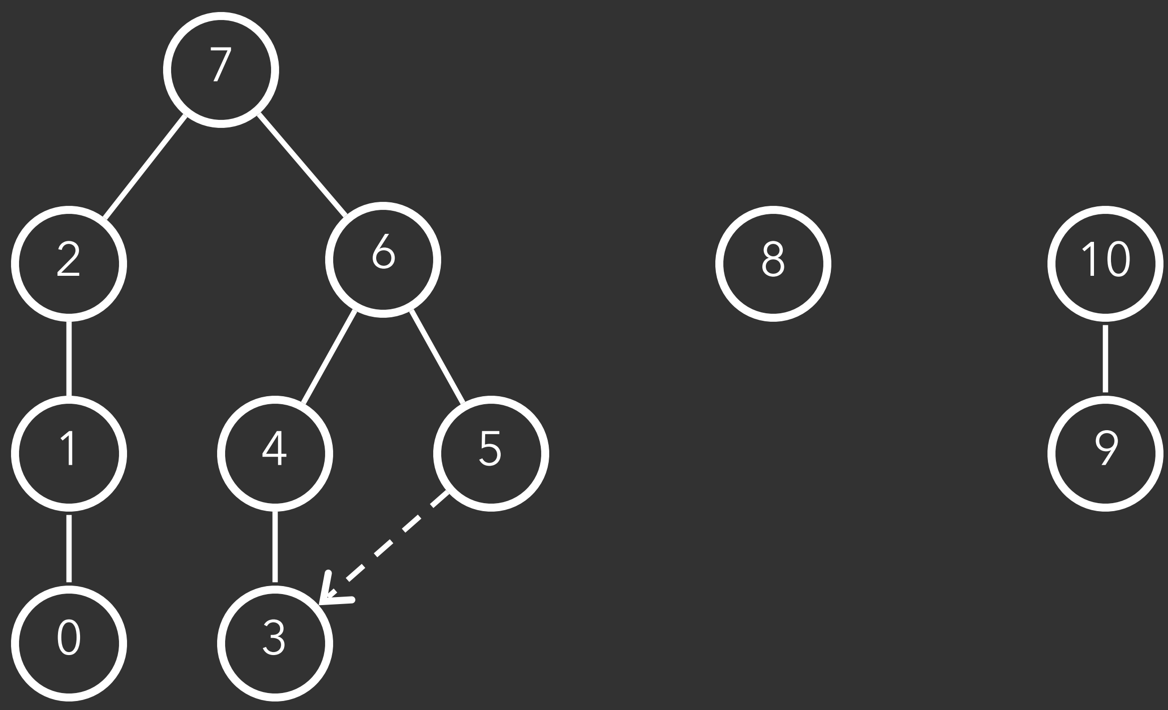

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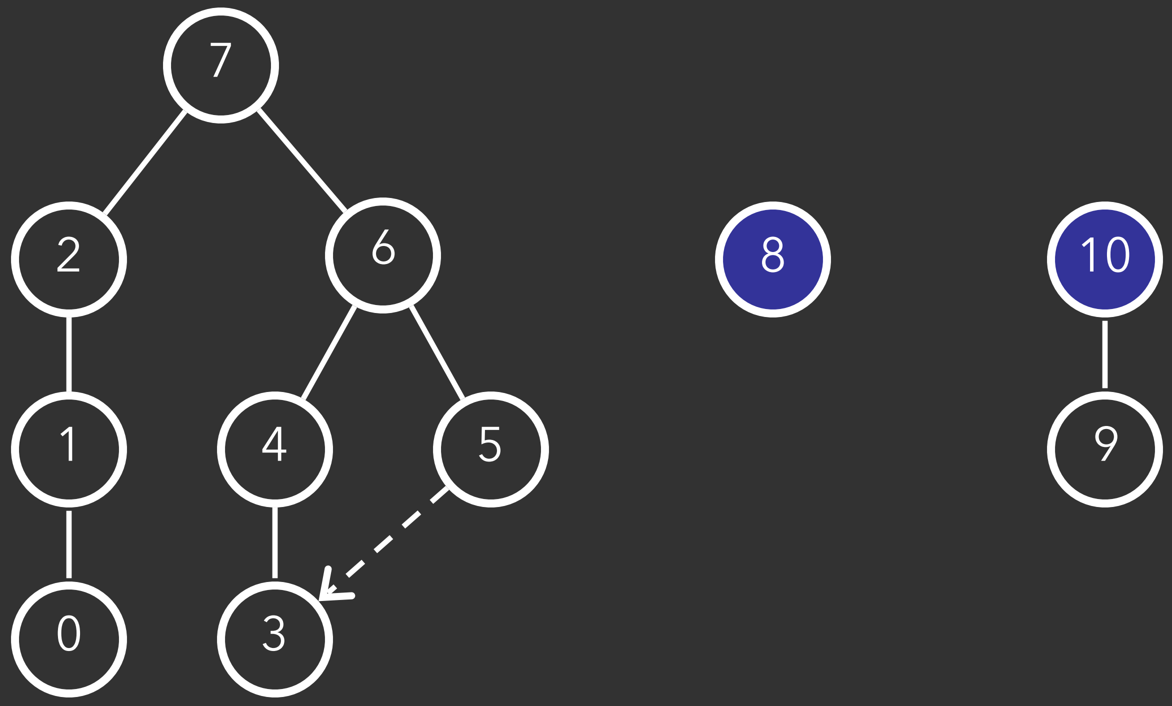

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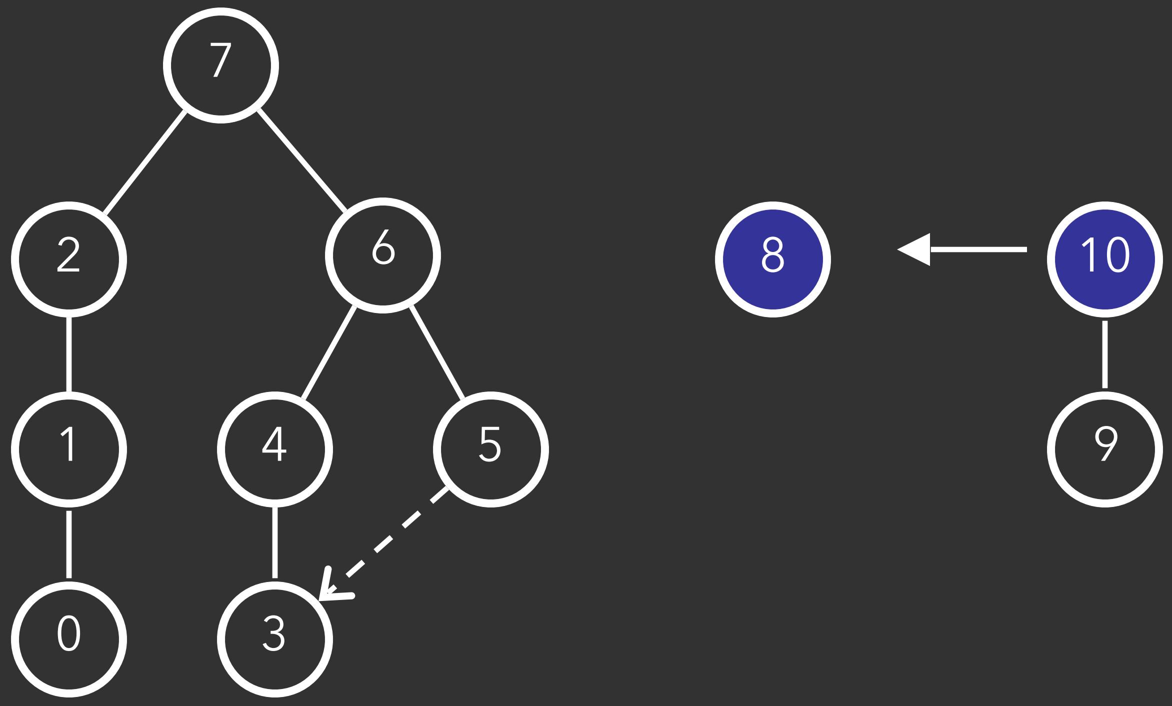

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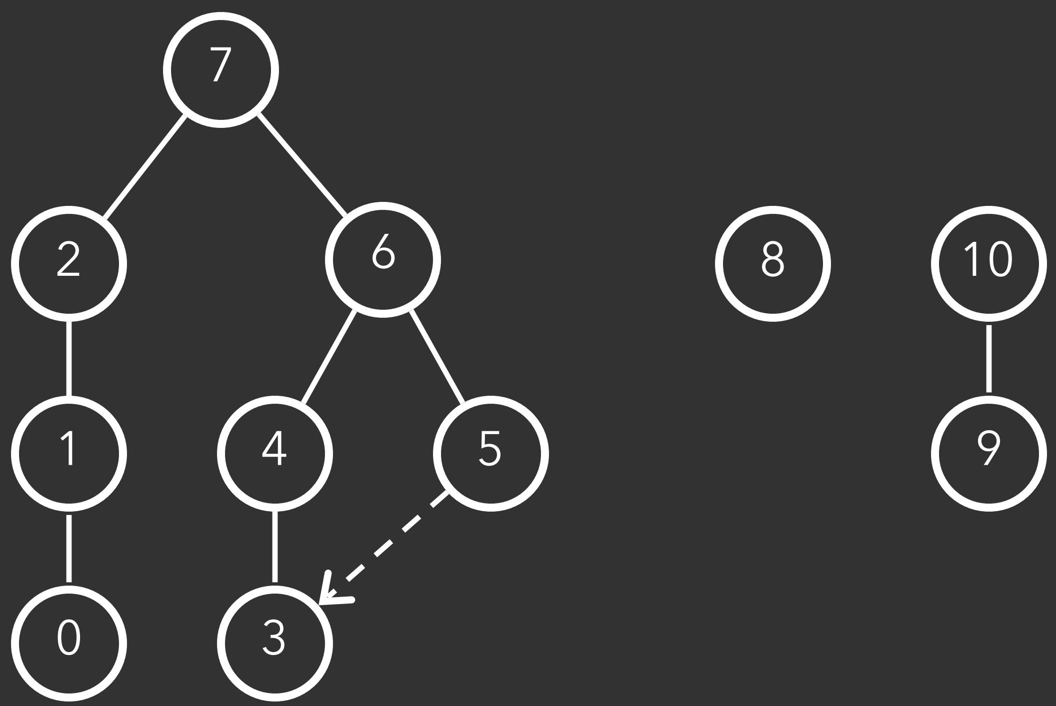

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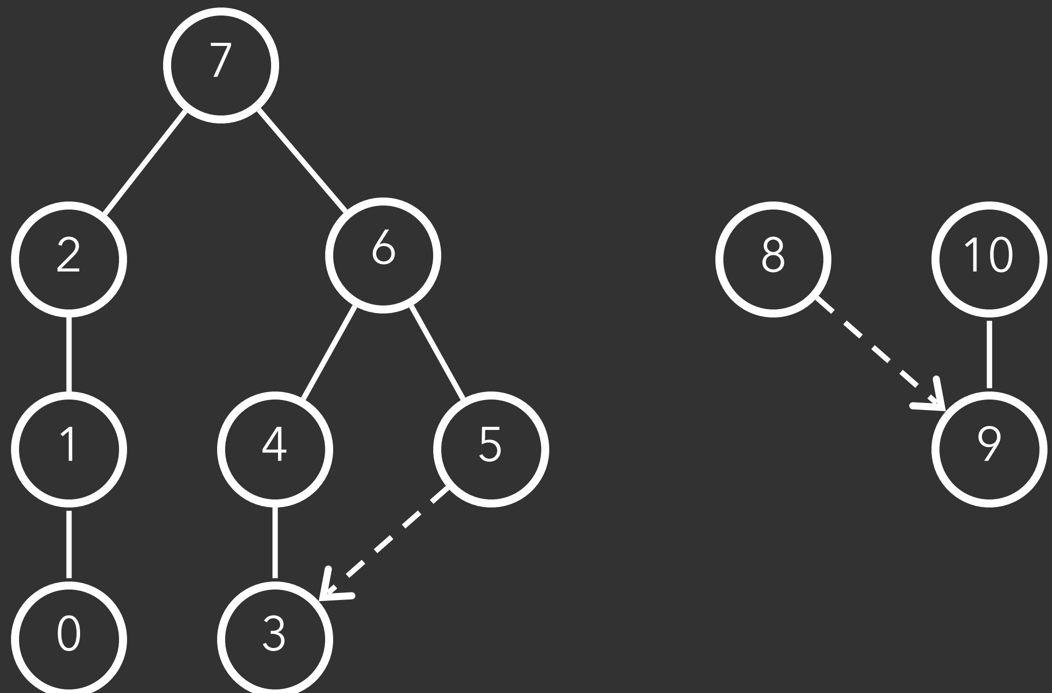

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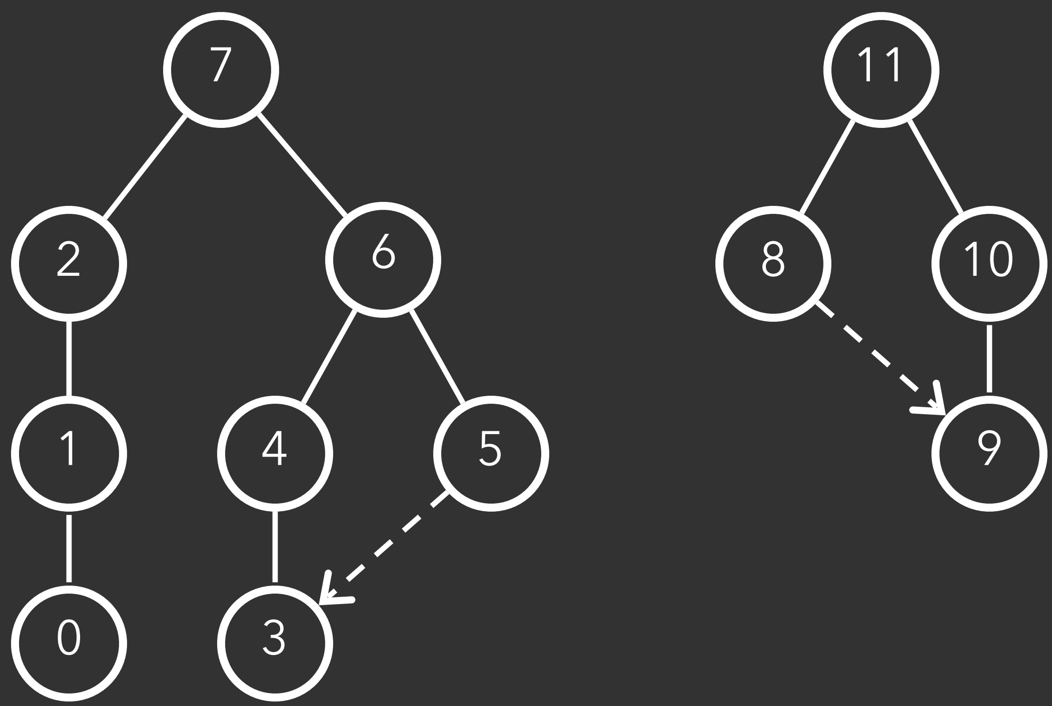

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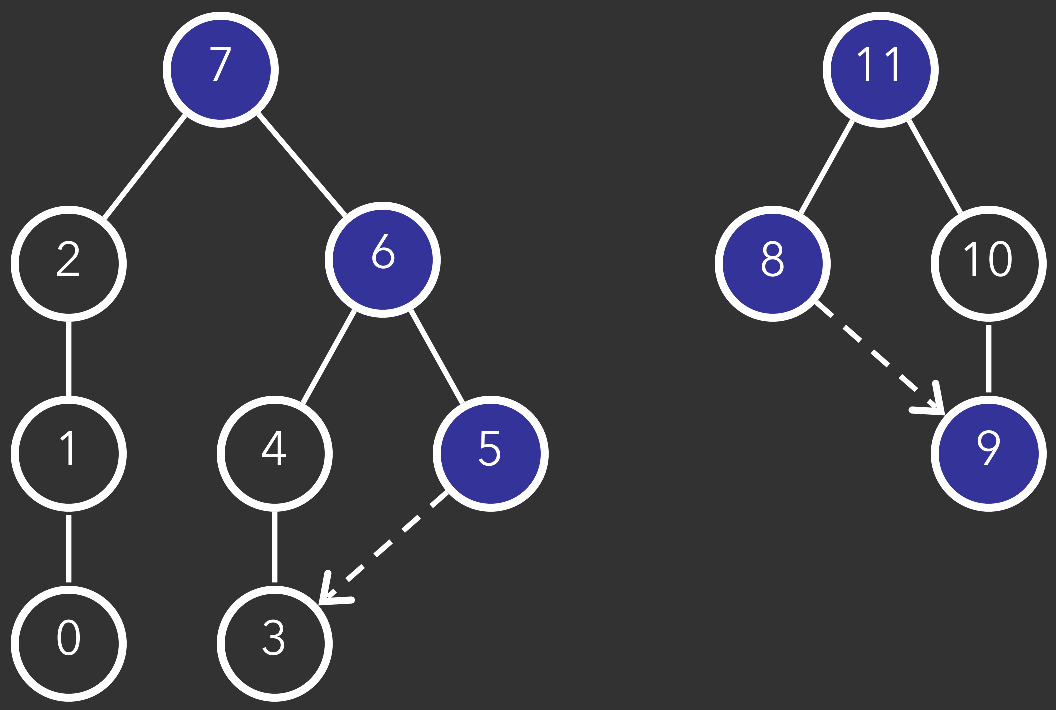

