Network Layout

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CS 448B: Visualization
Winter 2020

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Announcements

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Final project

New visualization research or data analysis project

- **Research**: Pose problem, Implement creative solution
- **Data analysis**: Analyze dataset in depth & make a visual explainer

Deliverables

- **Research**: Implementation of solution
- **Data analysis/explainer**: Article with multiple interactive visualizations
- 6-8 page paper

Schedule

- Project proposal: Wed 2/19
- Design review and feedback: 3/9 and 3/11
- Final presentation: 3/16 (7-9pm) Location: TBD
- Final code and writeup: 3/18 11:59pm

Grading

- Groups of up to 3 people, graded individually
- Clearly report responsibilities of each member

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Network Layout

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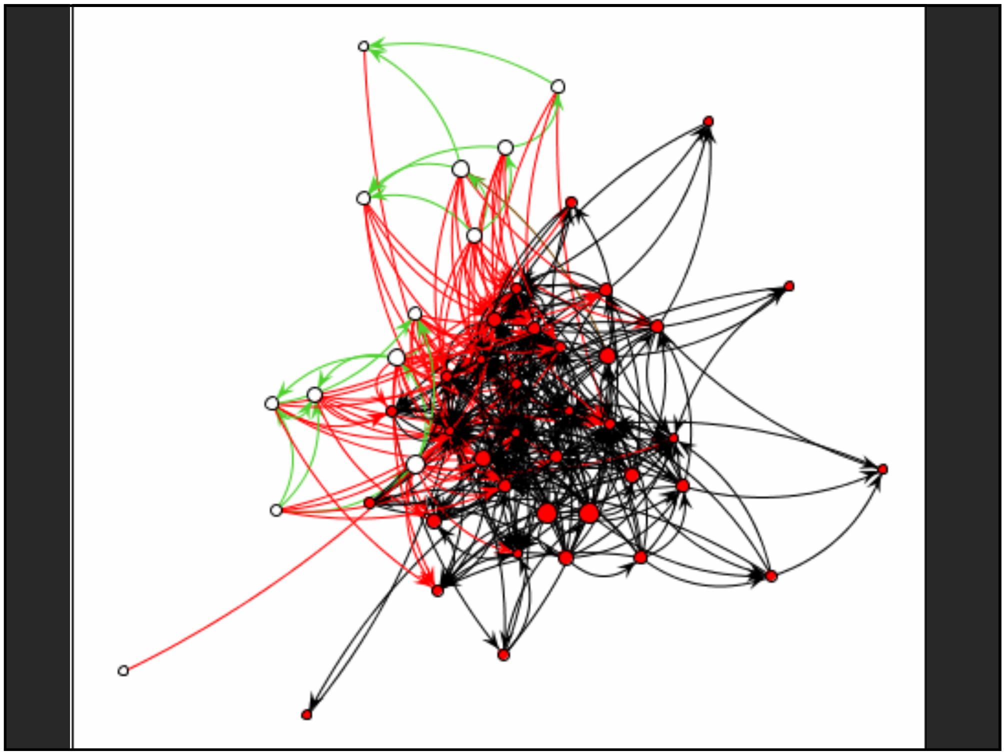

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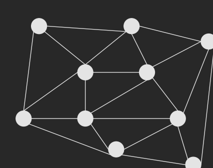
Graphs and Trees

Graphs

Model relations among data

Nodes and *edges*

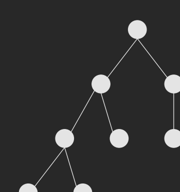


Trees

Graphs with hierarchical structure

Connected graph with N-1 edges

Nodes as *parents* and *children*



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Spatial Layout

Primary concern – layout of nodes and edges

Often (but not always) goal is to depict structure

- Connectivity, path-following
- Network distance
- Clustering
- Ordering (e.g., hierarchy level)

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Applications

Tournaments
Organization Charts
Genealogy
Diagramming (e.g., Visio)
Biological Interactions (Genes, Proteins)
Computer Networks
Social Networks
Simulation and Modeling
Integrated Circuit Design

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Topics

Tree Layout
Network Layout
- Sugiyama-Style Layout
- Force-Directed Layout

Alternatives to Network Layout
- Matrix Diagrams
- Attribute-Drive Layout

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Tree Layout

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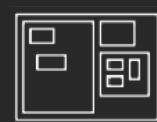
Tree Visualization

Indentation
- Linear list, indentation encodes depth

Node-Link diagrams
- Nodes connected by lines/curves

Enclosure diagrams
- Represent hierarchy by enclosure



Layering
- Layering and alignment

Tree layout is fast: O(n) or O(n log n), enabling real-time layout for interaction

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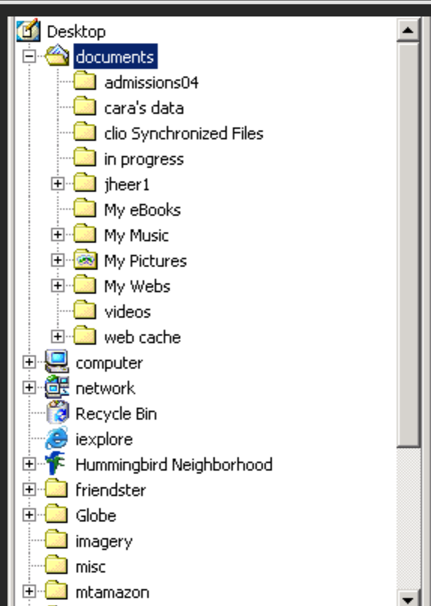
Indentation



Items along vertically spaced rows

Indentation shows parent/child relationships

Often used in interfaces

Breadth/depth contend for space

Often requires scrolling

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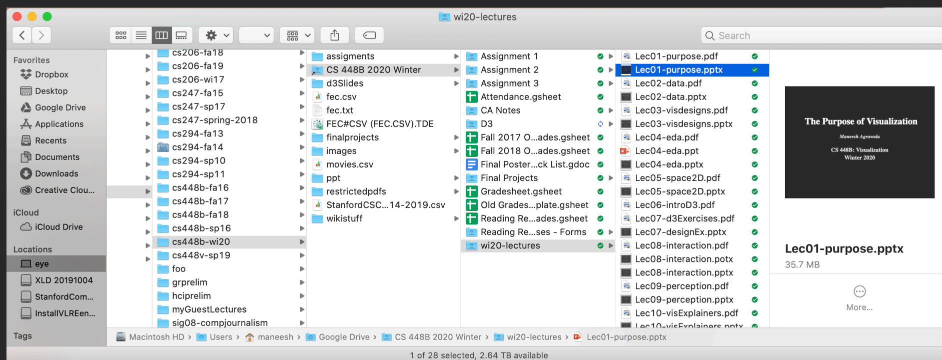
Single-Focus (Accordion) List



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

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Node-Link Diagrams

Nodes distributed in space, connected by lines
Use 2D space to break apart breadth and depth
Space used to communicate hierarchical orientation
- Typically towards authority or generality

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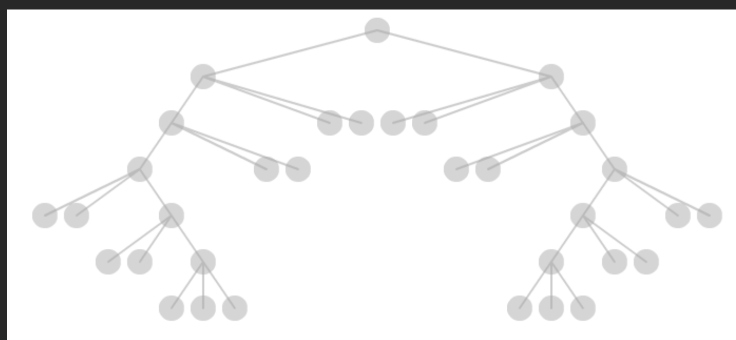
Basic Recursive Approach

Repeatedly divide space for subtrees by leaf count

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



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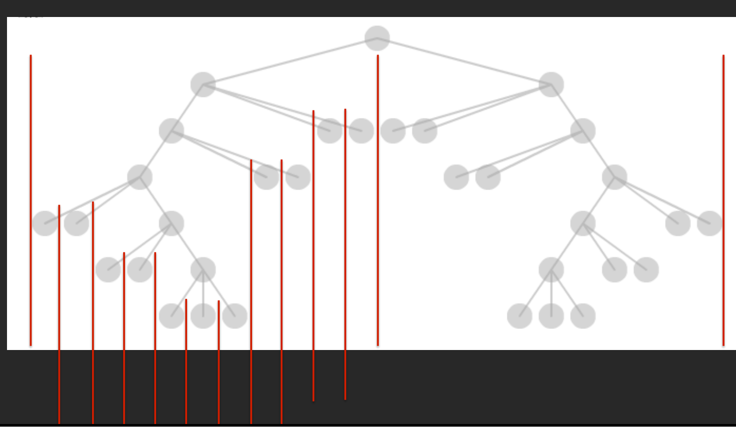
Basic Recursive Approach

Repeatedly divide space for subtrees by leaf count

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

Problem:



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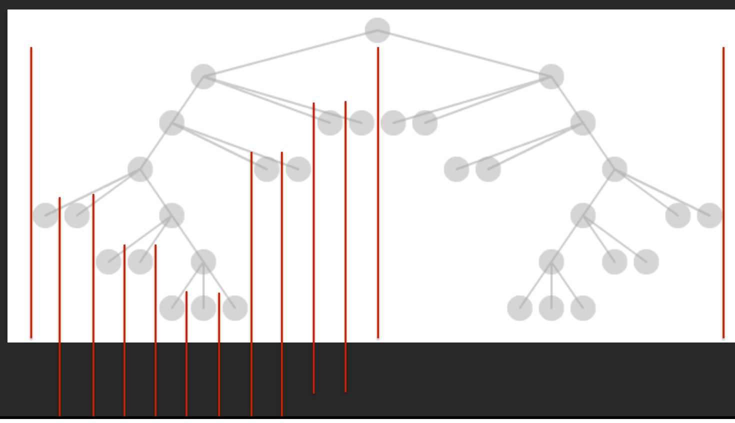
Basic Recursive Approach

Repeatedly divide space for subtrees by leaf count

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

Problem: Exponential growth of breadth



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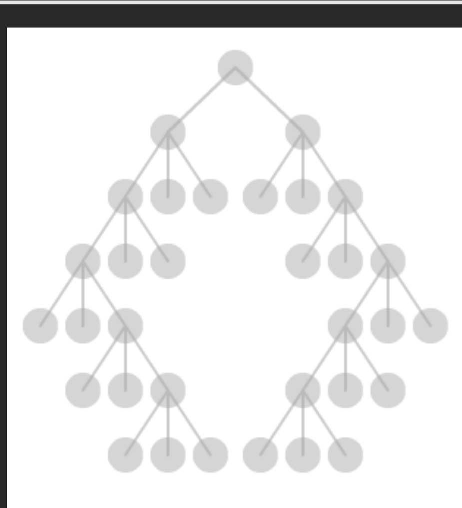
Reingold & Tilford's Tidier Layout



Goal: maximize density and symmetry.