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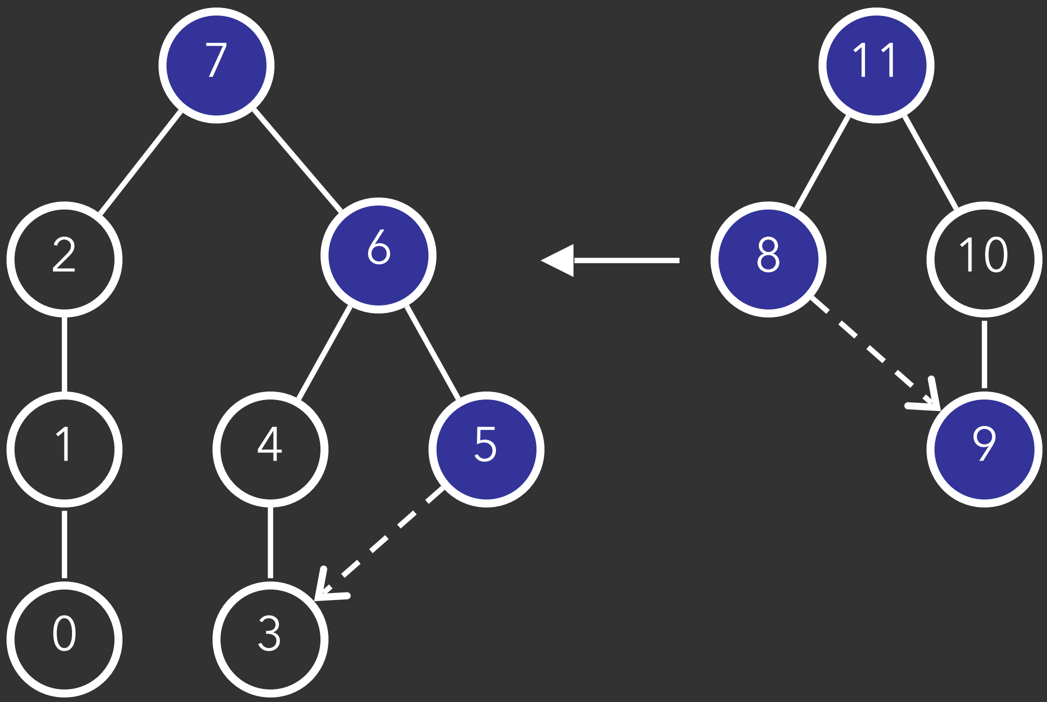

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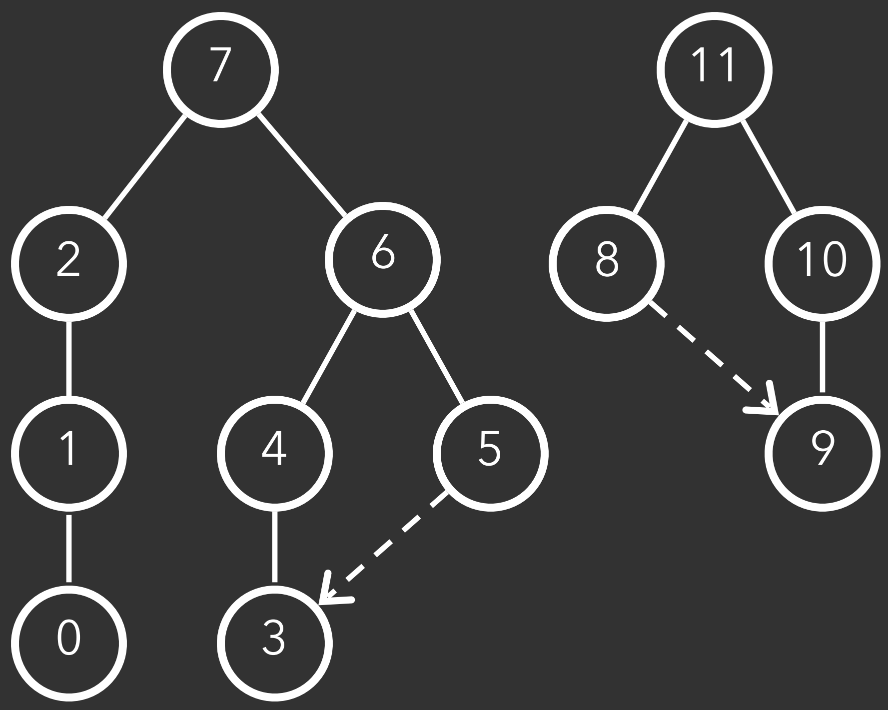

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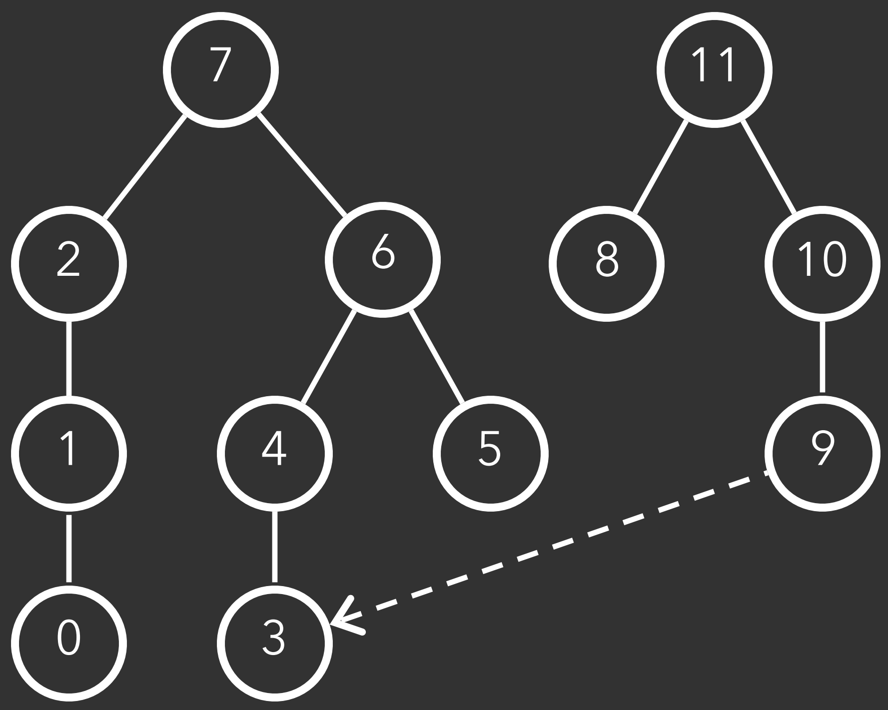

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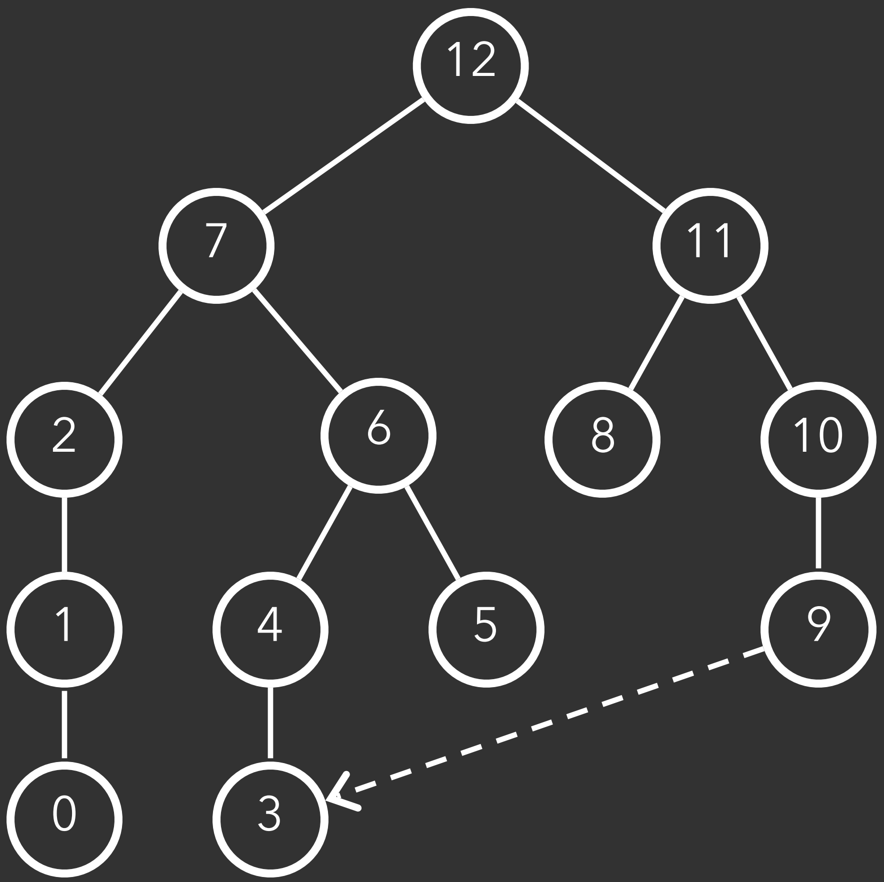
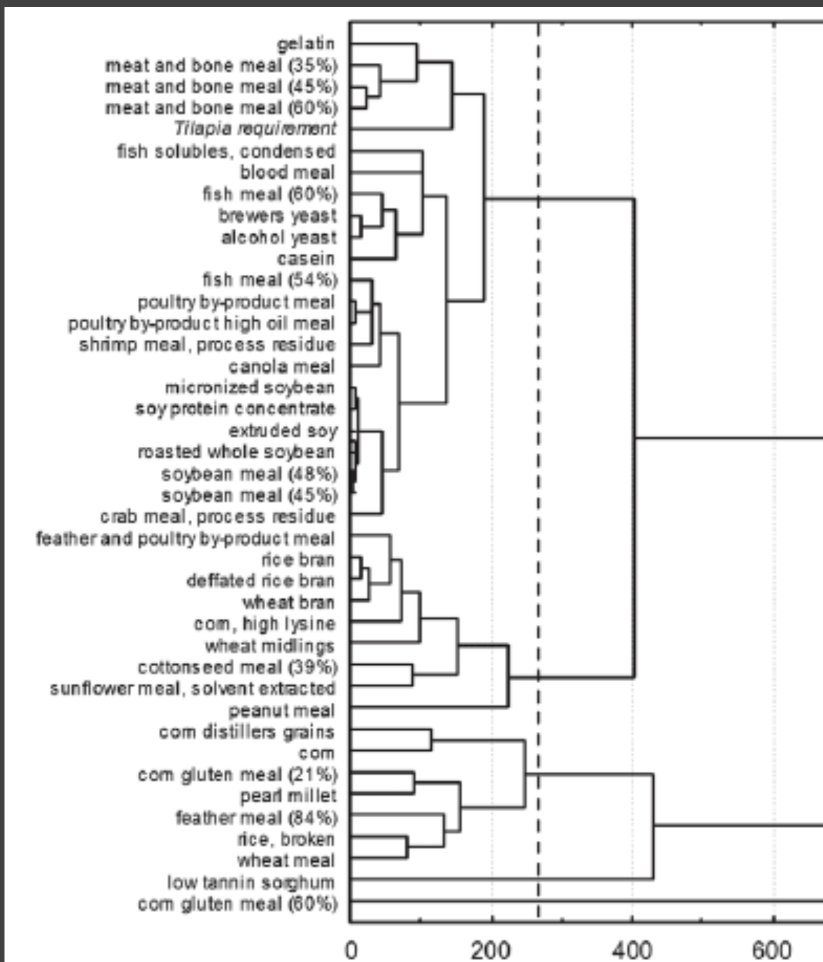


# Cluster Dendrograms




Depicts cluster trees produced by hierarchical clustering algorithms.

Leaf nodes arranged in a line, internal node depth indicates order/value at which clusters merge.

Naïve recursive layout with orthogonal two-segment edges.

# Radial Tree Layout

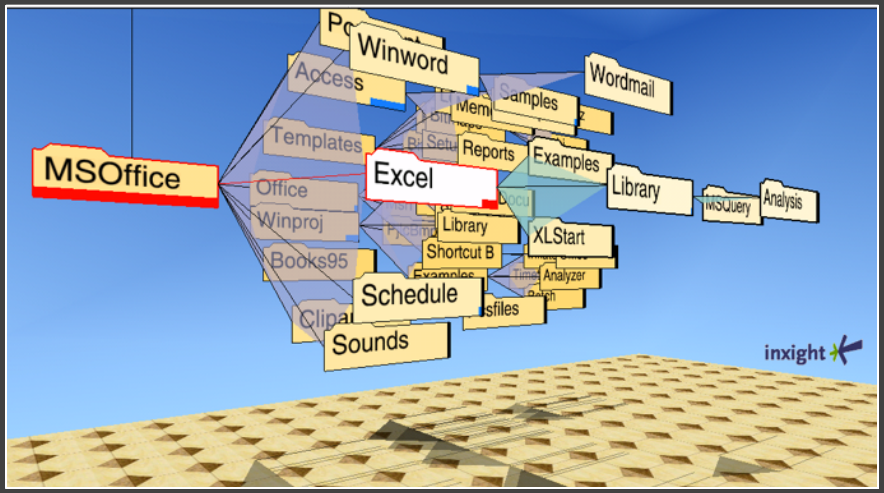

Node-link diagram in polar co-ordinates.

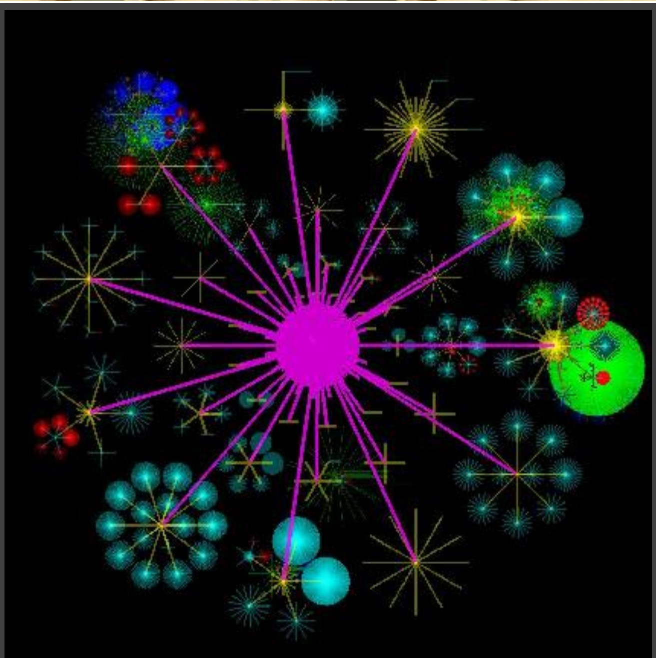
Radius encodes depth, with root in the center.

Angular sectors assigned to subtrees (often with naïve recursive layout).

Reingold-Tilford method can also be applied here.

# Circular Tree Layout



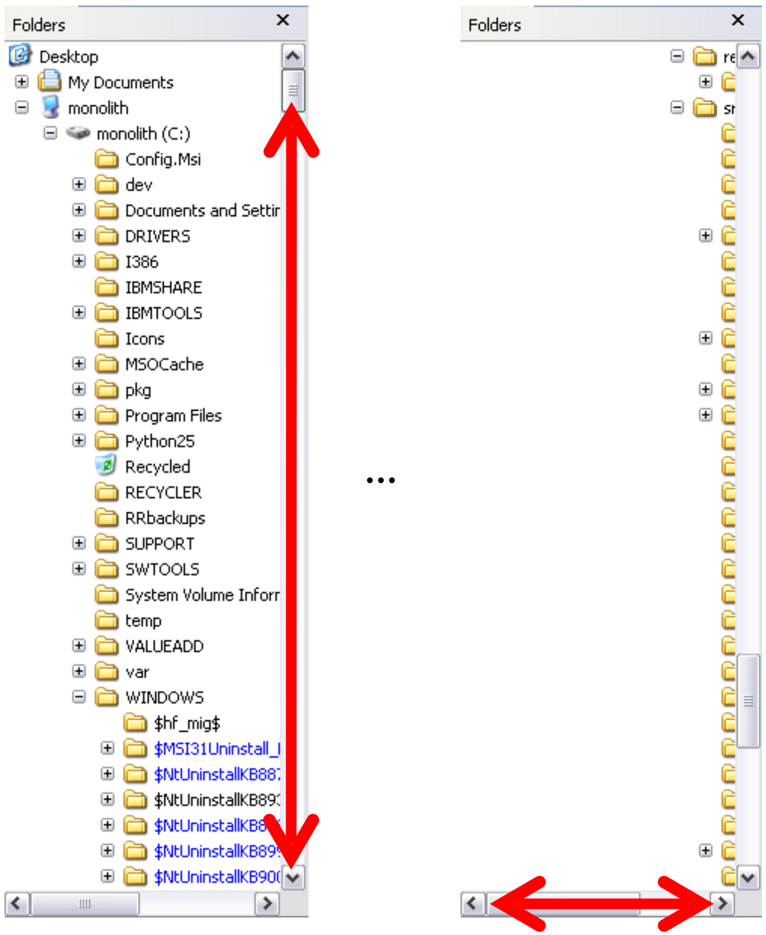



Layout in 3D to form Cone Trees.