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

This extension was corrected by Buchheim et al. to achieve a linear time algorithm

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Reingold-Tilford Layout

Design concerns

- Clearly encode depth level
- No edge crossings
- Isomorphic subtrees drawn identically
- Ordering and symmetry preserved
- *Compact layout (don't waste space)*

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Reingold-Tilford Algorithm

Linear algorithm – starts with bottom-up (postorder) pass
Set Y-coord by depth, arbitrary starting X-coord
Merge left and right subtrees

- Shift right as close as possible to left
  - Computed efficiently by maintaining subtree contours
- "Shifts" in position saved for each node as visited
- Parent nodes are centered above their children

Top-down (preorder) pass for assignment of final positions

- Sum of initial layout and aggregated shifts

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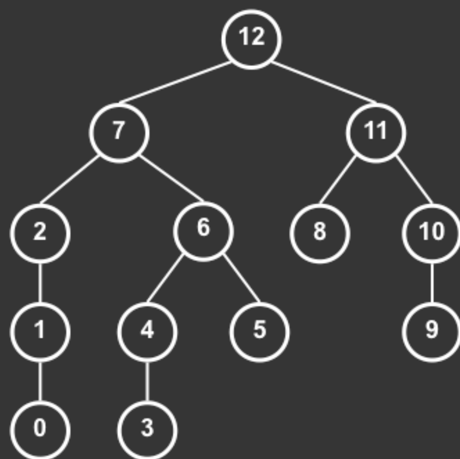
Reingold-Tilford Algorithm



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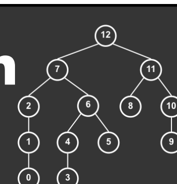
Reingold-Tilford Algorithm



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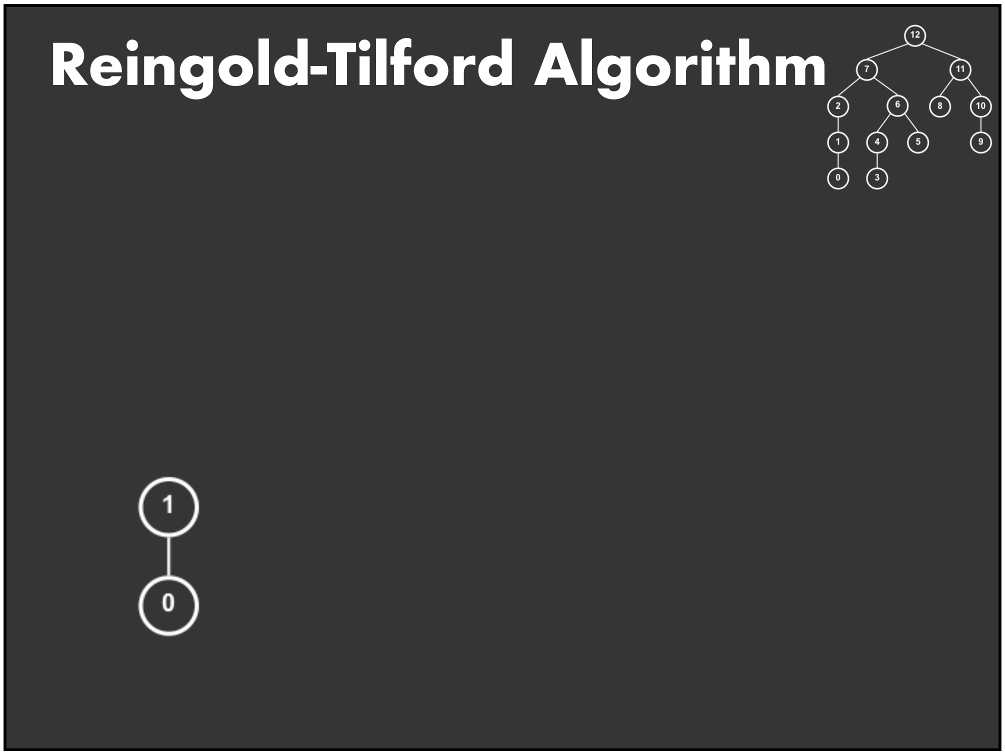
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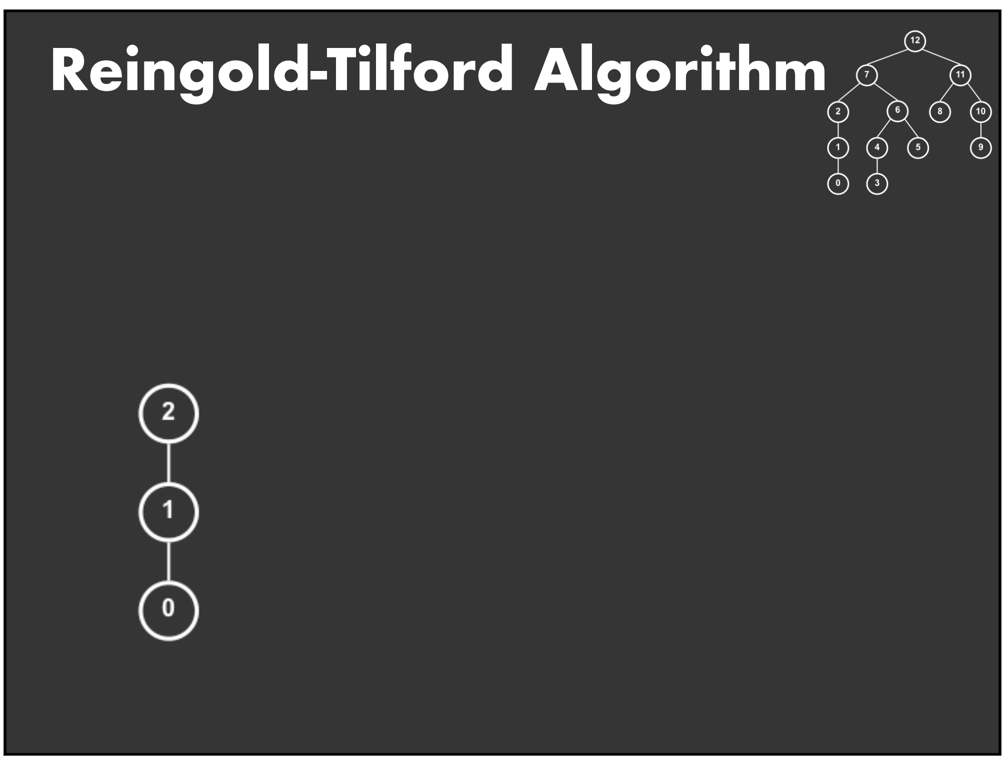
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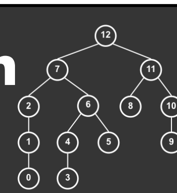

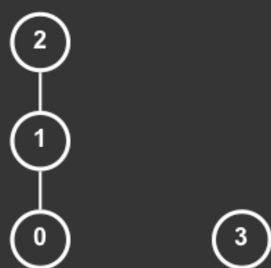

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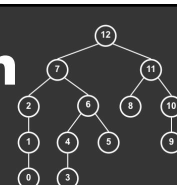
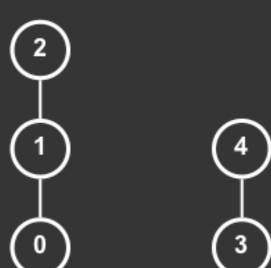
Reingold-Tilford Algorithm