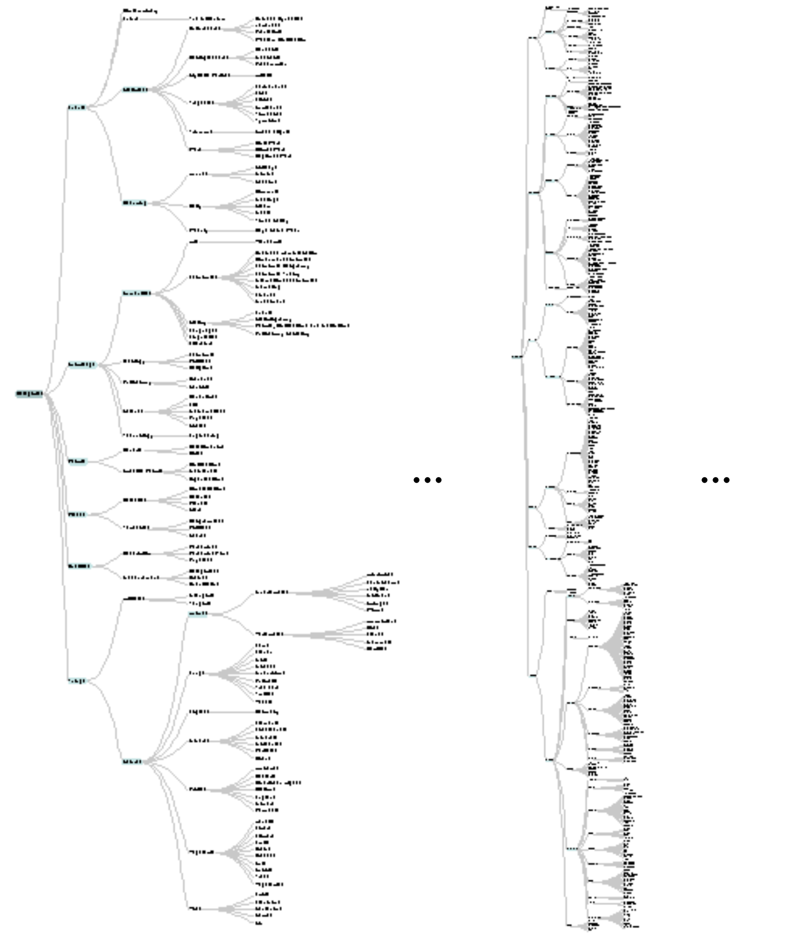
Balloon Trees can be described as a 2D variant of a Cone Tree. Not just a flattening process: circles must not overlap.

# Focus + Context

# Visualizing Large Hierarchies




Indented Layout



Reingold-Tilford Layout

# More Nodes, More Problems…

**Scale**

Tree breadth often grows exponentially

Even with tidy layout, quickly run out of space

**Possible Solutions**

Filtering

Focus+Context

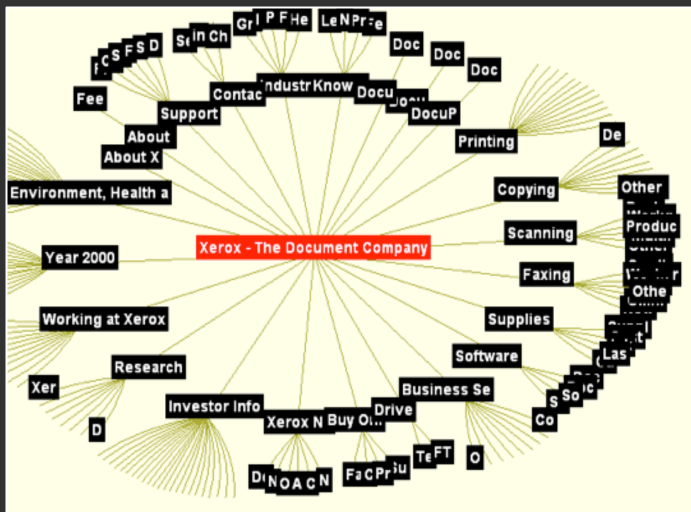
Scrolling or Panning

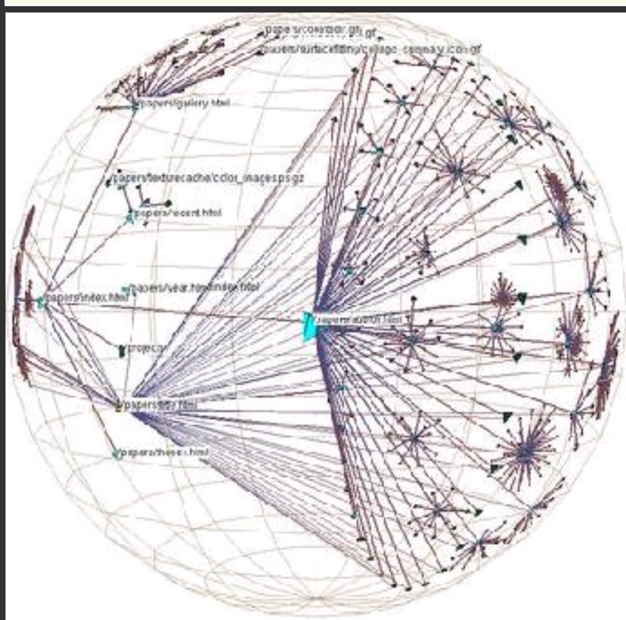
Zooming

Aggregation

MC Escher, *Circle Limit IV*

# Hyperbolic Layout



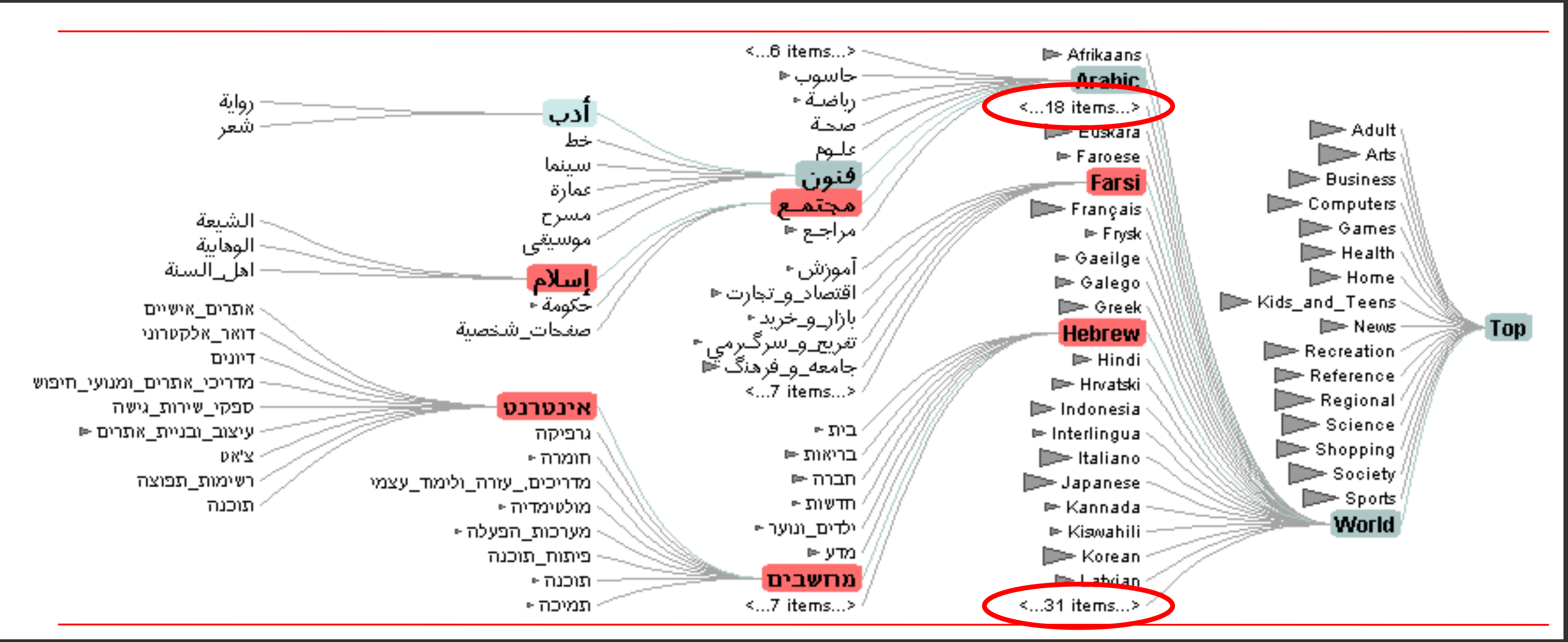



Perform tree layout in hyperbolic geometry, project the result on to the Euclidean plane.

Why? Like tree breadth, the hyperbolic plane expands exponentially!

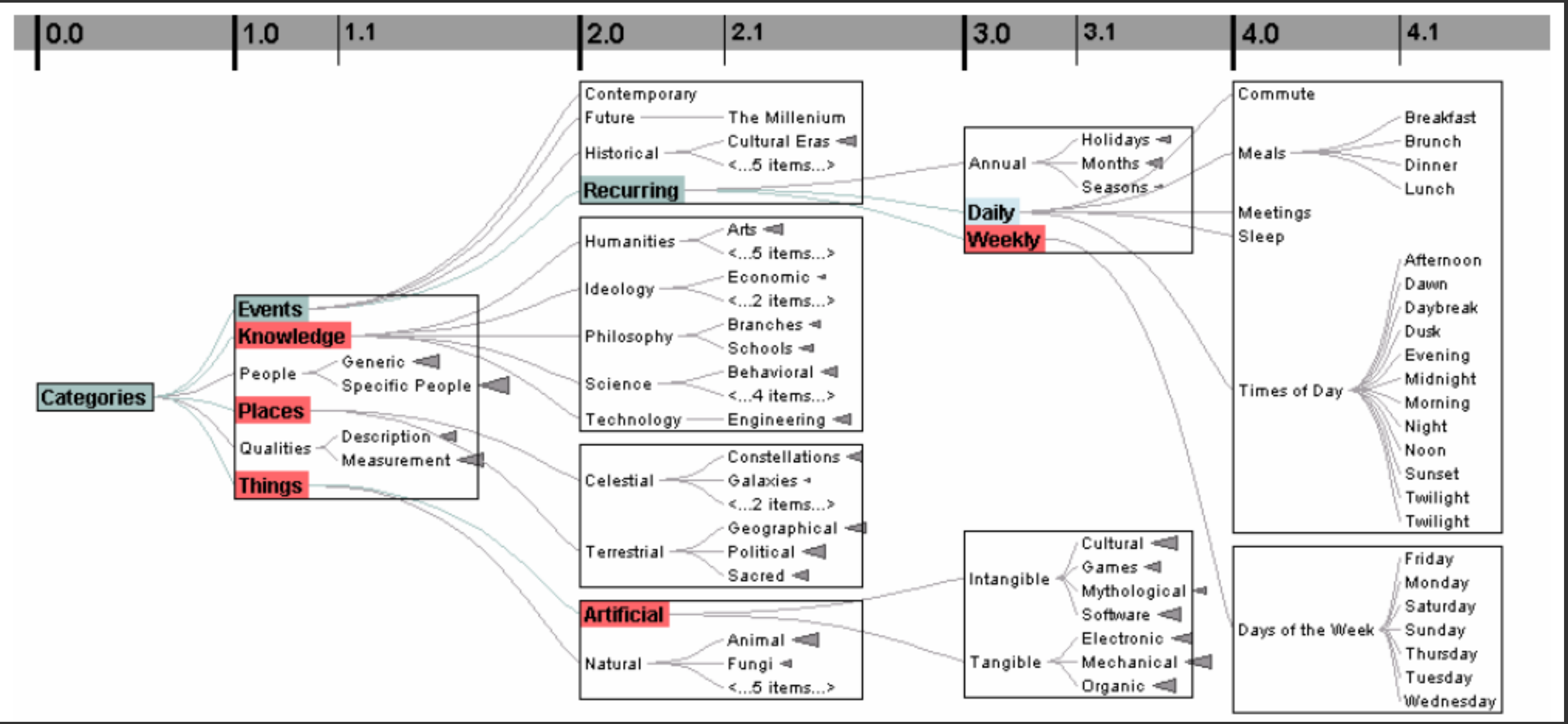
Also computable in 3D, projected into a sphere.

# Degree-of-Interest Trees




Space-constrained, multi-focal tree layout

# Degree-of-Interest Trees




Remove "low interest" nodes at a given depth level until all blocks on a level fit within bounds.
Attempt to center child blocks beneath parents.

# Enclosure

# Enclosure Diagrams

Encode structure using **spatial enclosure**
Popularly known as **treemaps**

**Benefits**
Provides a single view of an entire tree
Easier to spot large/small nodes

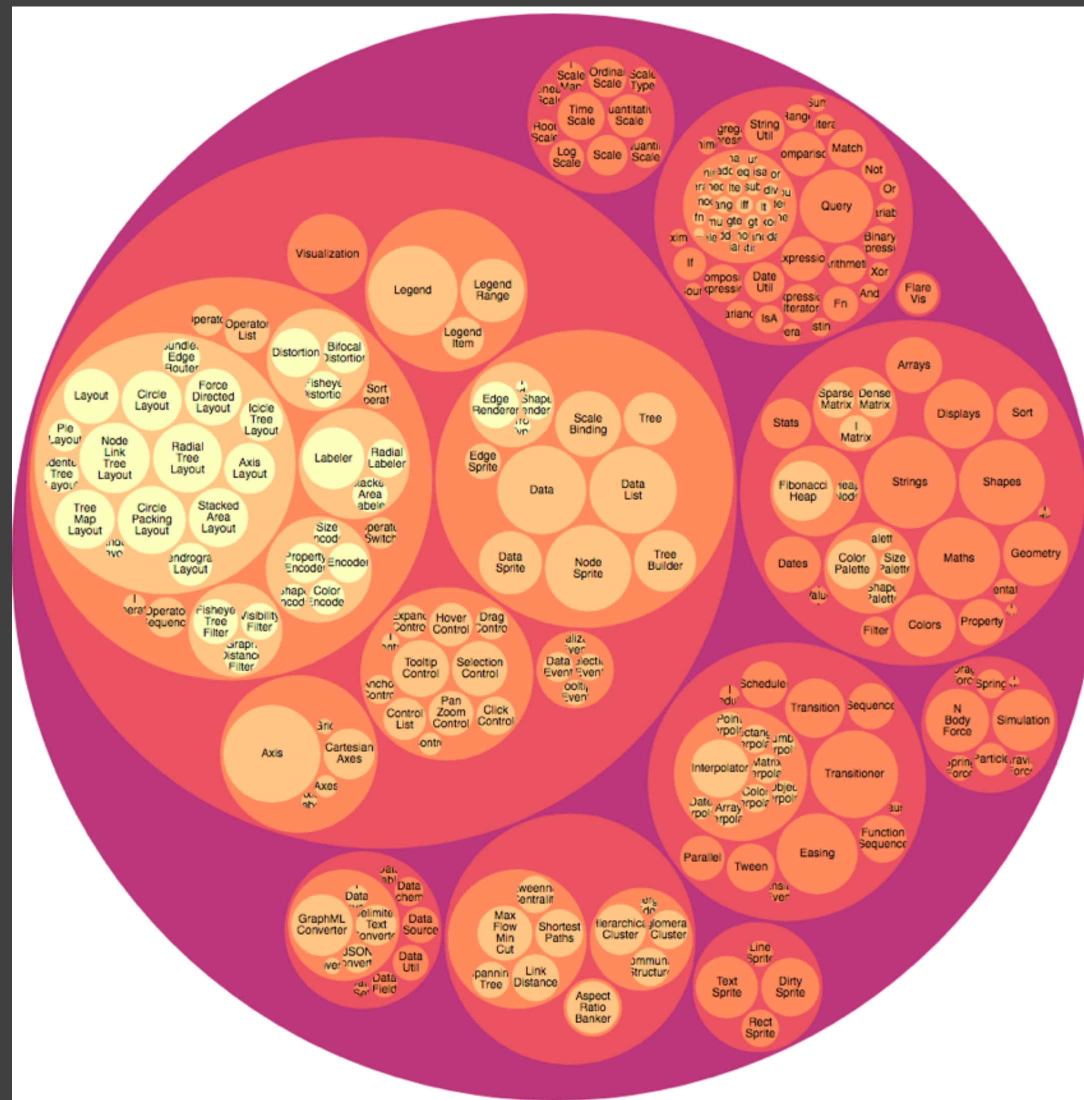
**Problems**
Difficult to accurately read structure / depth

# Circle Packing Layout

Nodes are represented as sized circles.

Nesting shows parent-child relationships.

*Issues?*
Inefficient use of space.
Parent size misleading?

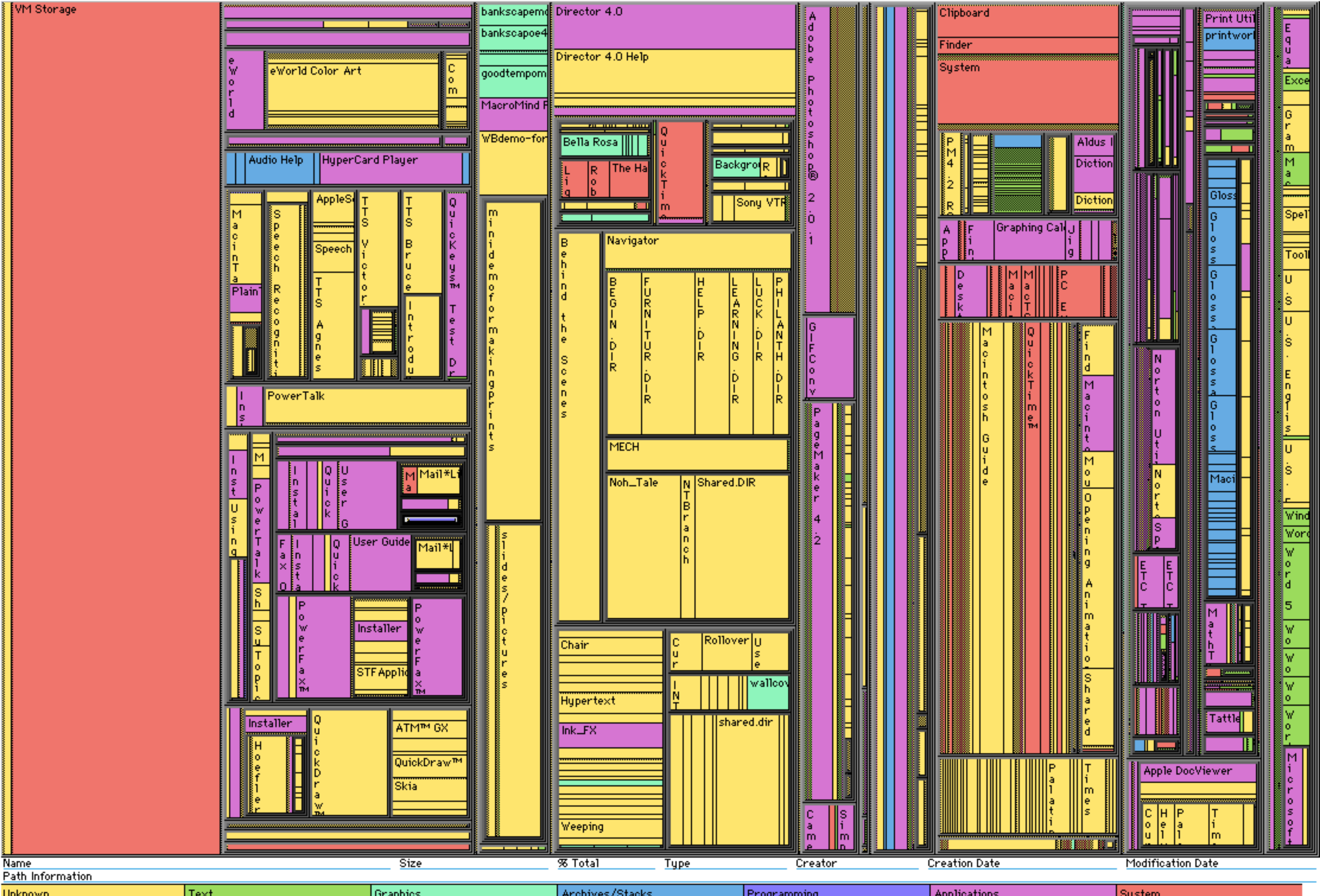


# Treemaps

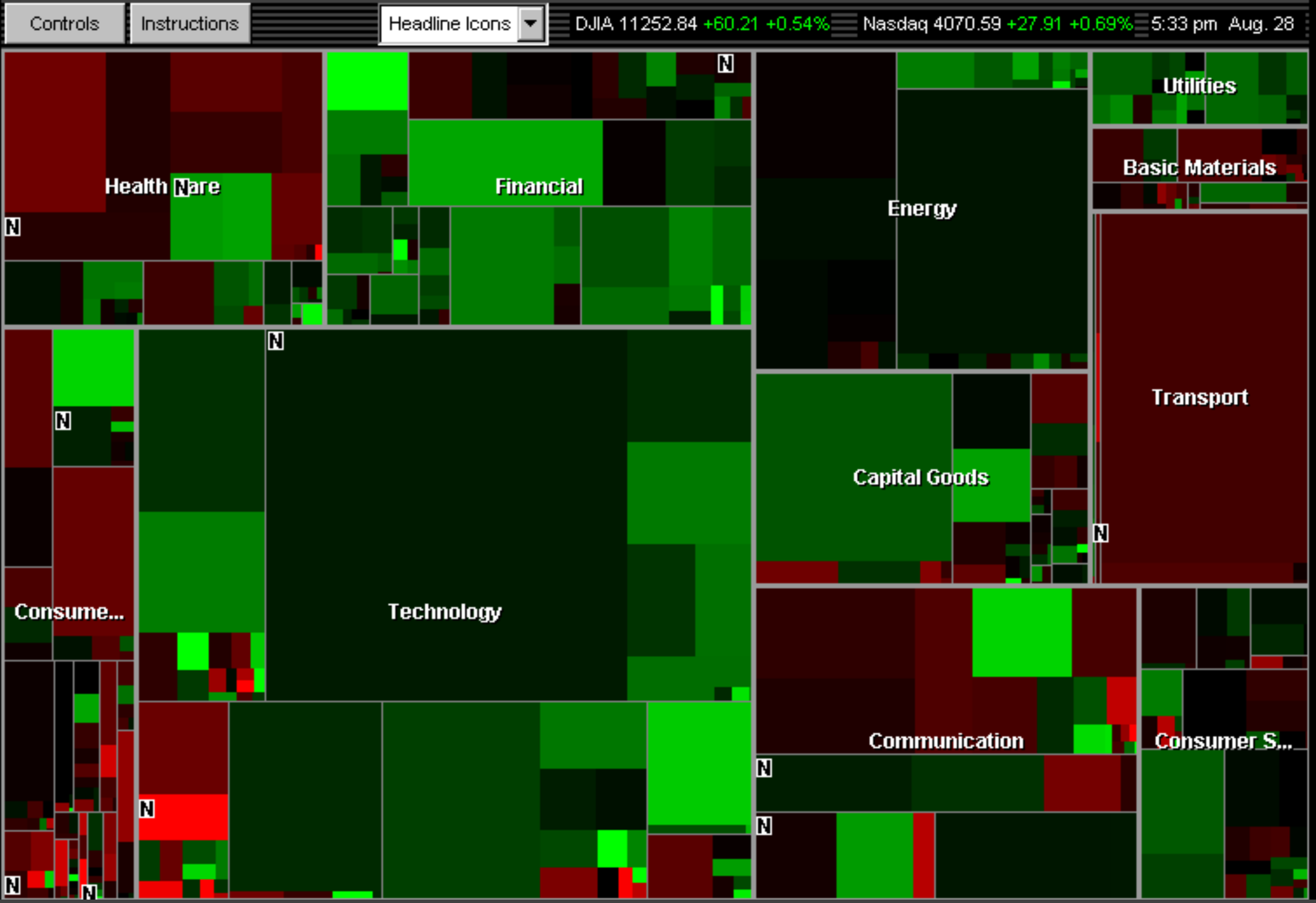
Hierarchy visualization that emphasizes values of nodes via area encoding.

Partition 2D space such that leaf nodes have sizes proportional to data values.

First layout algorithms proposed by Shneiderman et al. in 1990, with focus on showing file sizes on a hard drive.




*Slice & Dice* layout: Alternate horizontal / vertical partitions.

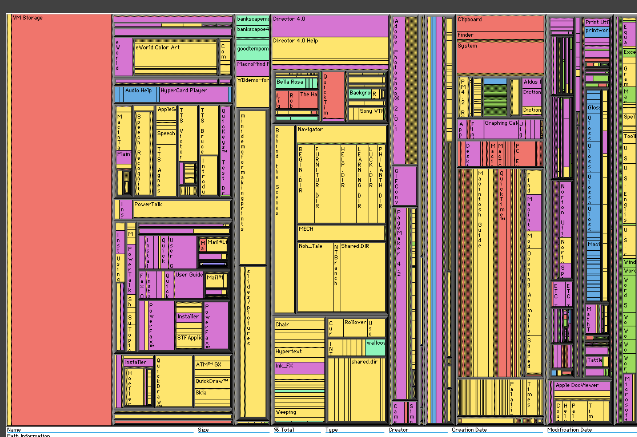



*Squarifed* layout: Try to produce square (1:1) aspect ratios

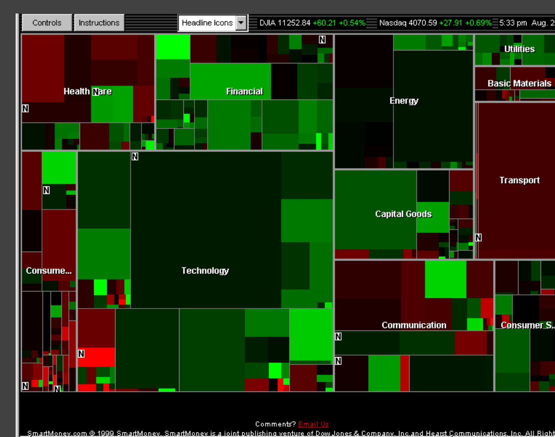
# **Squarified Treemaps** [Bruls et al. '00]

*Slice & Dice* layout suffers from extreme aspect ratios. How might we do better?

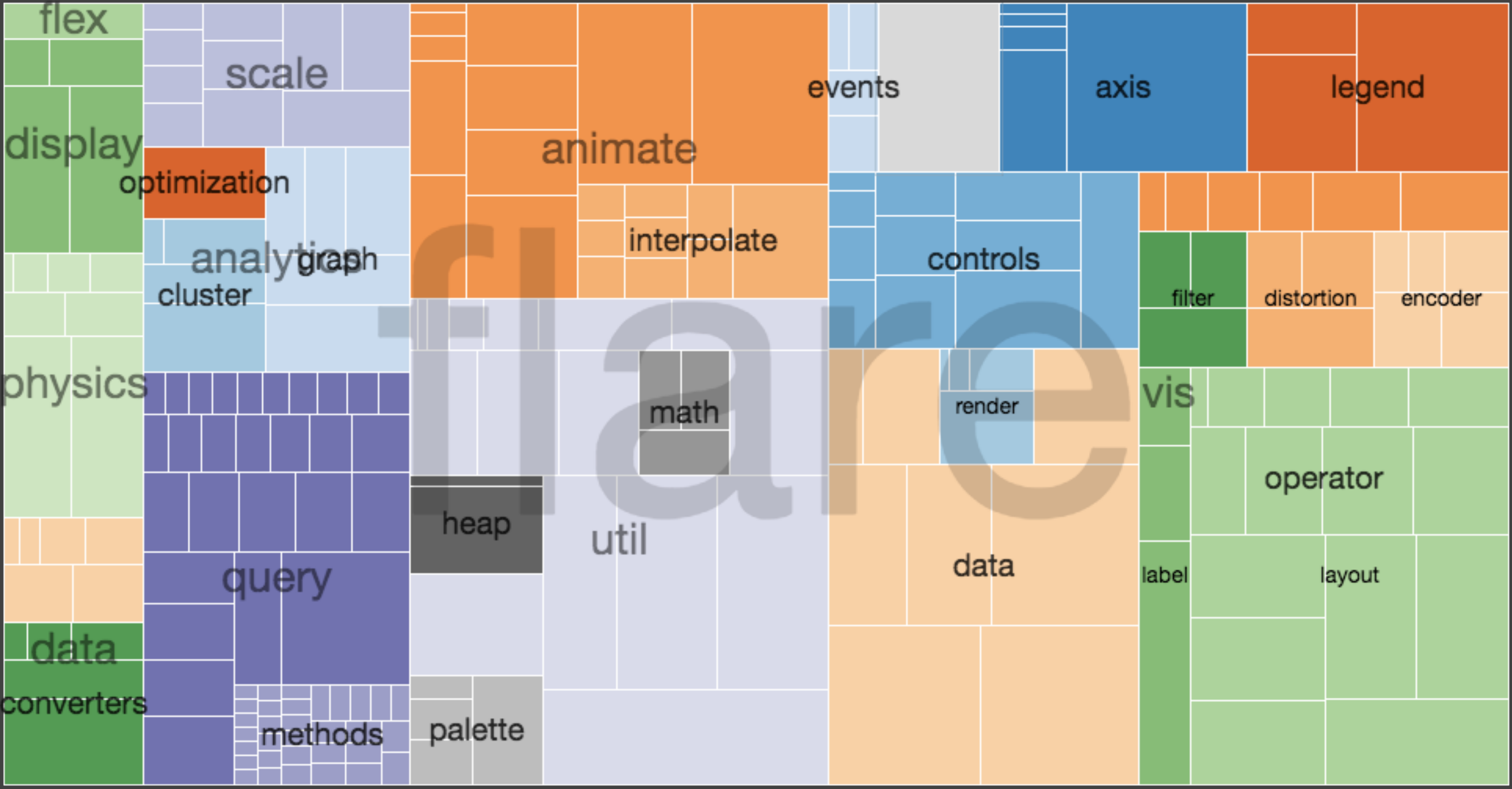
*Squarified* layout: greedy optimization for objective of square rectangles. Slice/dice within siblings; alternate whenever ratio worsens.



*vs.*



# Interactive Example...



# Why Squares? [Bruls et al. '00]

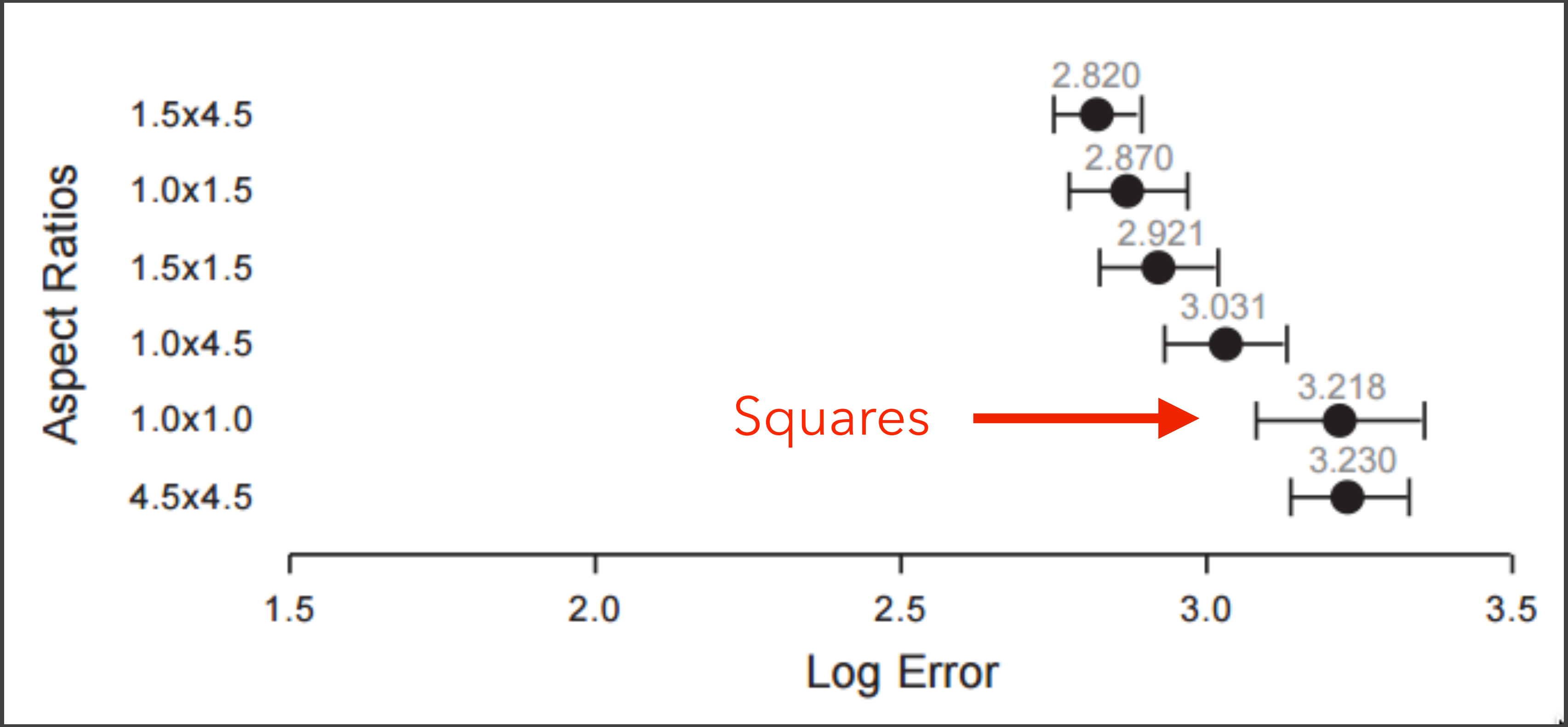
## Posited Benefits of 1:1 Aspect Ratios

1. Minimize perimeter, reducing border ink.
   *Mathematically true!*

2. Easier to select with a mouse cursor.
   *Validated by empirical research & Fitt's Law!*

3. Similar aspect ratios are easier to compare.
   *Seems intuitive, but is this true?*

# Comparison Error vs. Aspect Ratio




Study by Kong, Heer & Agrawala, InfoVis '10.