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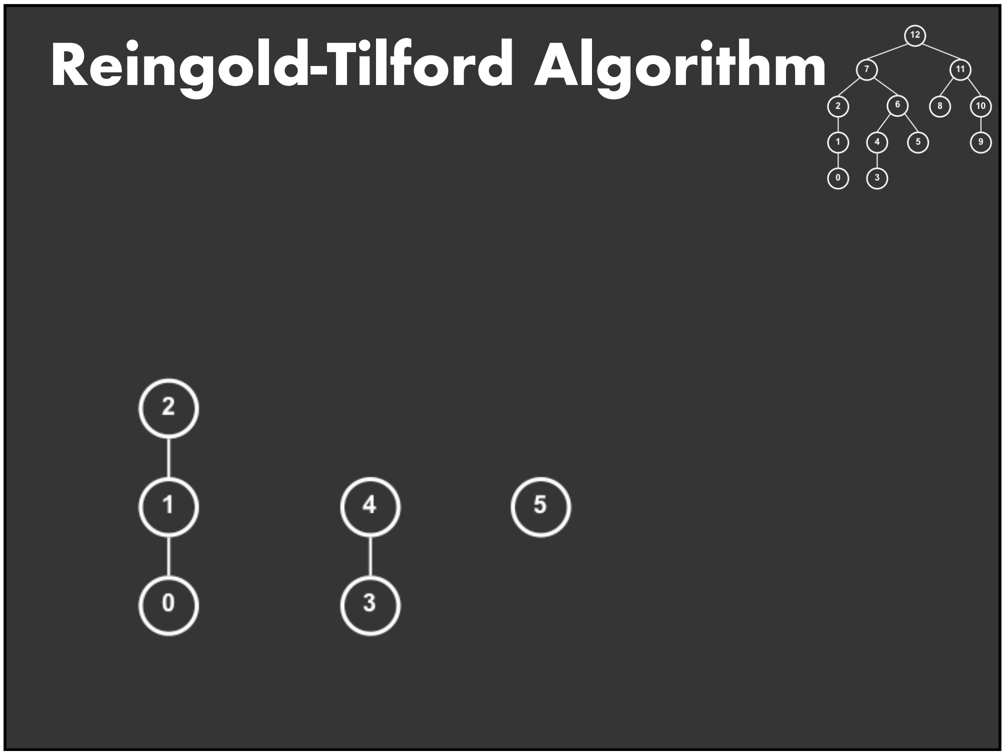
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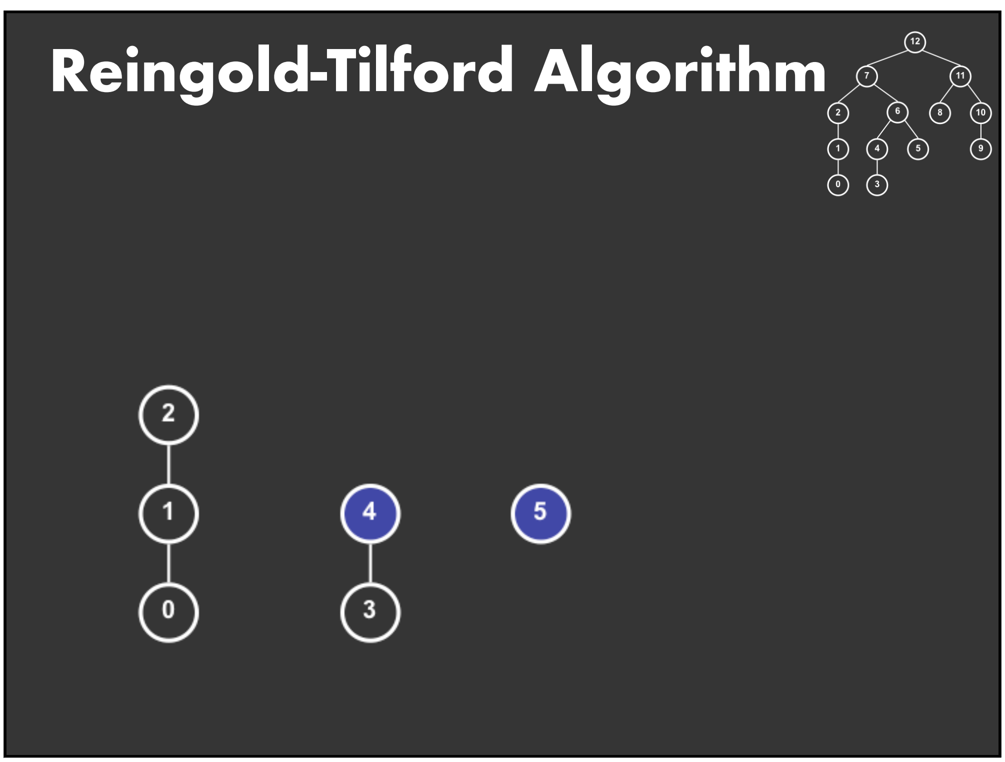
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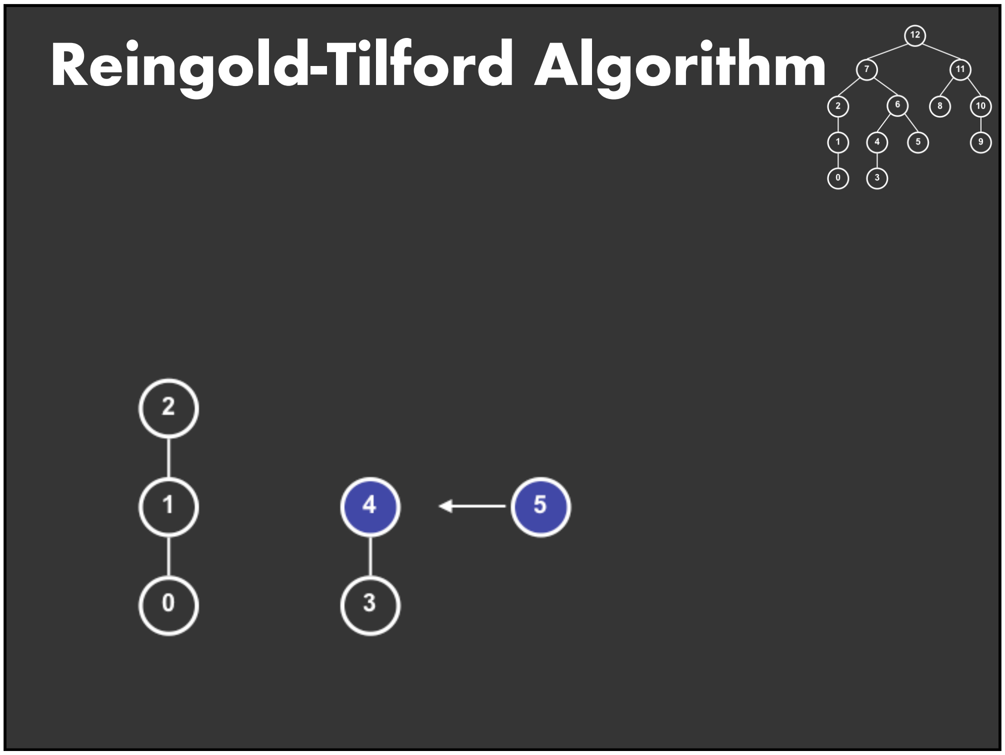
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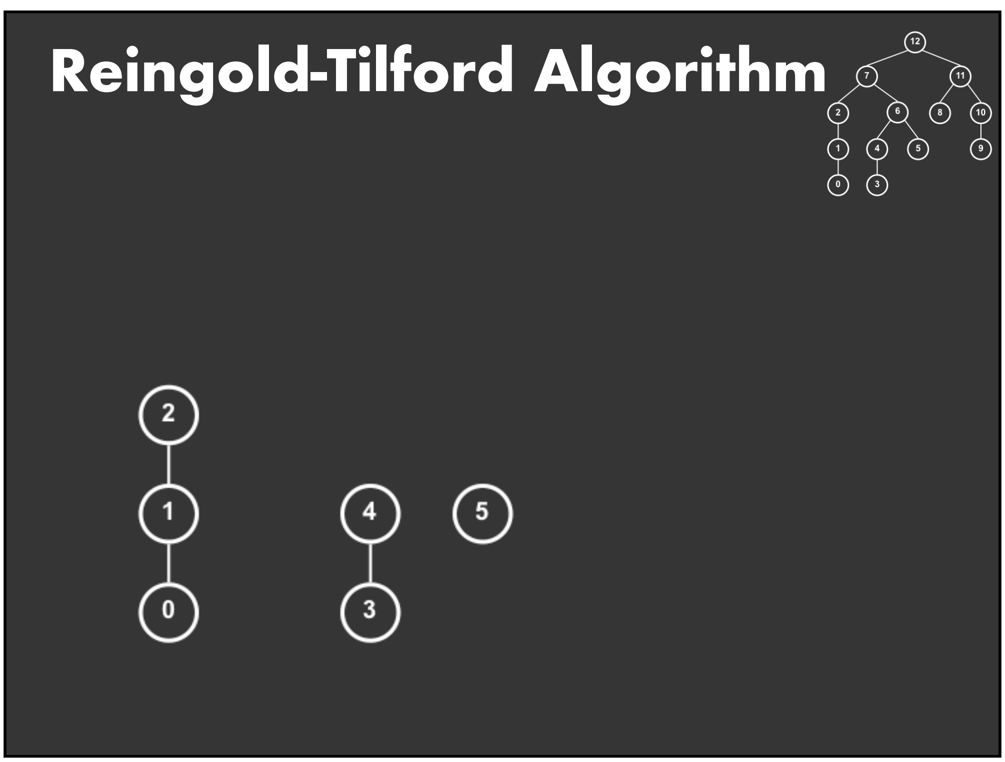
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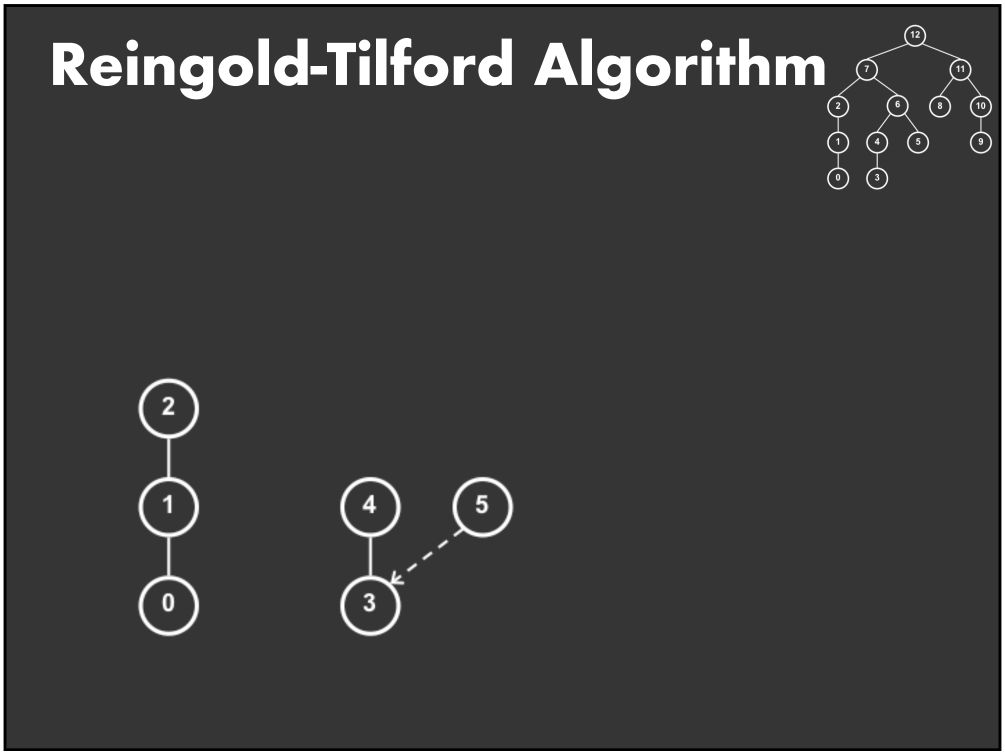
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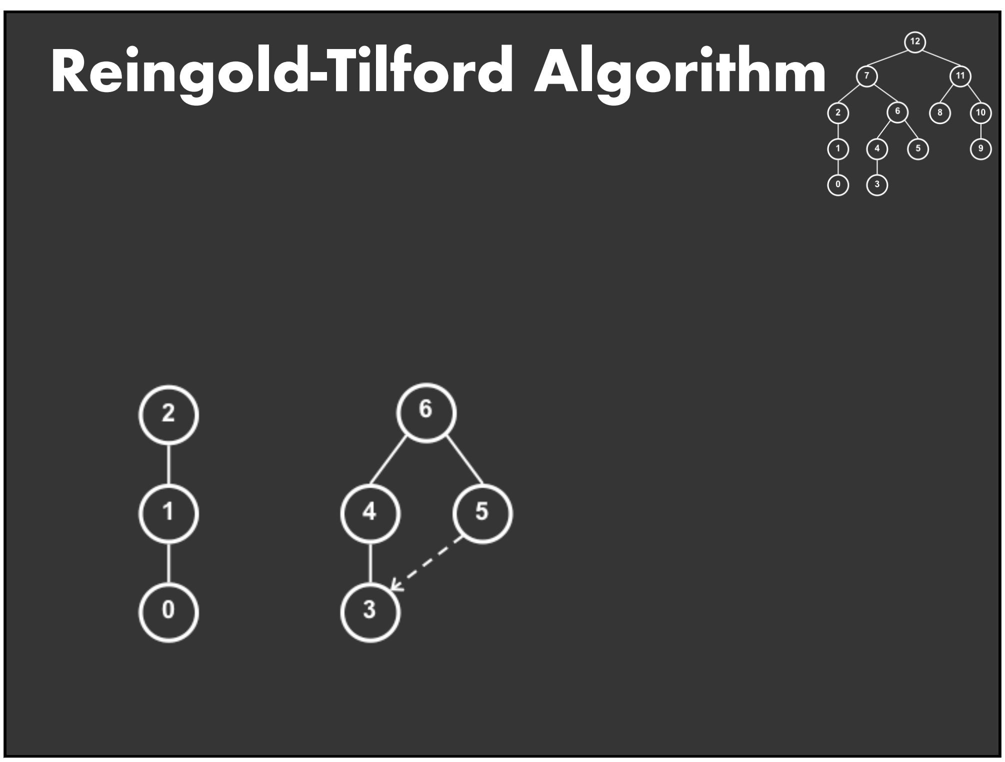
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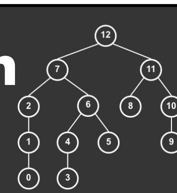