Comparison of squares has higher error!

"Squarify" works because it fails to meet its objective?

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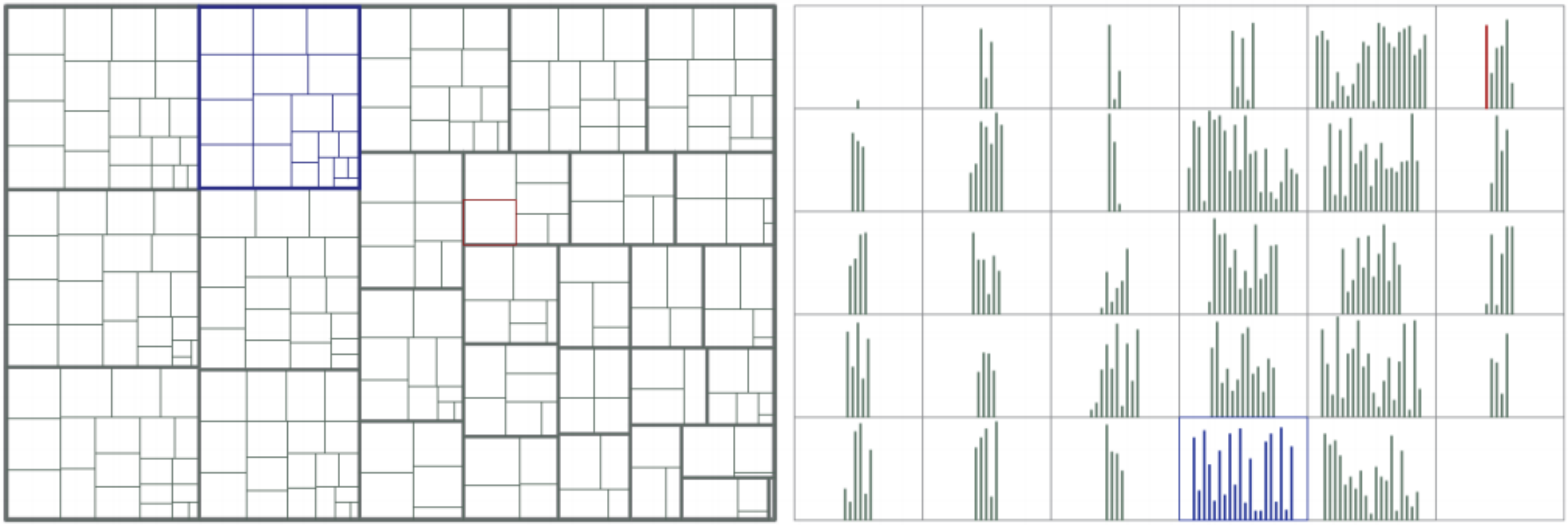
3. ~~Similar aspect ratios are easier to compare.~~
   *Extreme ratios & squares-only more inaccurate.*
   *Balanced ratios better? Target golden ratio?*

# Treemaps vs. Bar Charts [Kong et al. '10]

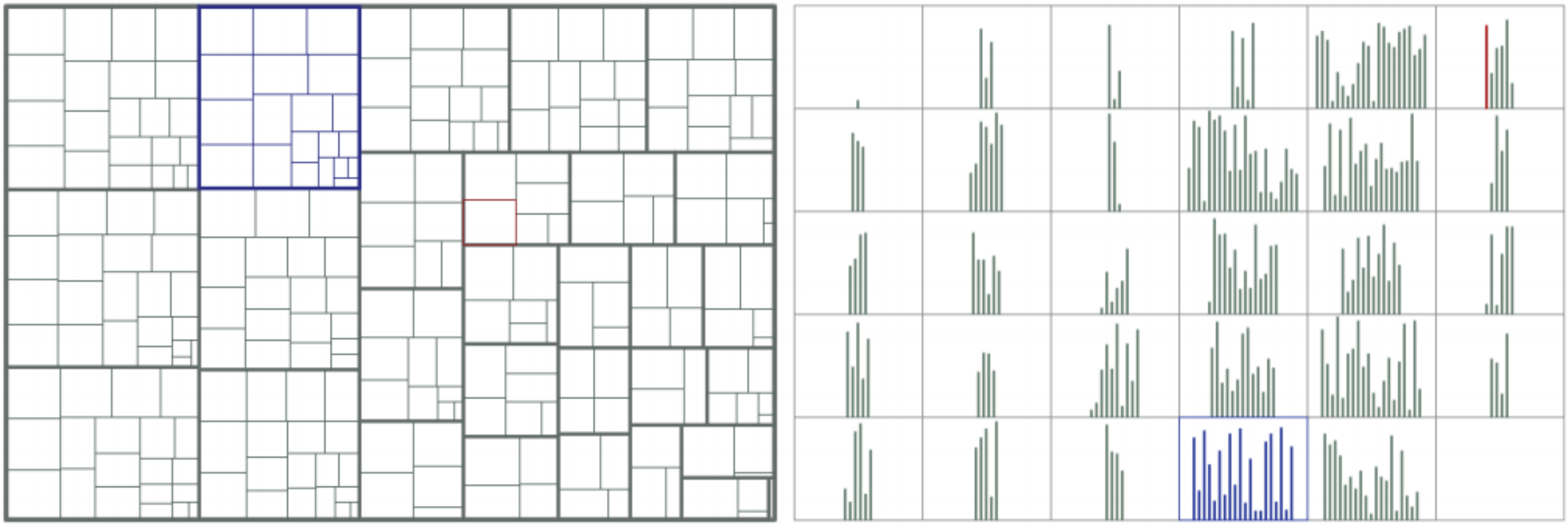


Position is generally more effective than area, but…

What happens when the element count gets high?

What happens when comparing groups of elements, such as leaf values vs. internal node values?

# Treemaps vs. Bar Charts [Kong et al. ’10]

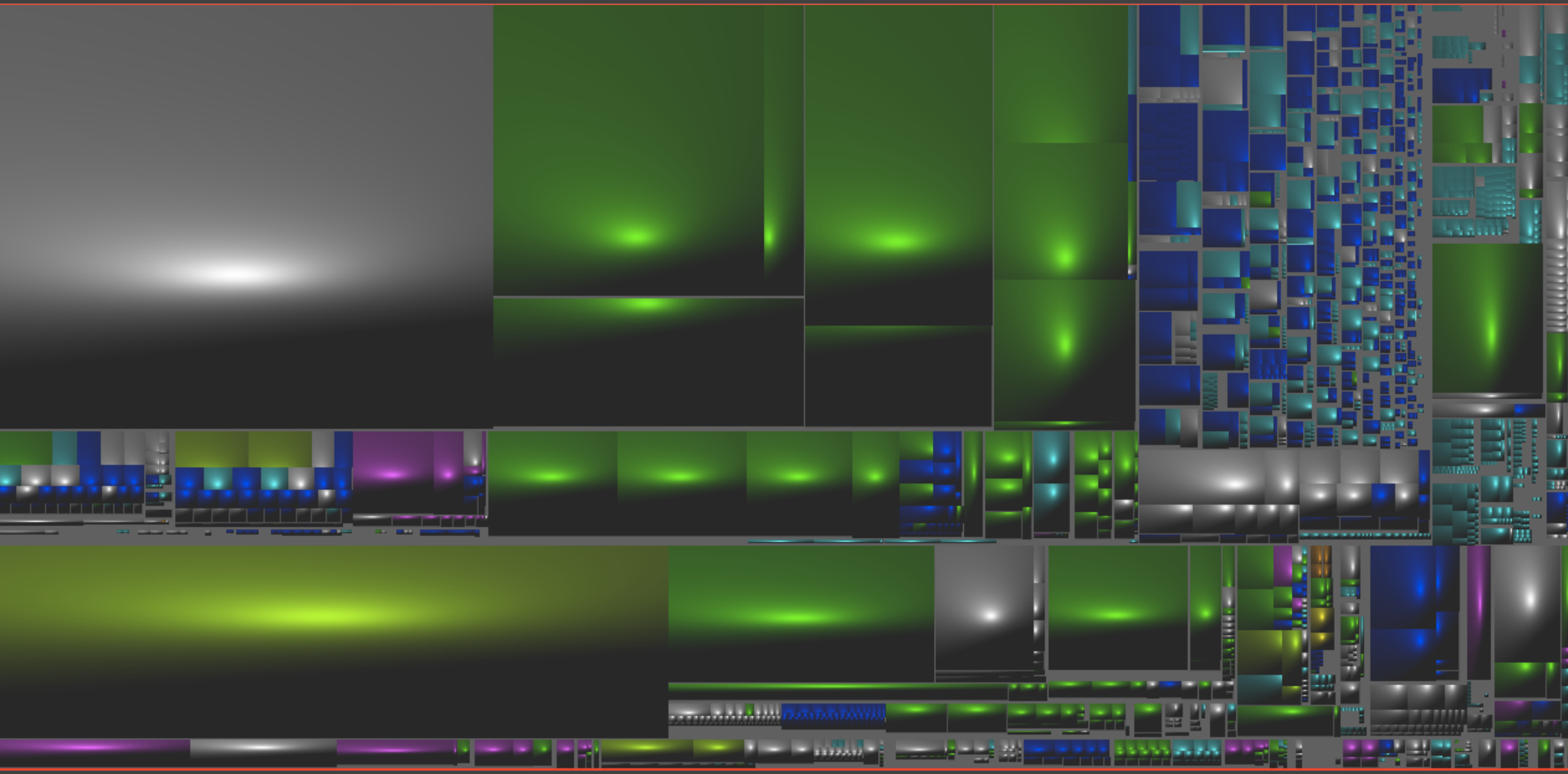


At low densities (< 4k elements), bar charts more accurate than treemaps for leaf-node comparisons.

At higher density, treemaps led to faster judgments.

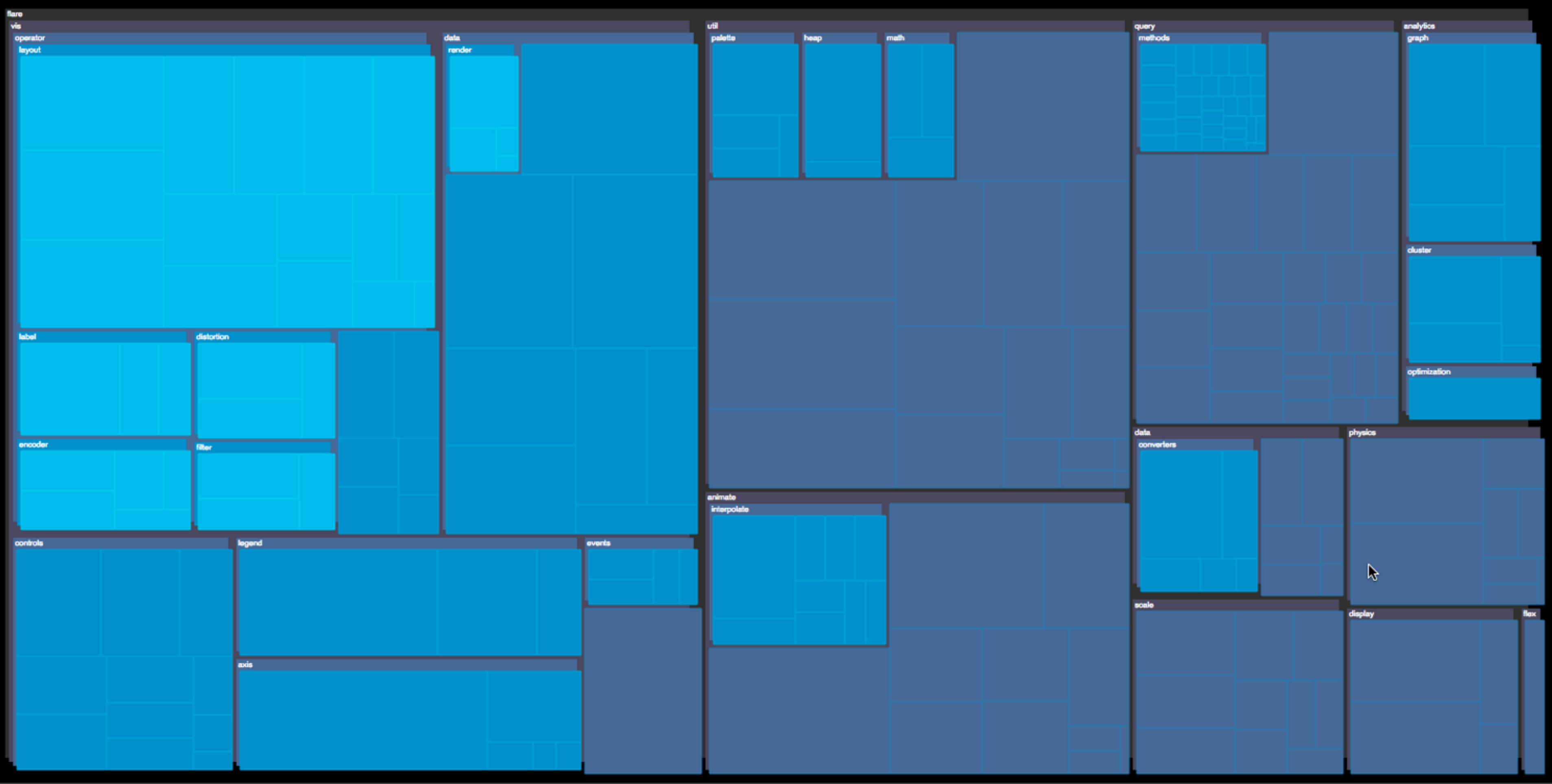
Treemaps better for group-level comparisons.

# Cushion Treemaps [van Wijk & Wetering '99]



Uses shading to emphasize hierarchal structure.