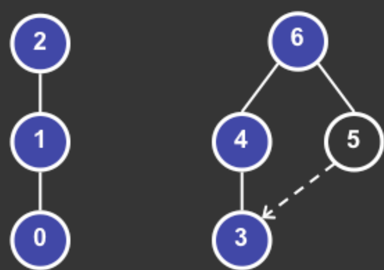

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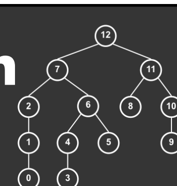

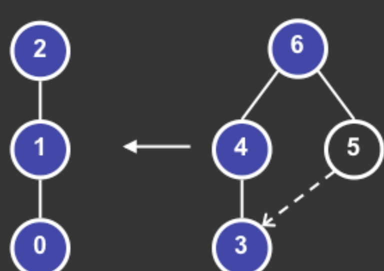

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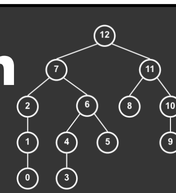

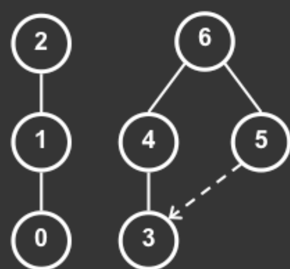

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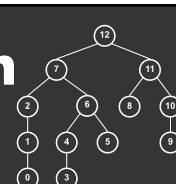

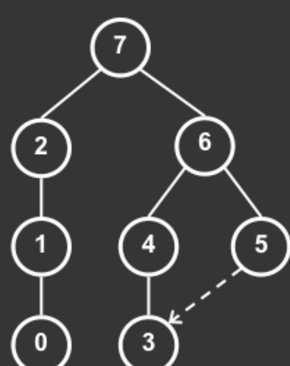

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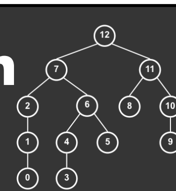

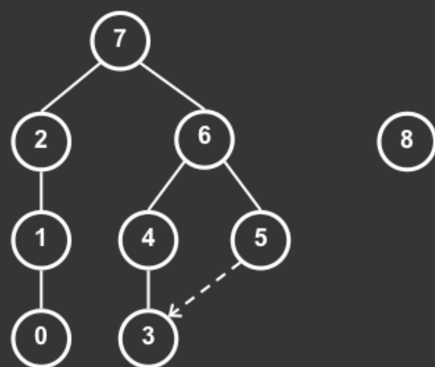

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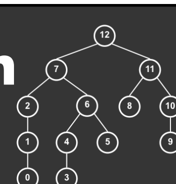
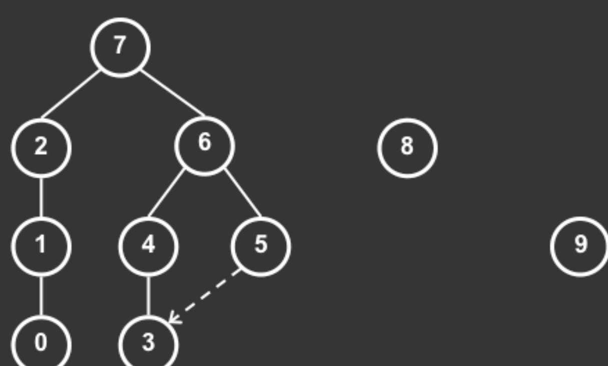
Reingold-Tilford Algorithm





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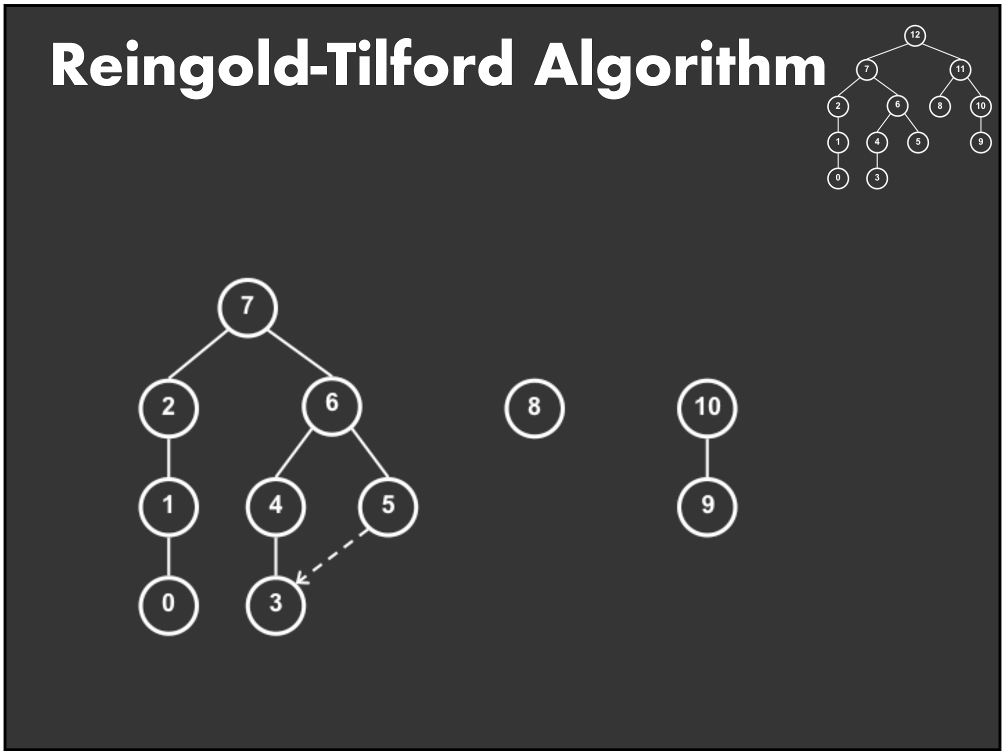
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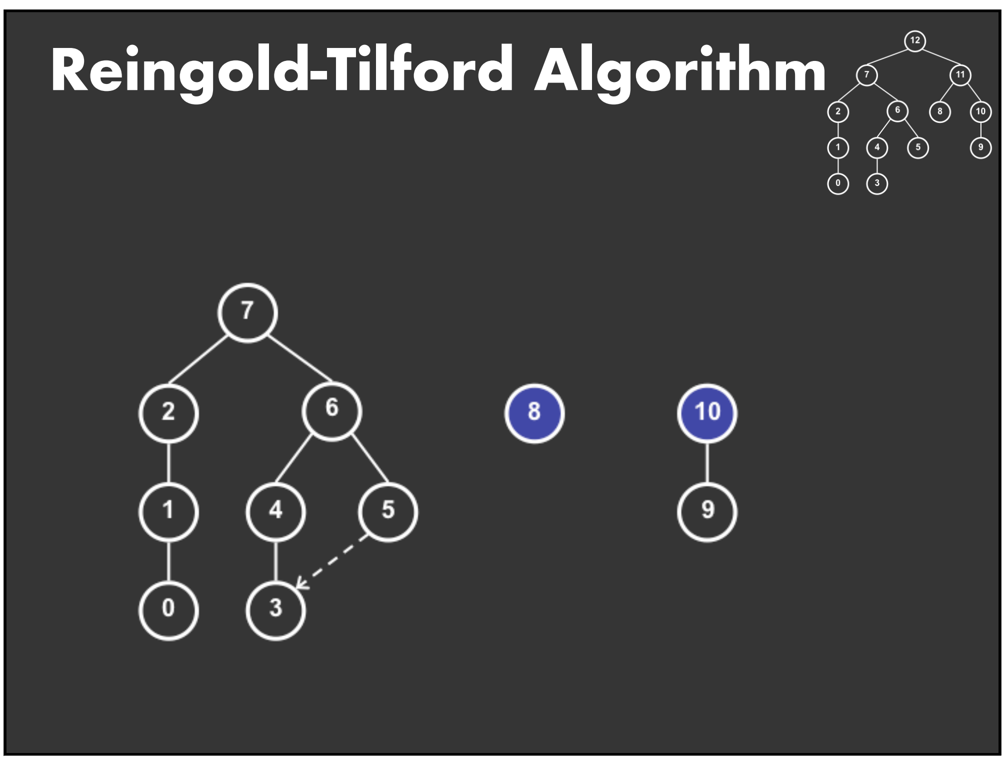
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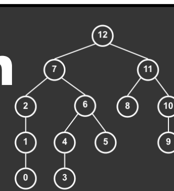

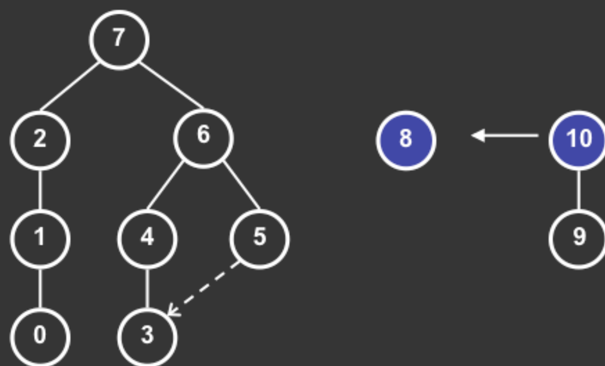

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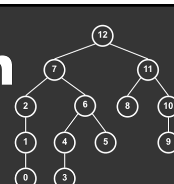