# Cascaded Treemaps [Lü & Fogarty '08]

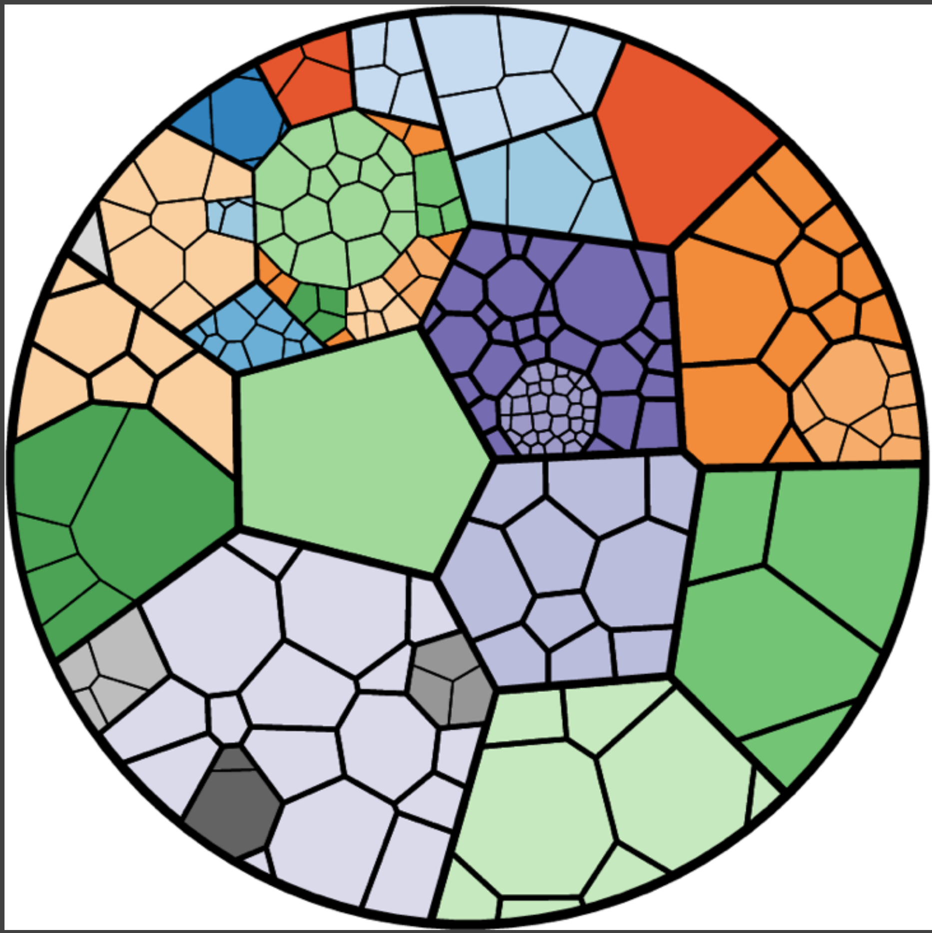


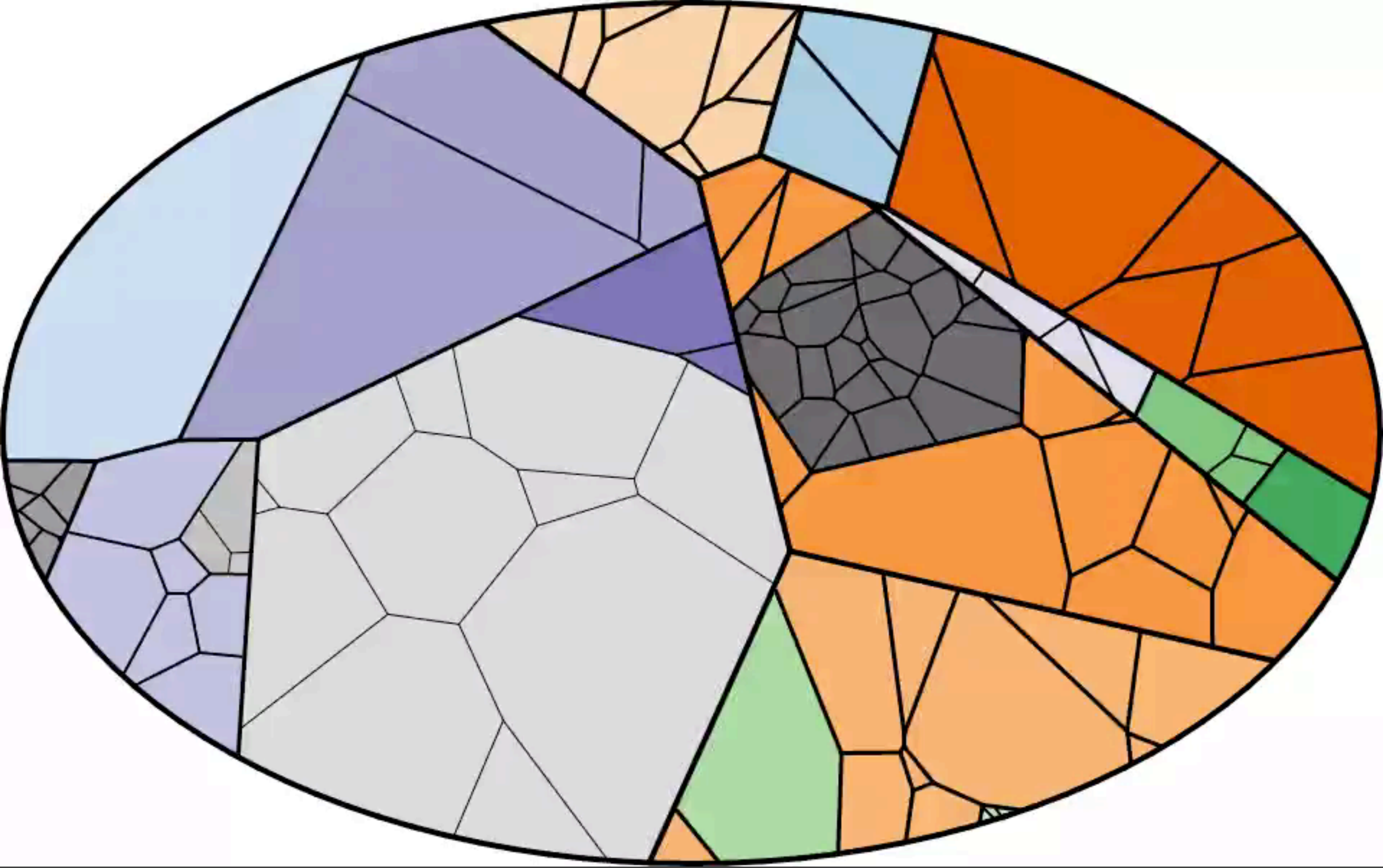

Uses 2.5D effect to emphasize hierarchy relations.

# **Voronoi Treemaps** [Balzer et al. '05]

Instead of rectangles, create treemaps with arbitrary polygonal shapes and boundary.

Use iterative, weighted Voronoi tessellations to achieve cells with value-proportional areas.

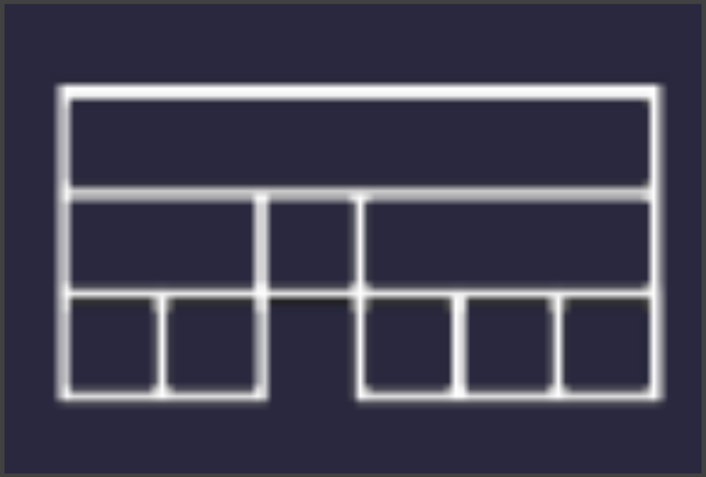




Iterative Voronoi Tesselations [Jason Davies]

# Layering

# Layered Diagrams

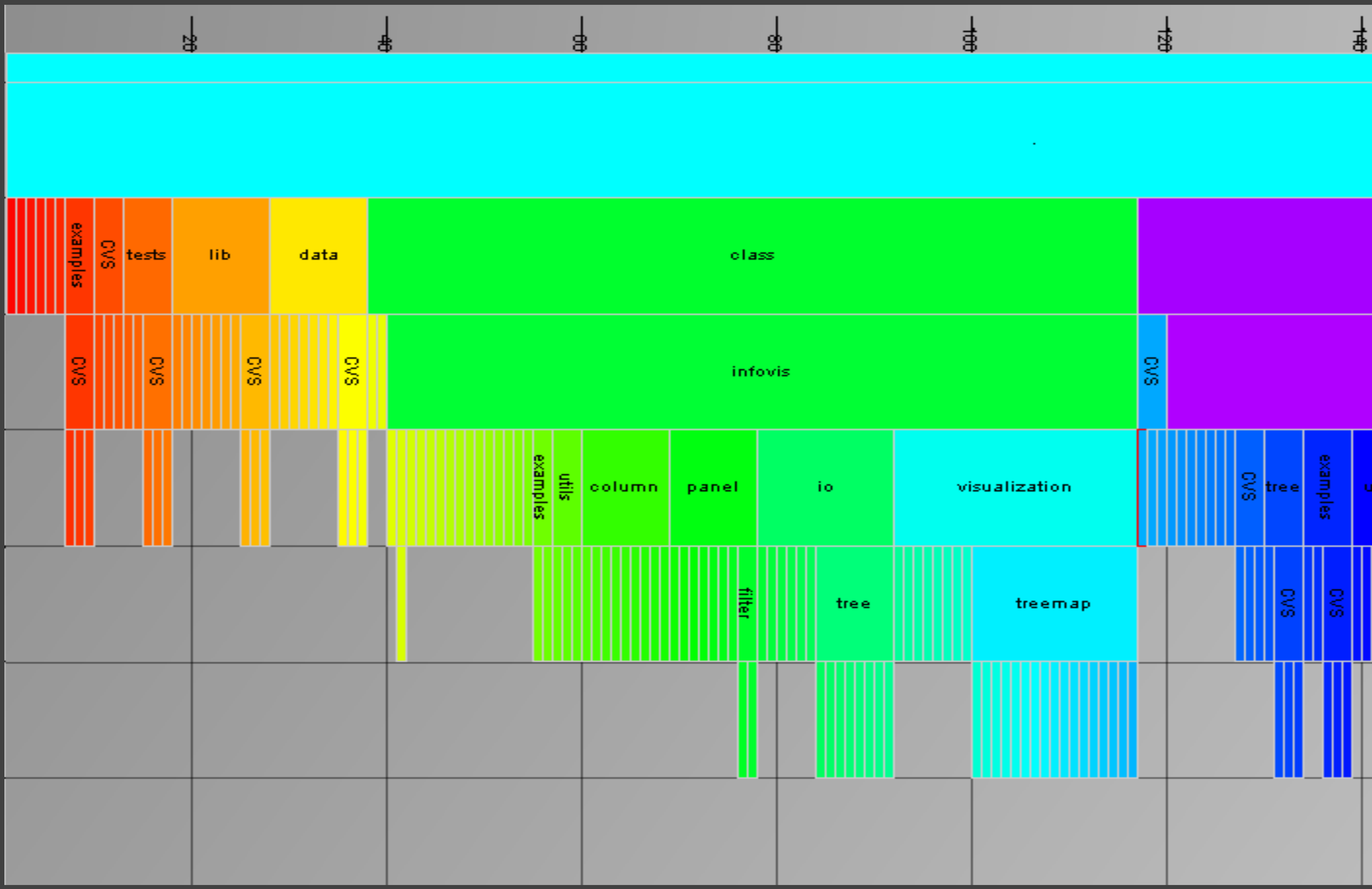


Signify tree structure using:
- Layering
- Adjacency
- Alignment

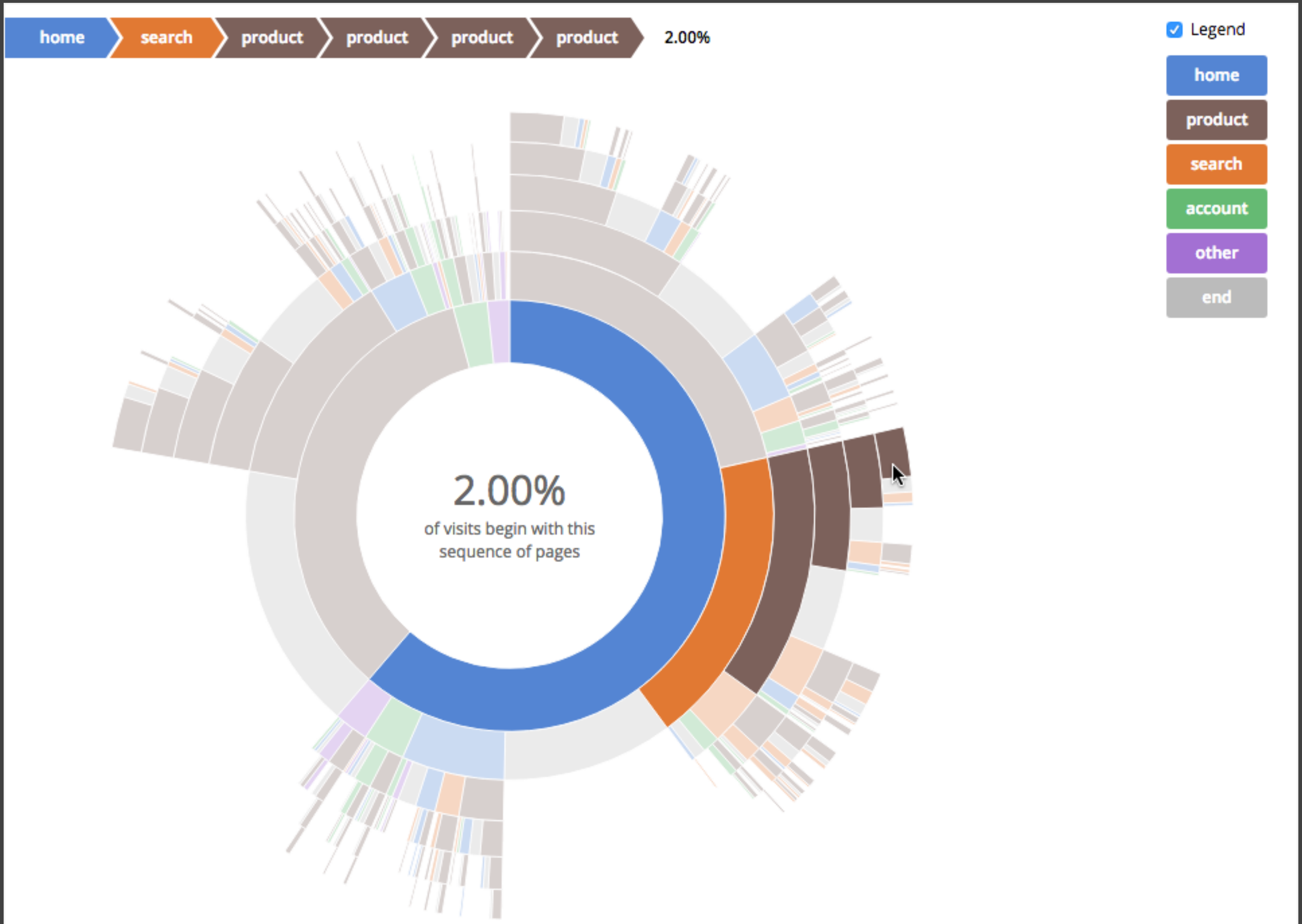
Involves recursive sub-division of space.

Leaf nodes may be sized by value, parent size visualizes sum of descendant leaf values.