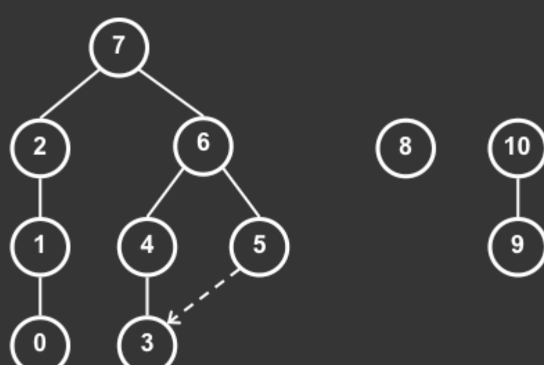

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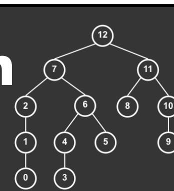

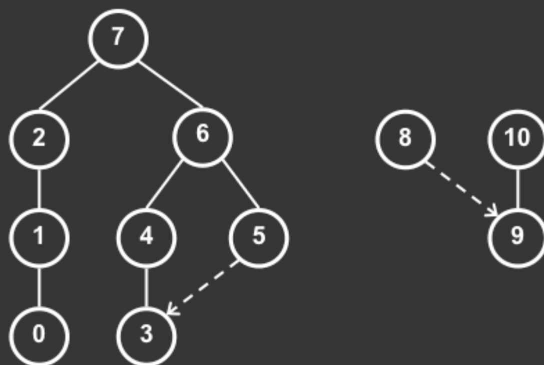

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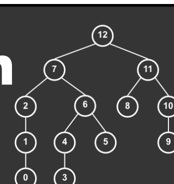
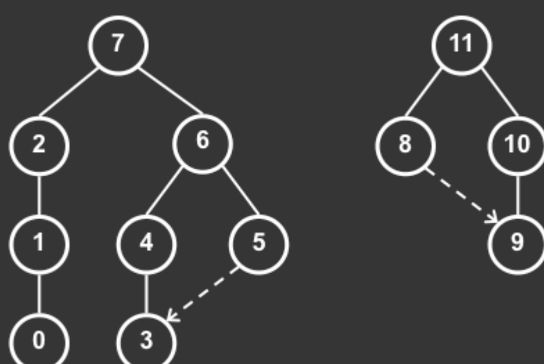
Reingold-Tilford Algorithm





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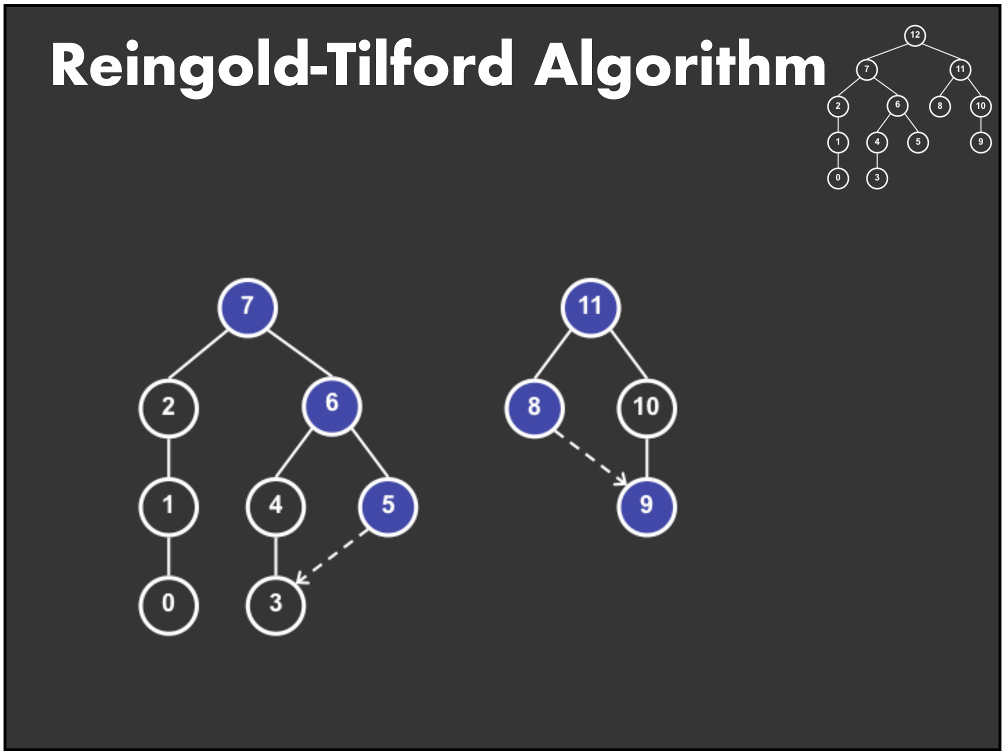
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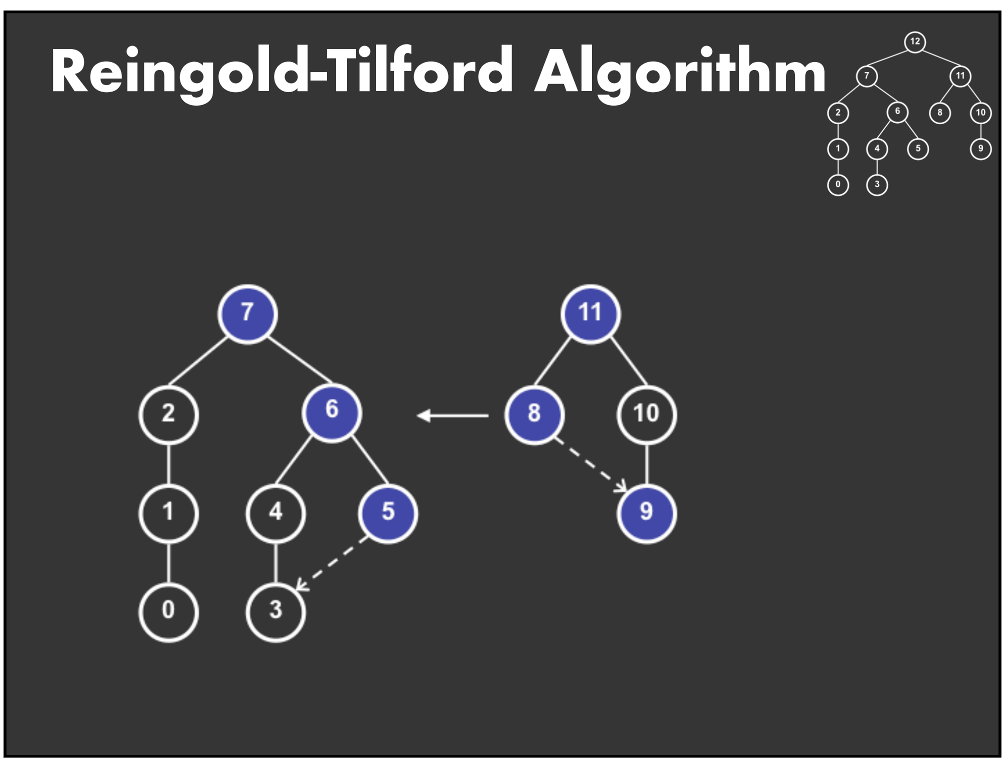
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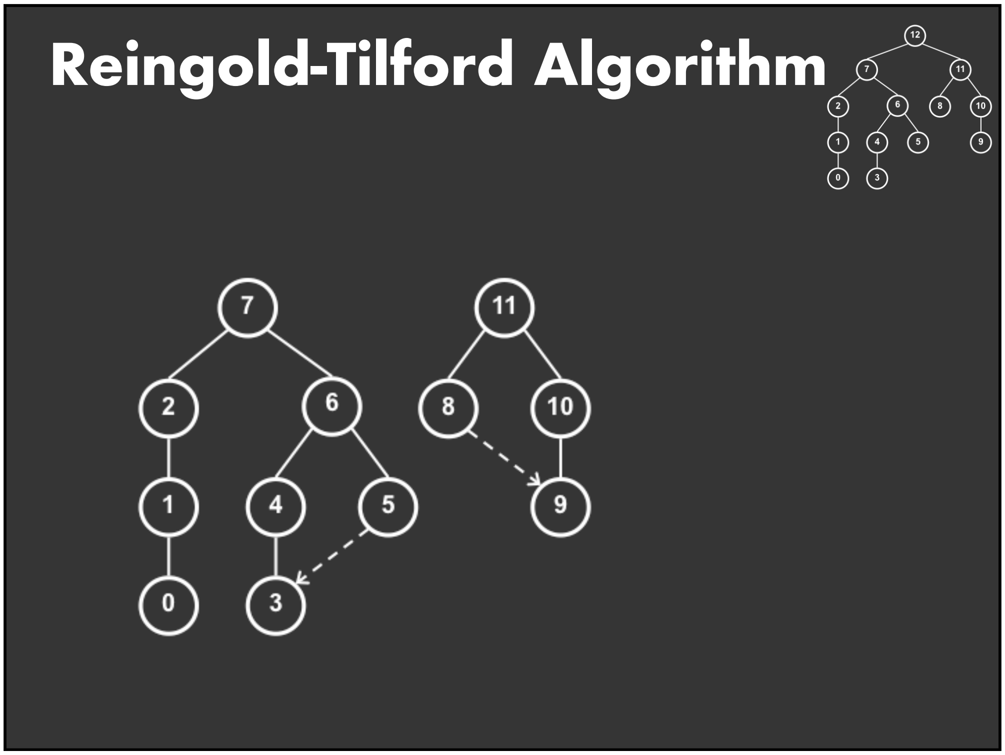
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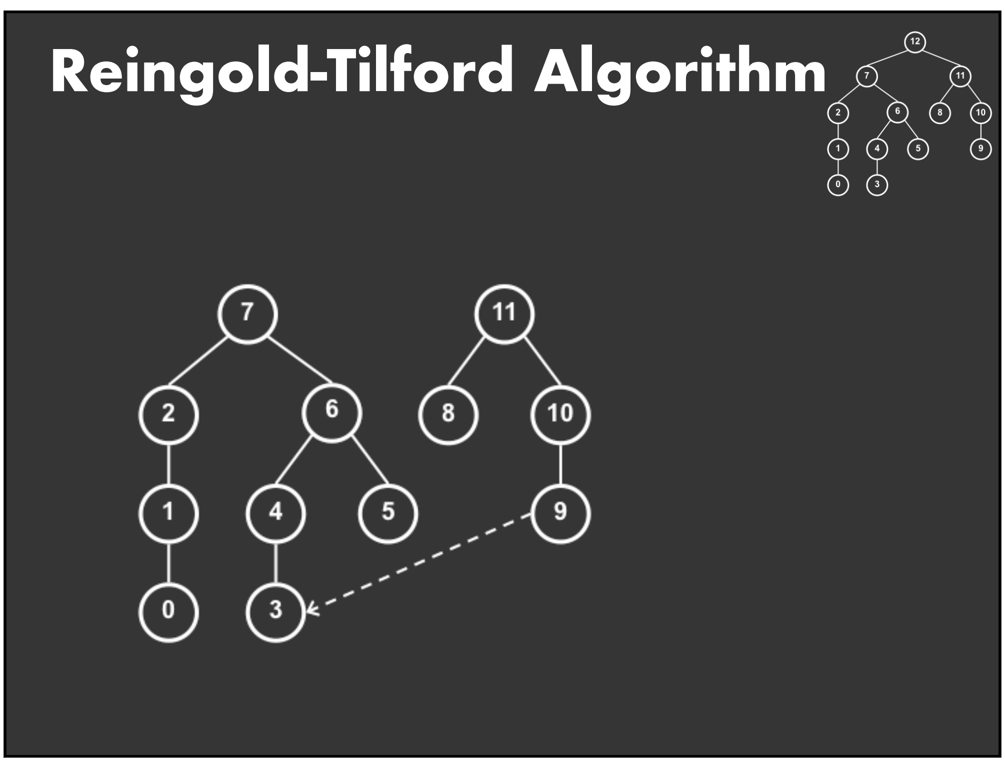
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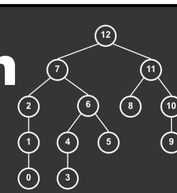
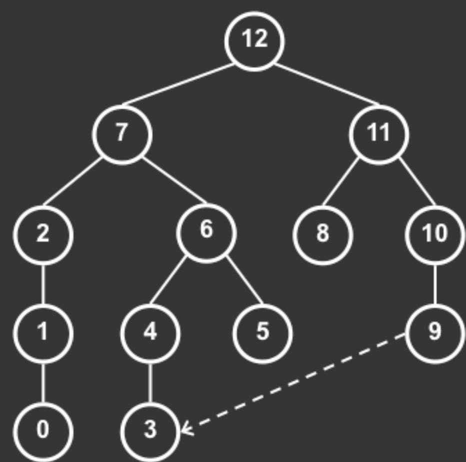
Reingold-Tilford Algorithm





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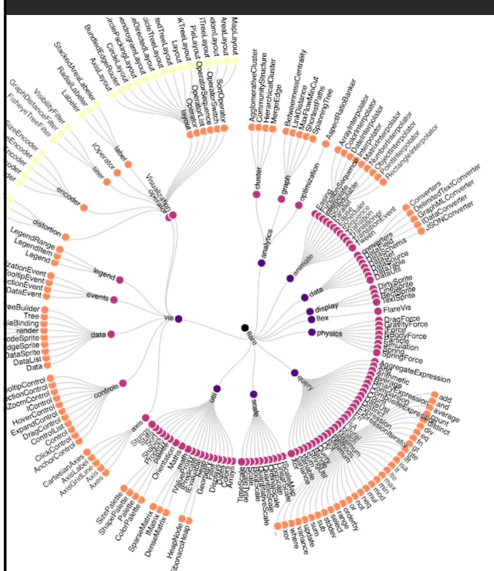
Radial Layout



- Node-link diagram in polar coords
- Radius encodes depth root at center
- Angular sectors assigned to subtrees (recursive approach)
- Reingold-Tilford approach can also be applied here

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Problems with Node-Link Diagrams

Scale

Tree breadth often grows exponentially
Even with tidier layout, quickly run out of space

Possible solutions

Filtering
Focus+Context
Scrolling or Panning
Zooming
Aggregation

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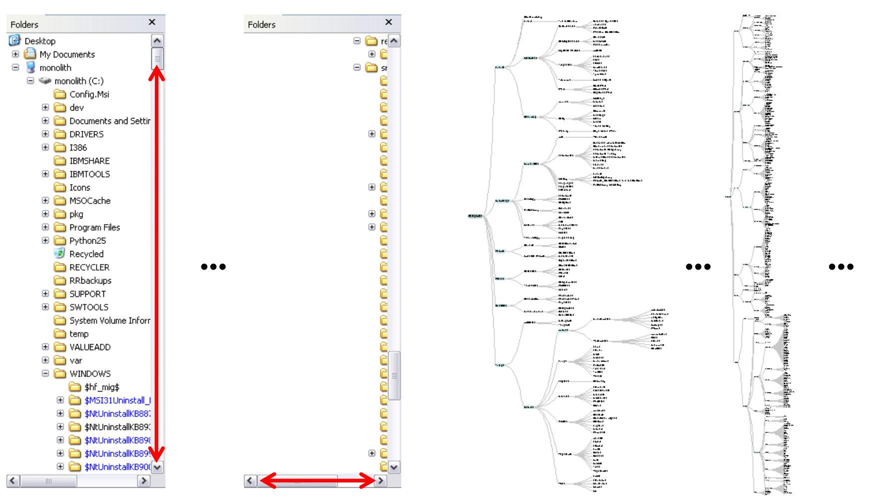
Visualizing Large Hierarchies



Indented Layout

Reingold-Tilford Layout

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MC Escher, *Circle Limit IV*

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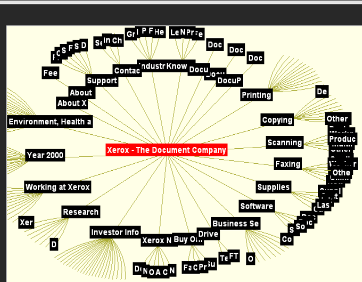
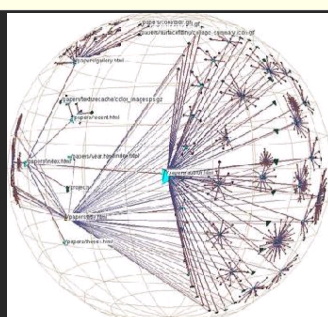
Hyperbolic Layout





Layout in hyperbolic space, then project on to Euclidean plane

Why? Like tree breadth, the hyperbolic plane expands exponentially

Also computable in 3D, projected into a sphere

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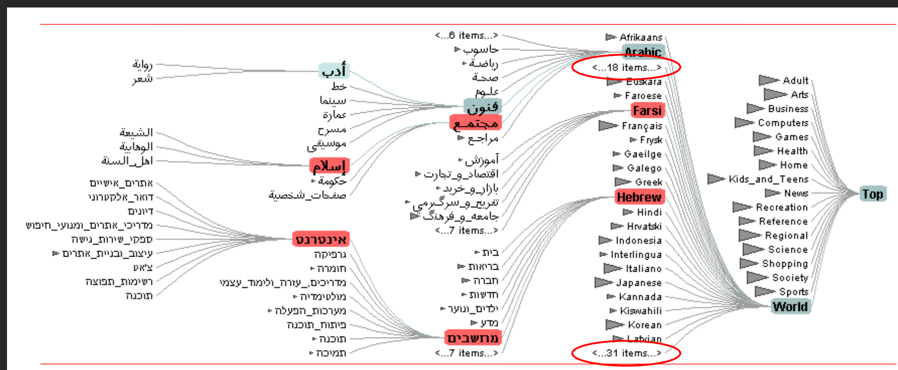
Degree-of-Interest Trees [AVI 04]



Space-constrained, multi-focal tree layout

https://www.youtube.com/watch?v=RTQ0N4QY0yc
https://observablehq.com/@d3/collapsible-tree

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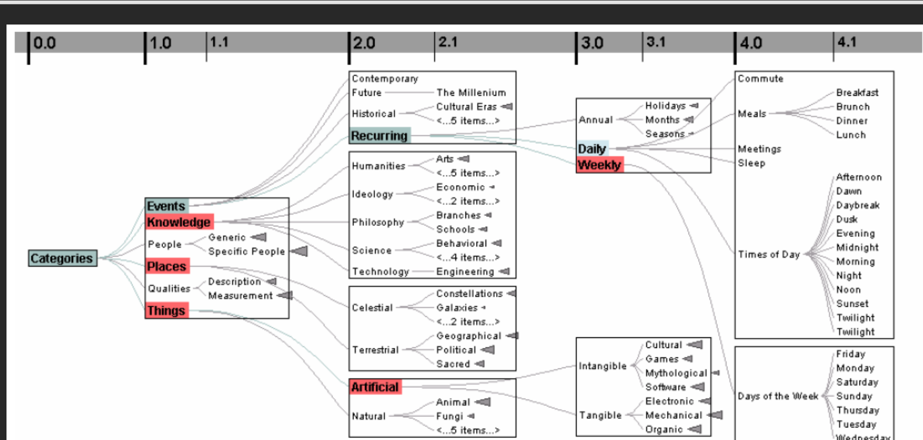
Degree-of-Interest Trees



Cull "un-interesting" nodes on a per block basis until all blocks on a level fit within bounds

Center child blocks under parents

https://www.youtube.com/watch?v=RTQ0N4QY0yc
https://observablehq.com/@d3/collapsible-tree

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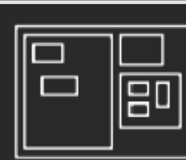
Enclosure Diagrams



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 depth

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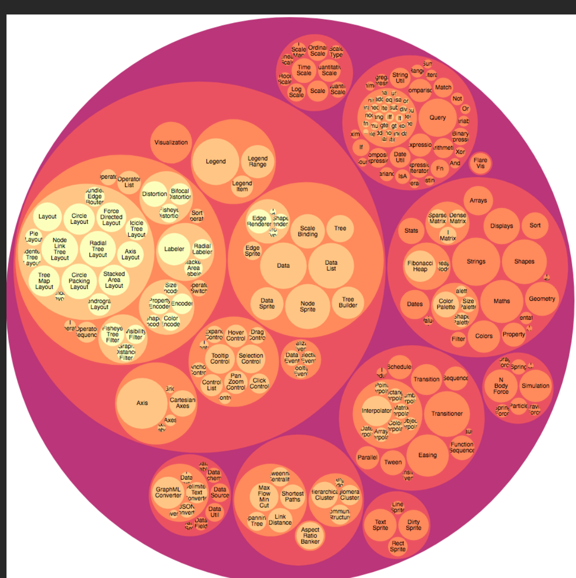
Circle Packing Layout