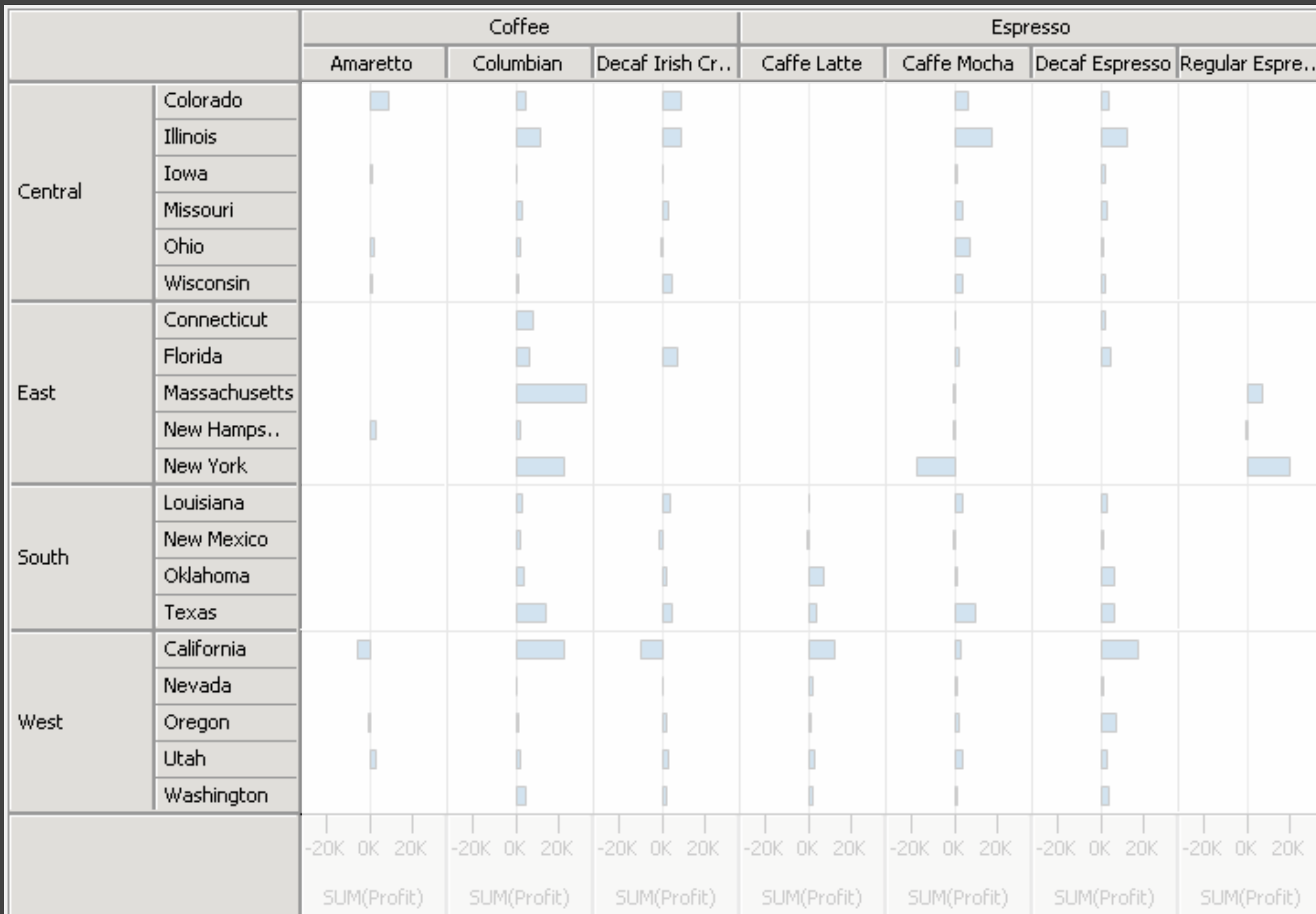
# Icicle Trees: Cartesian Partition



# "Sunburst" Trees: Polar Partition

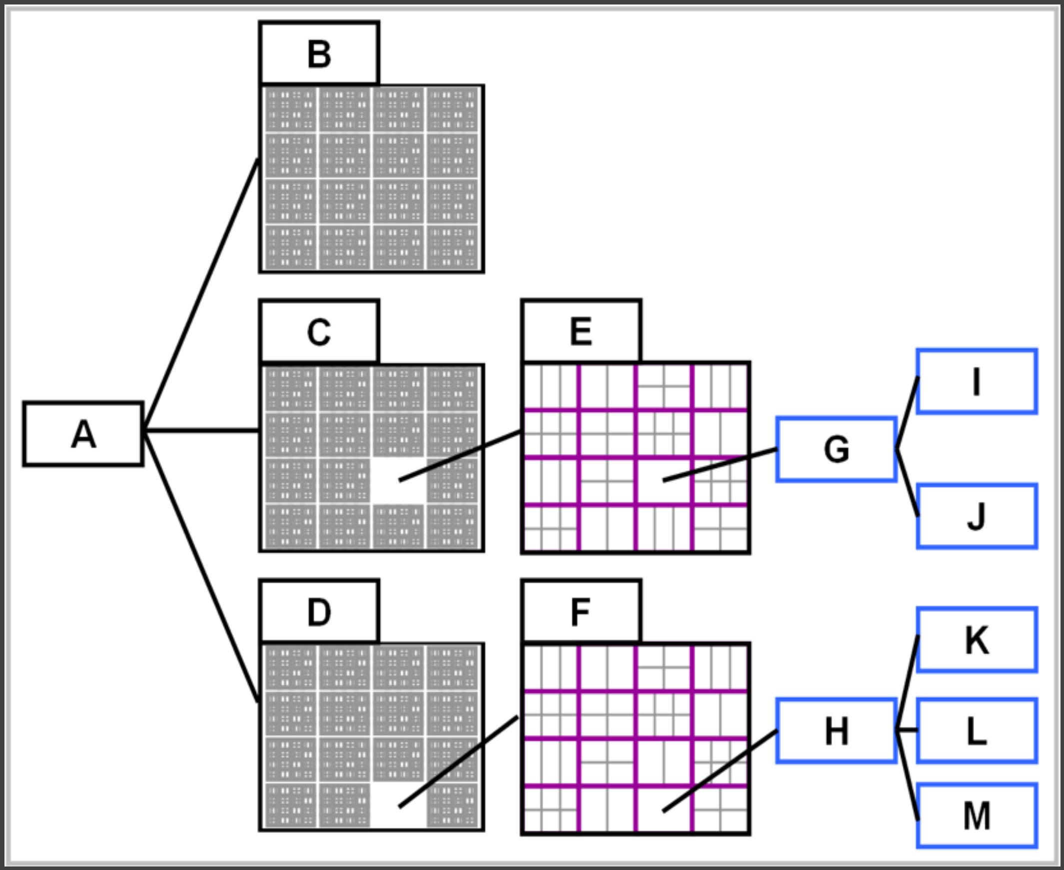


# Layered Trees Useful Elsewhere…



# Hybrids

# Hybrids are also possible…




“Elastic Hierarchies”

Node-link diagram with treemap nodes.

*Little uptake for real-world use…*

# Administrivia

# Final Project Deliverables

**Interactive Web Page**
Working (near-final) version due Wed 5/31.
Final version due by showcase on Mon 6/5.

**Demonstration Video** (<= 2 min)
Due Wed 5/31. We will show in-class on 6/1!

**Poster & Demo for Final Showcase**
Monday 6/5, 10:30am-1pm in Allen Center atrium.
External judges will award top projects!

Read assignment description for more!

# Final Project Showcase

**When:** Monday June 5, 10:30am - 1pm.
**Where:** Allen Center Atrium

The event is open to the public. Invite your friends!

Public showing begins at 11am. **Arrive at 10:30am** to set up your poster and demo. Be prepared to give a **~3 min. presentation + demo** to visitors.

Invited judges will rate & award the top projects.

Refreshments will be served!

# Tips for a Successful Project

Focus on a compelling **real-world use**.
Who is your user? How do you gauge success?

Consider **multiple design alternatives**.
Prototype quickly (use Tableau, R, Gephi…).

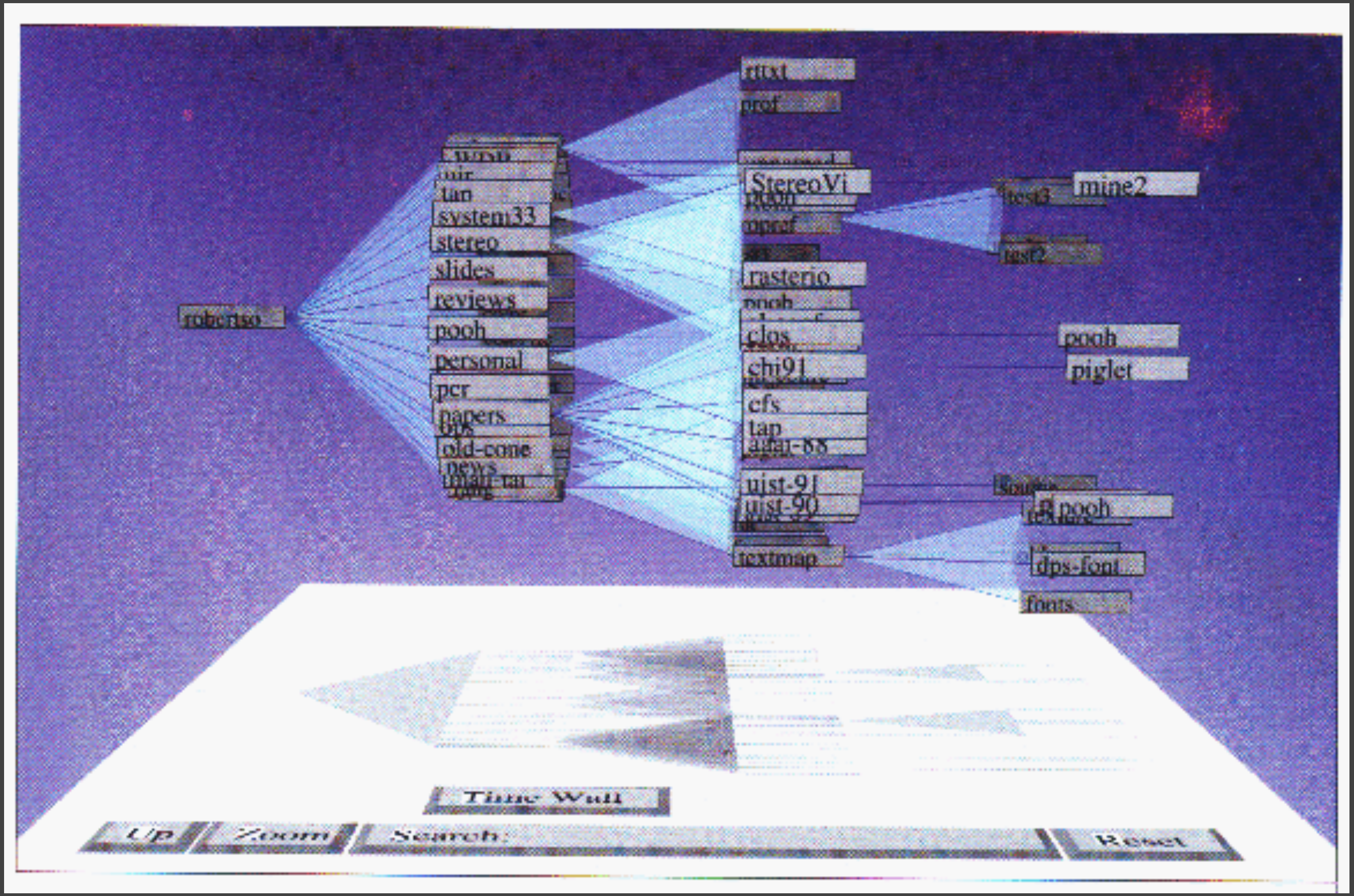
**Seek feedback** (representative users, peers, …).
Even informal usage can provide insights.

Choose **appropriate team roles**.

**Start early** (and read the suggested paper!)

# Animated Transitions in Tree Visualizations

# Cone Trees [Robertson 91]



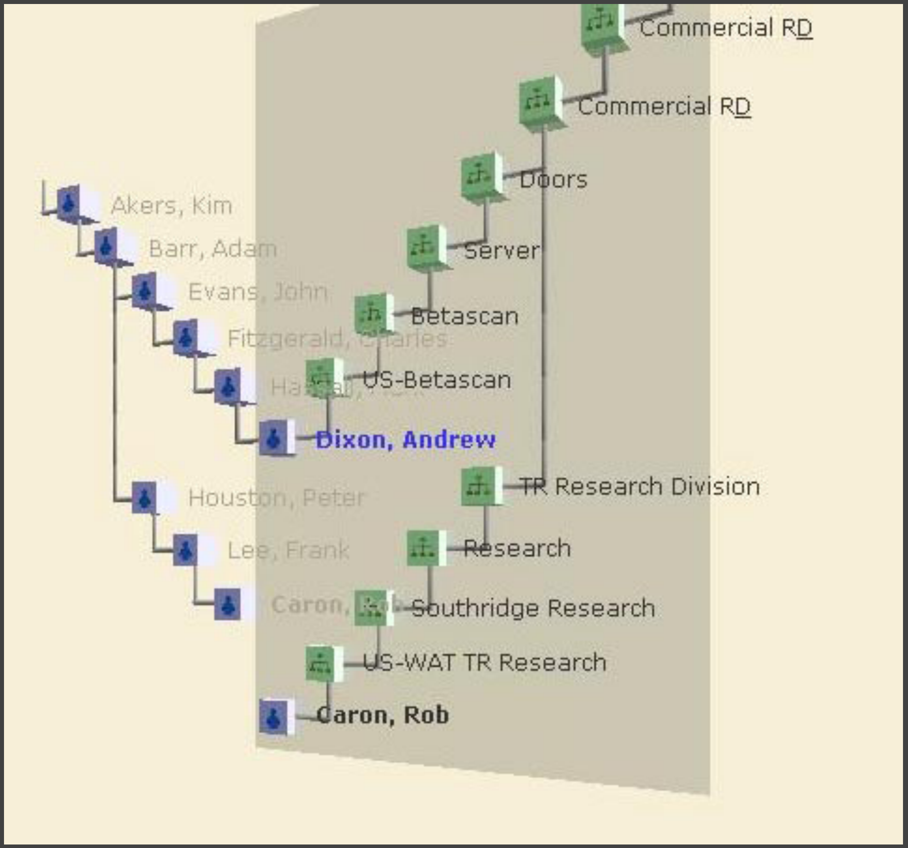
# Polyarchies [Robertson 02]

Animate pivots across intersecting hierarchies.

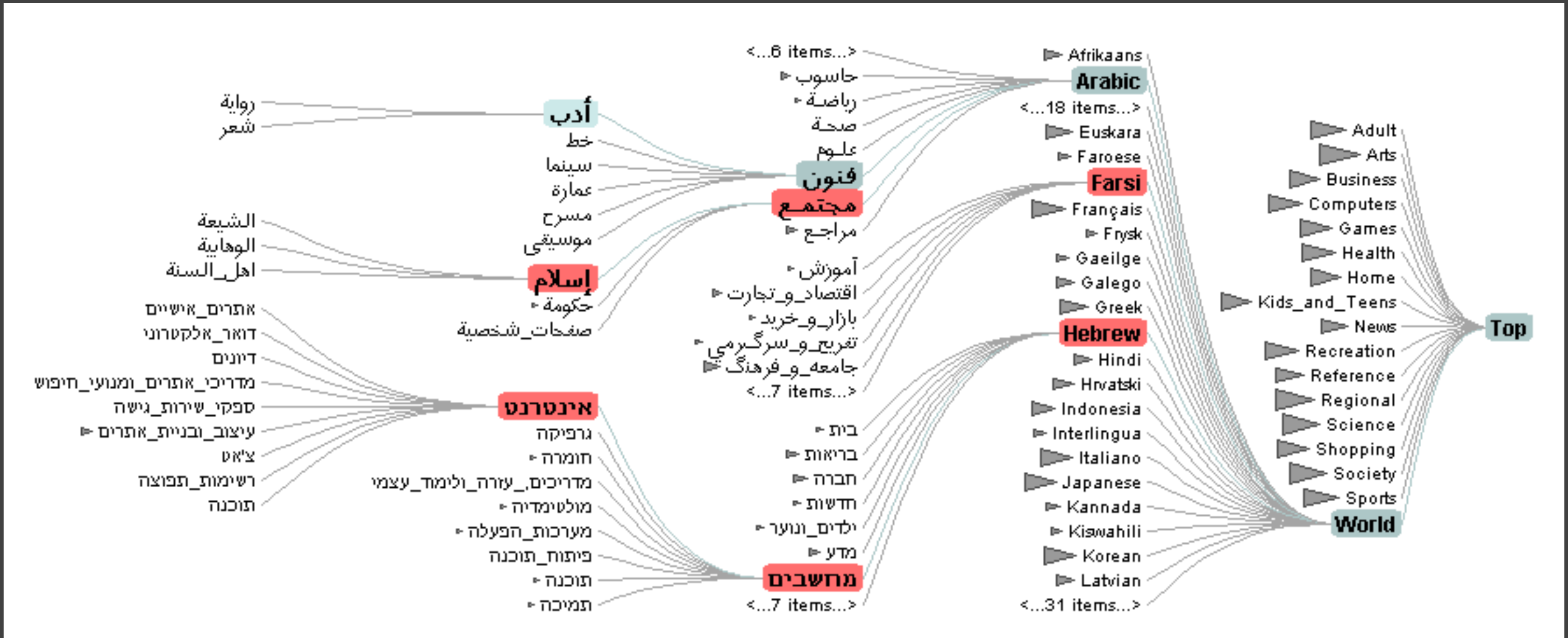
Tested a number of animation parameters.

Best duration: ~1 sec

Rotational movement degraded performance, translation preferred.