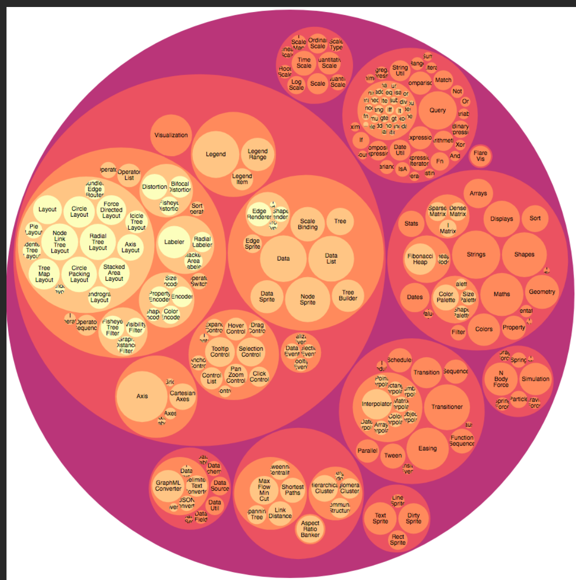
Nodes represented as sized circles

Nesting to show parent-child relationships

Problems:

64

Circle Packing Layout



Nodes represented as sized circles

Nesting to show parent-child relationships

Problems:

- Inefficient use of space
- Parent size misleading

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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

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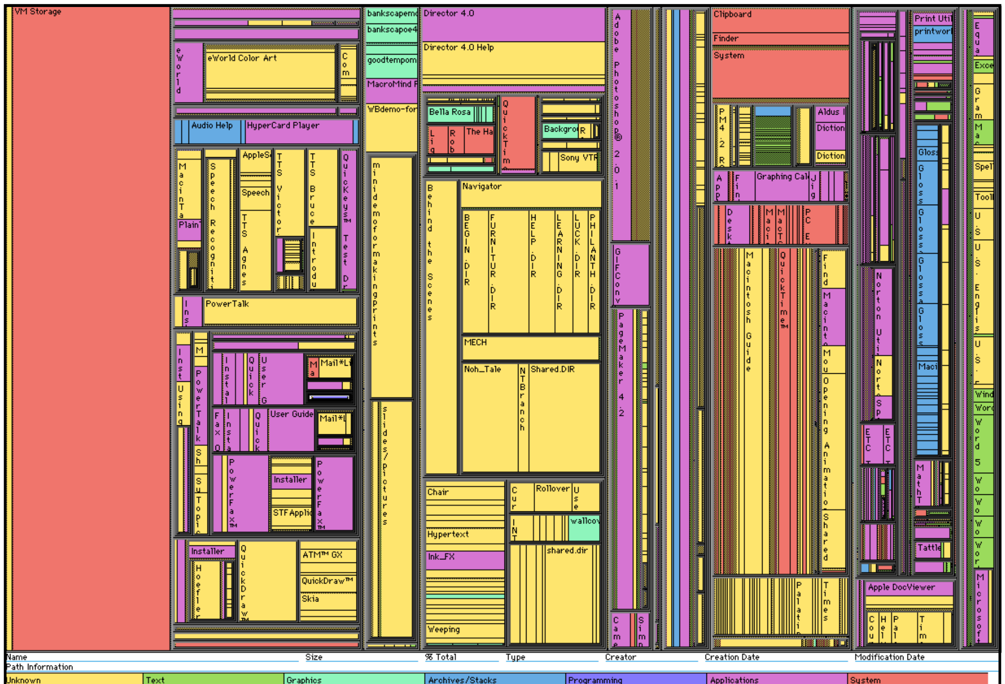
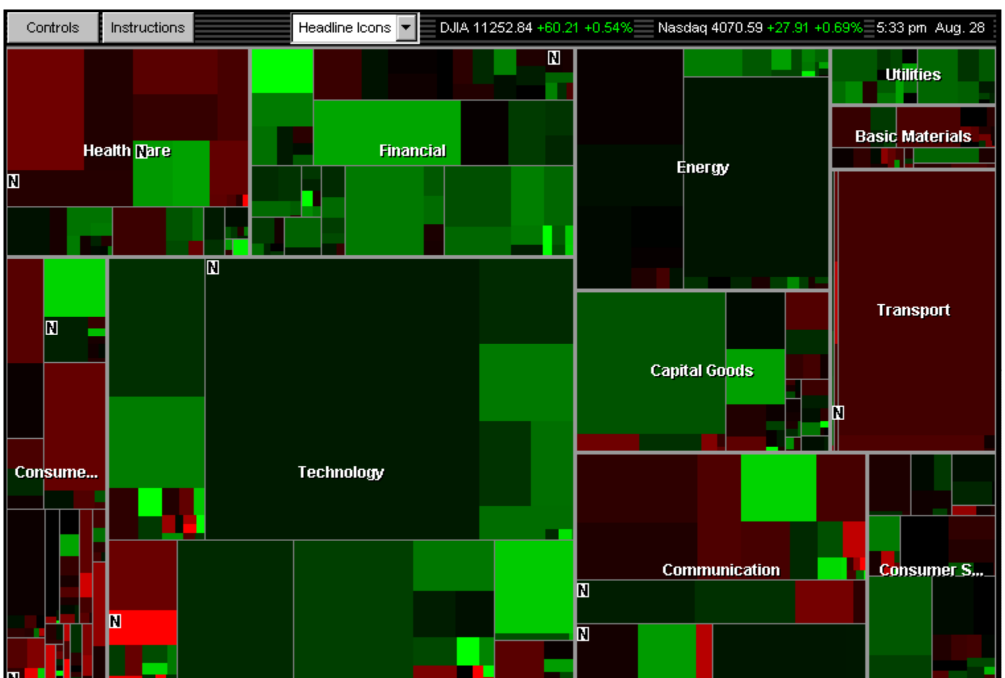


Slice & Dice **layout: Alternate horizontal / vertical partitions.**

68



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

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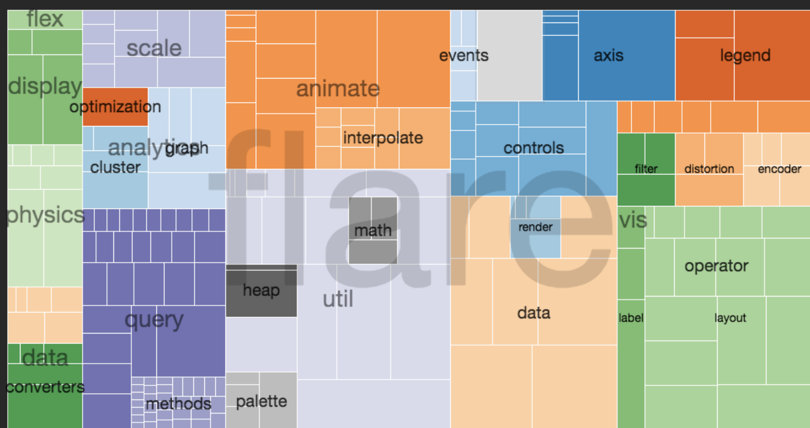
Squarified Treemaps [Bruls 00]

Greedy optimization for objective of square rectangles
Slice/dice within siblings; alternate whenever ratio worsens



https://vega.github.io/vega/examples/treemap/

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Why Squares

Posited Benefits of 1:1 Aspect Ratios

1. Minimize perimeter, reducing border ink.
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?

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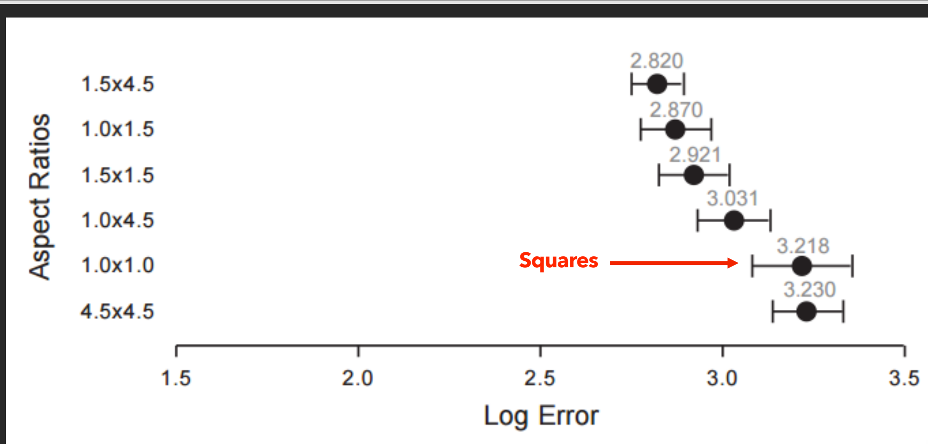
Error vs. Aspect Ratio [Kong 10]



1. Comparison of squares has higher error!
2. Squarify works because it fails to meet its objective?

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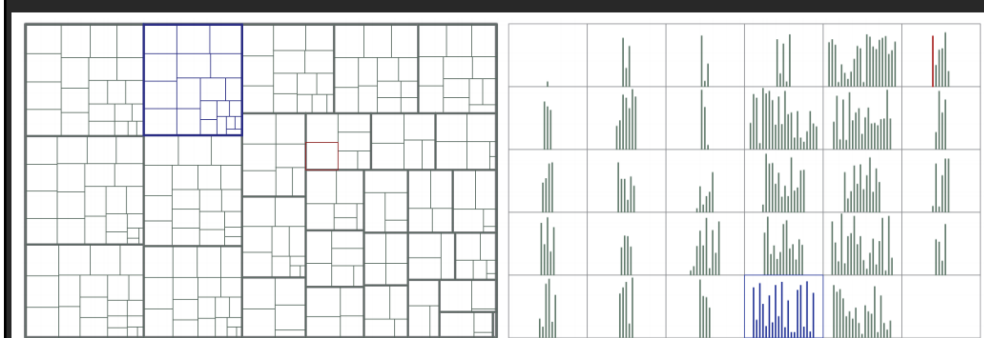
Treemaps vs. Bar Charts [Kong 10]



Height more perceptually effective than area

What if element count is high?
What about comparing groups of elements such as leaf values to internal node values?