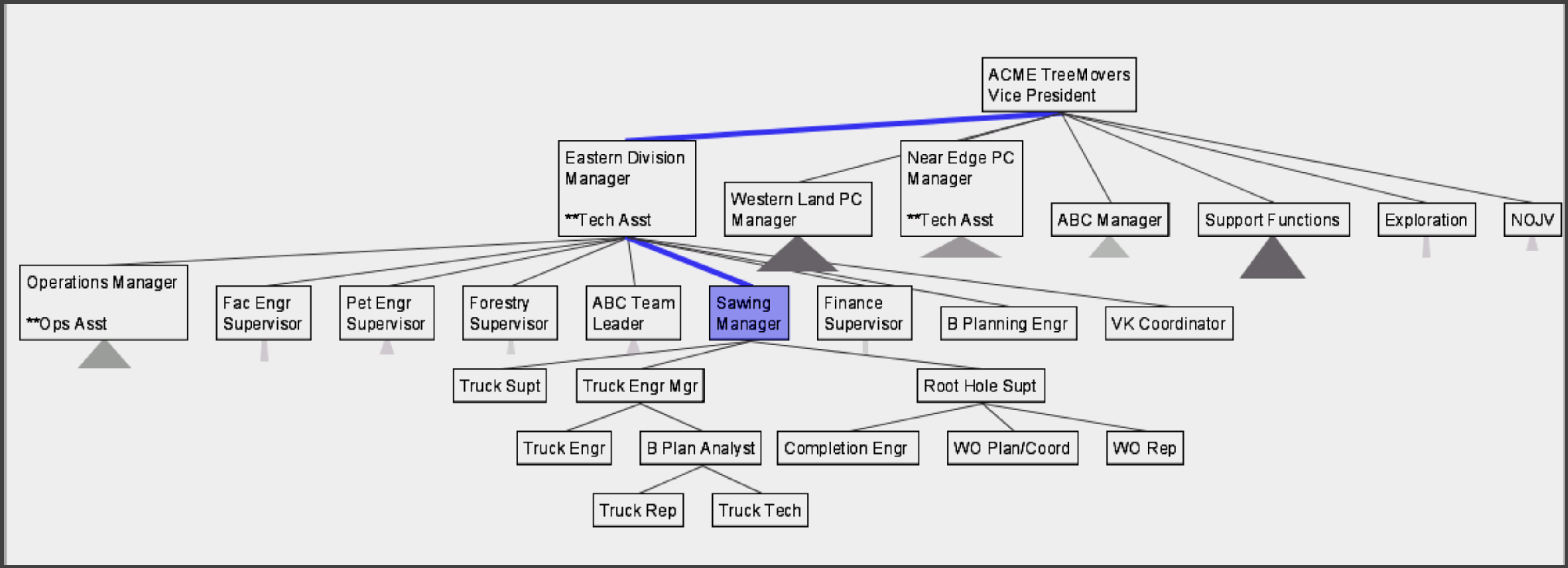


# Degree-of-Interest Trees [Heer 04]



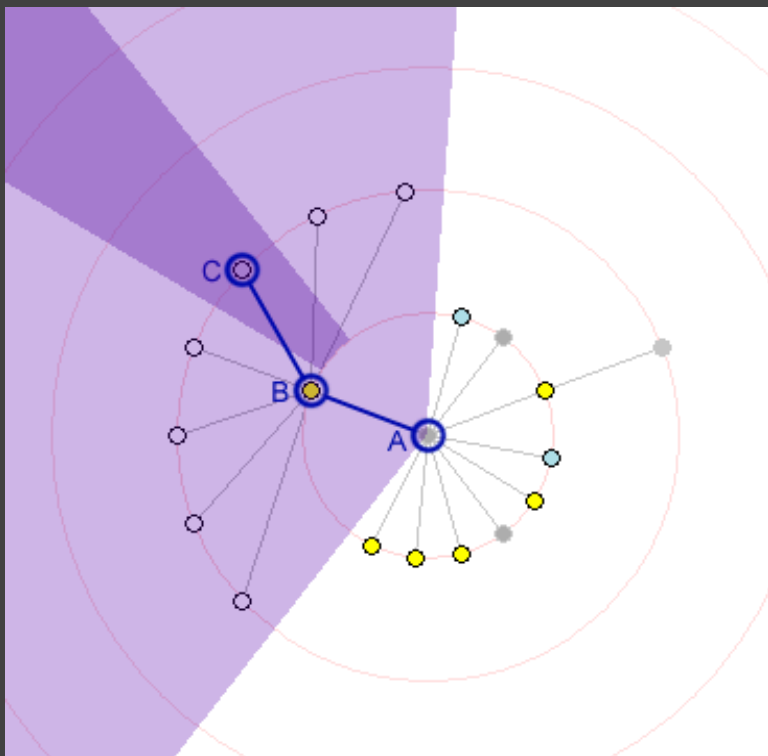

Animation of expanding/collapsing branches

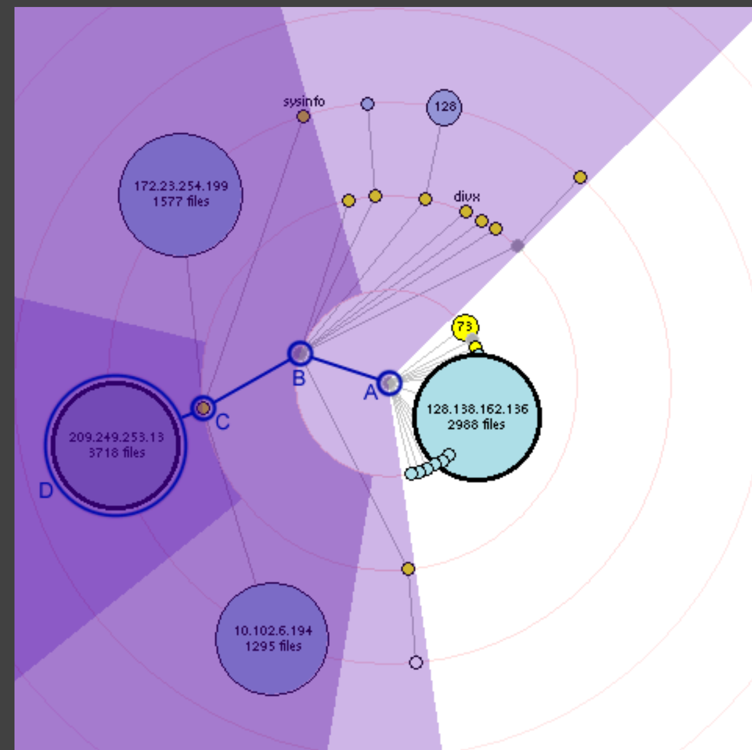
# Space Tree [Grosjean 04]




Break animated transitions into discrete stages

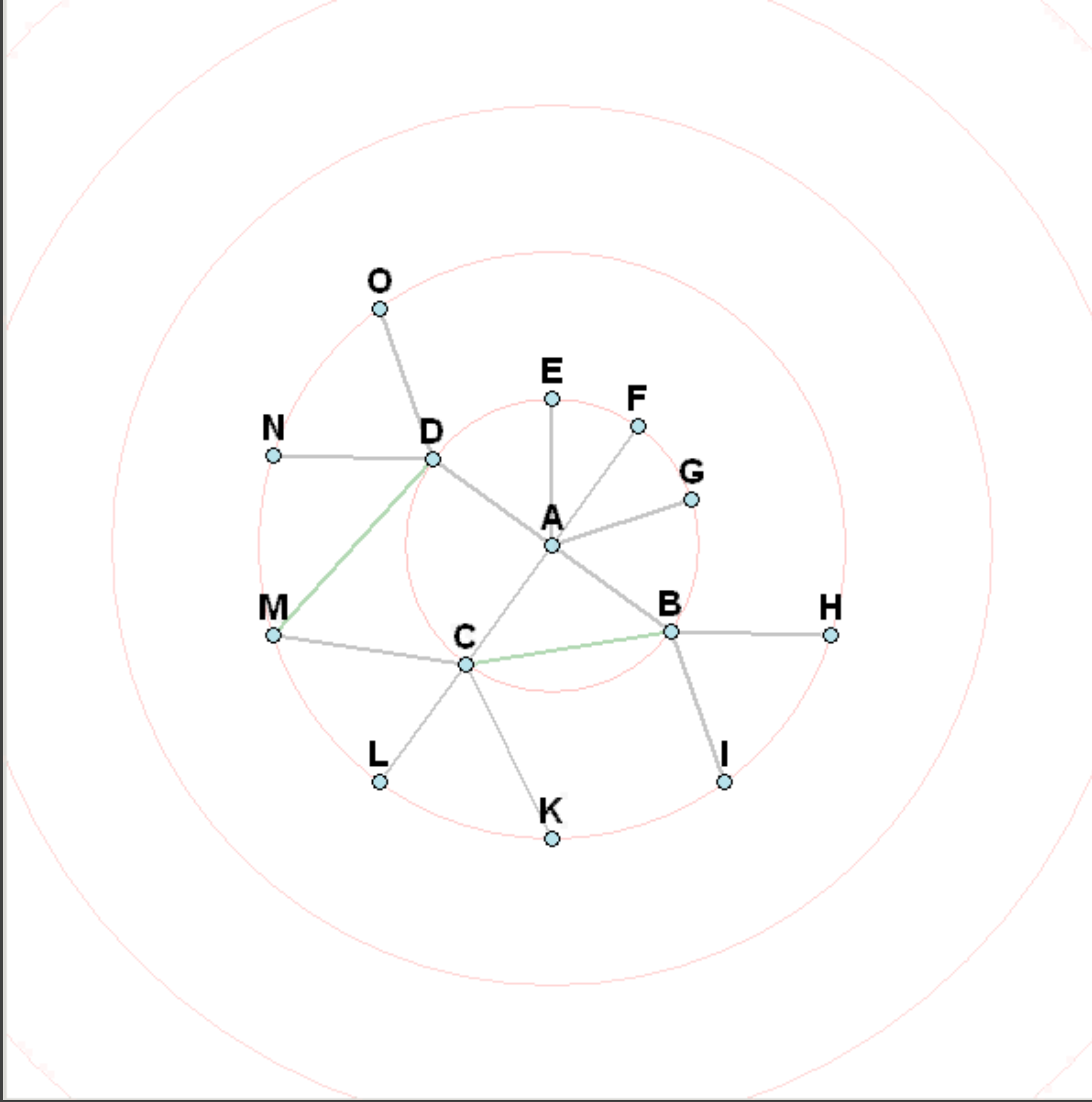
# Radial Graph Layout




Optimize animation to aid comprehension

http://people.ischool.berkeley.edu/~rachna/gtv/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# Animation in Radial Graph Layout

Help maintain context of nodes and general orientation of user during refocus.

**Transition Paths**

Linear interpolation of polar coordinates
Node moves in an arc, not straight lines
Moves along circle if not changing levels
When changing levels, spirals to next ring

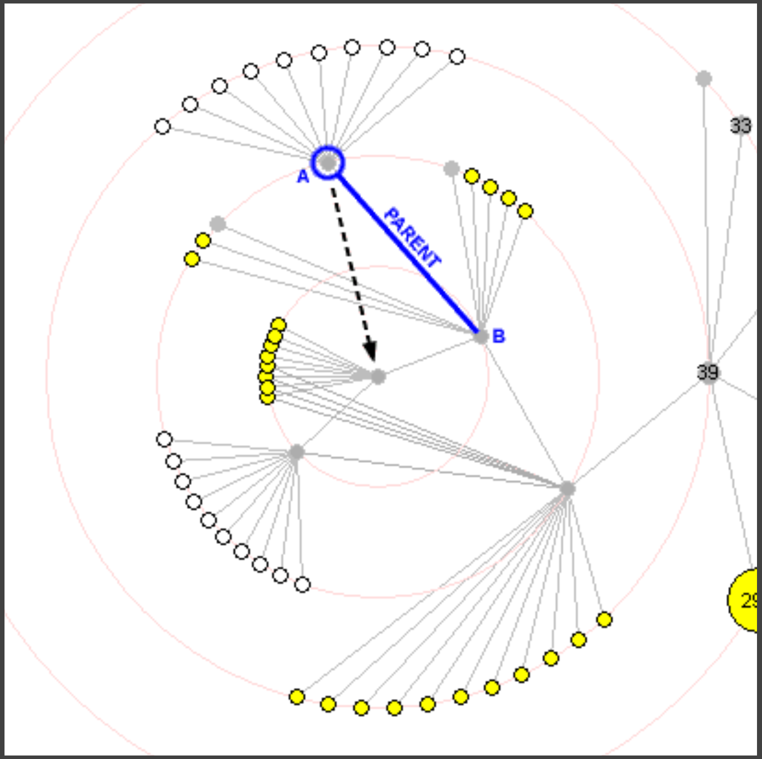
# Animation in Radial Graph Layout

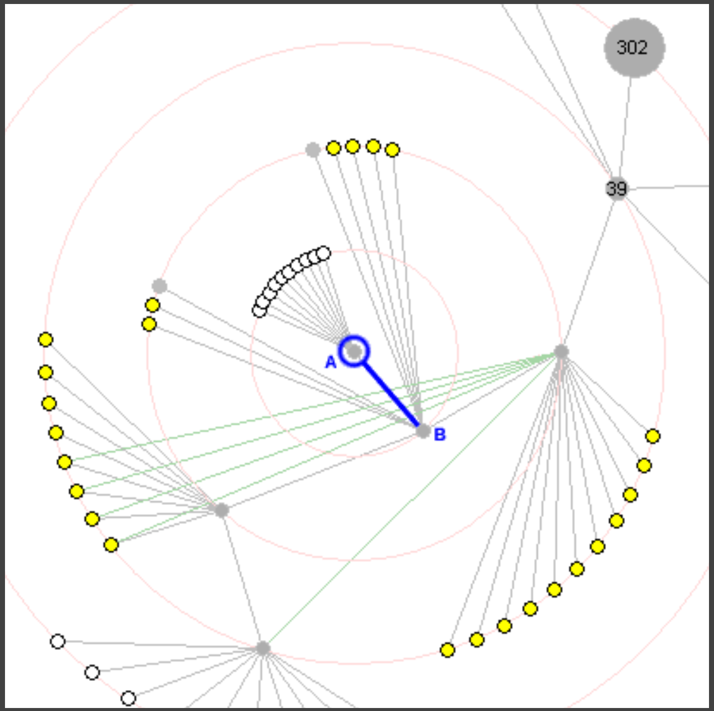
**Transition constraints**

Minimize rotational travel (move former parent away from new focus in same orientation)

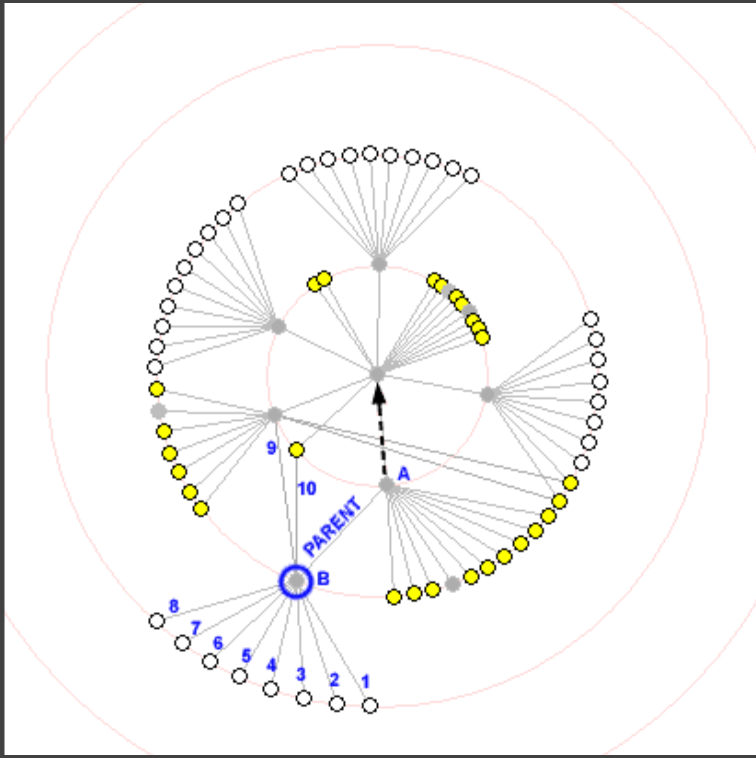
Avoid cross-over of edges

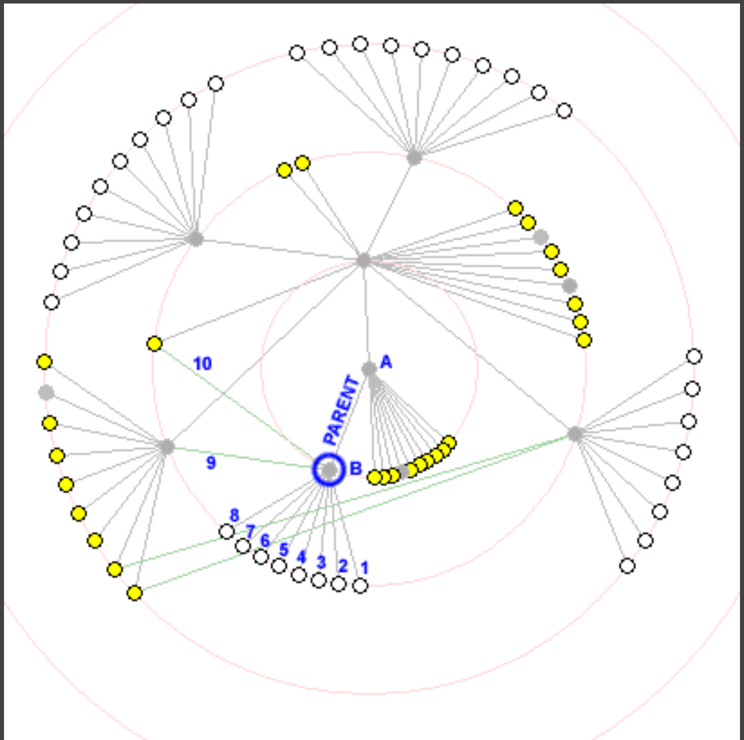
# Retain Edge Orientation



# Retain Neighbor Order



# Summary: Tree Visualization

**Indentation**

Linear list, indentation encodes depth

**Node-Link diagrams**

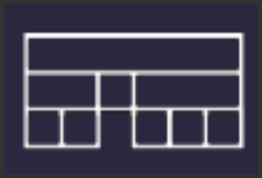
Nodes connected by lines/curves

**Enclosure diagrams**

Represent hierarchy by enclosure

**Layering**

Relative position and alignment



*Focus* + *Context* techniques for scale!