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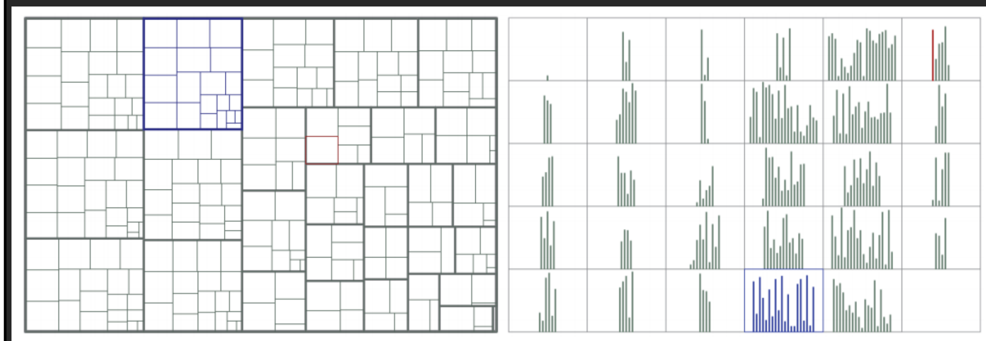
Treemaps vs. Bar Charts [Kong 10]



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.

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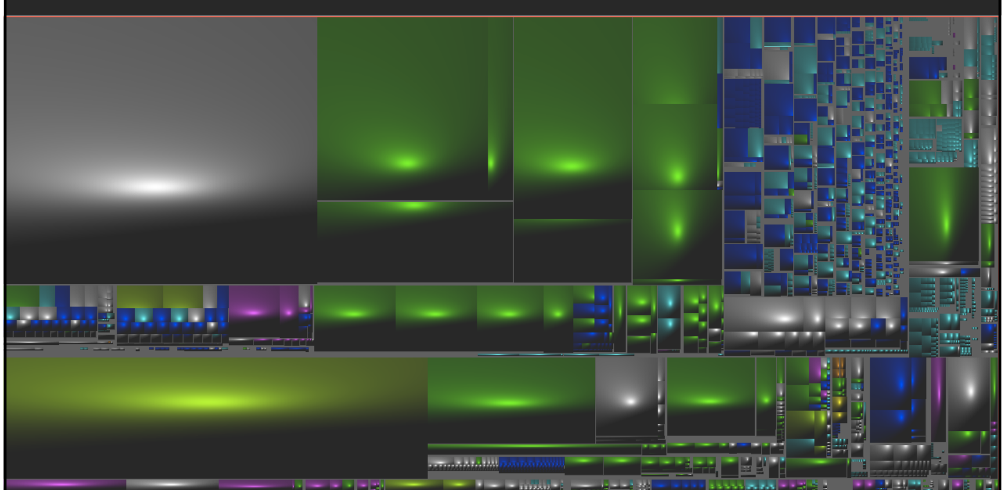
Cushion Treemaps [van Wijk 99]



Use shading to emphasize hierarchical structure

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Cascaded Treemaps [Lü 08]

Use 2.5D effect emphasize hierarchical structure

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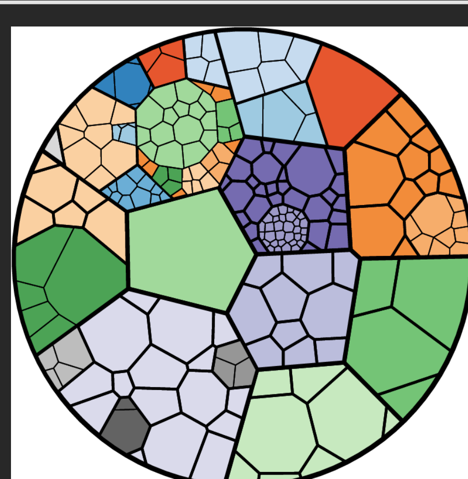
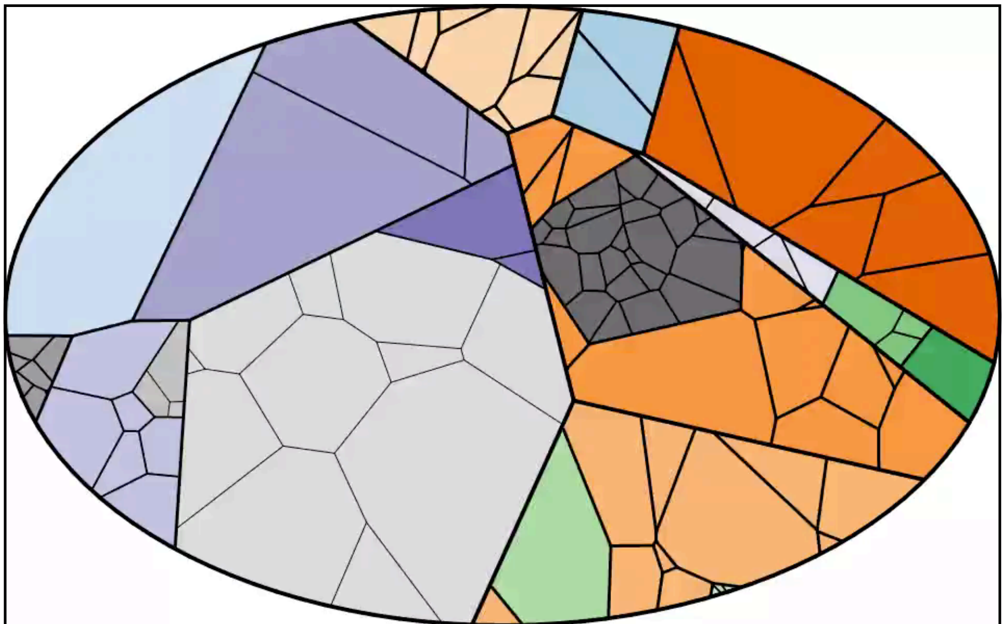
Voronoi Treemaps [Balzer 05]

Treemaps with arbitrary polygonal shape and boundary

Uses iterative, eighted Voronoi tessellations to achieve cells with value-proportional areas



78



Iterative Voronoi Tesselations [Jason Davies]

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Layered Diagrams

Signify tree structure using

Layering

Adjacency

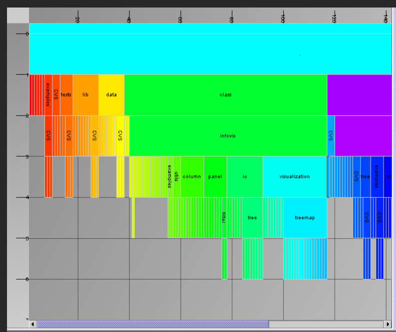
Alignment

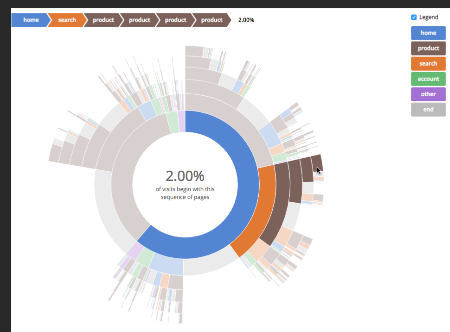
Involves recursive sub-division of space

Can apply the same set of approaches as in node-link layout

80

Icicle and Sunburst Trees





Higher-level nodes get a larger layer area, whether that is horizontal or angular extent

Child levels are layered, constrained to parent’s extent

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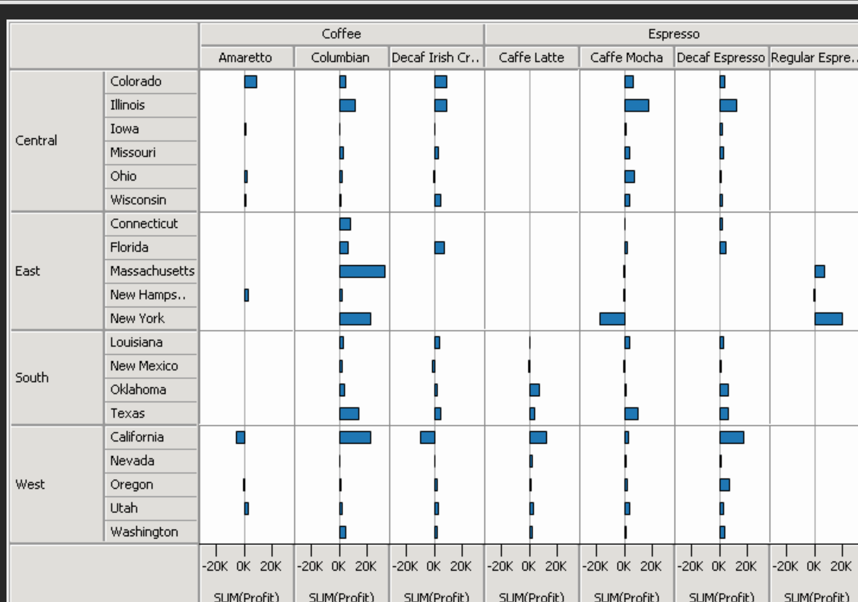
Layered Tree Drawing



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Node-Link Graph Layout

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Spanning Tree Layout

Many graphs are tree-like or have useful spanning trees

- Websites, Social Networks

Use tree layout on spanning tree of graph

- Trees created by BFS / DFS
- Min/max spanning trees

Fast tree layouts allow graph layouts to be recalculated at interactive rates

Heuristics may further improve layout

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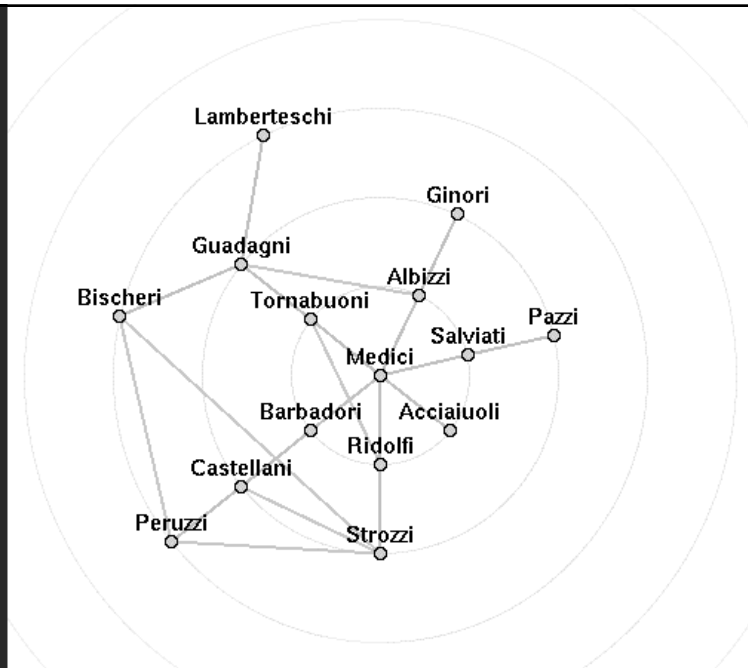

Spanning tree layout may result in arbitrary parent node

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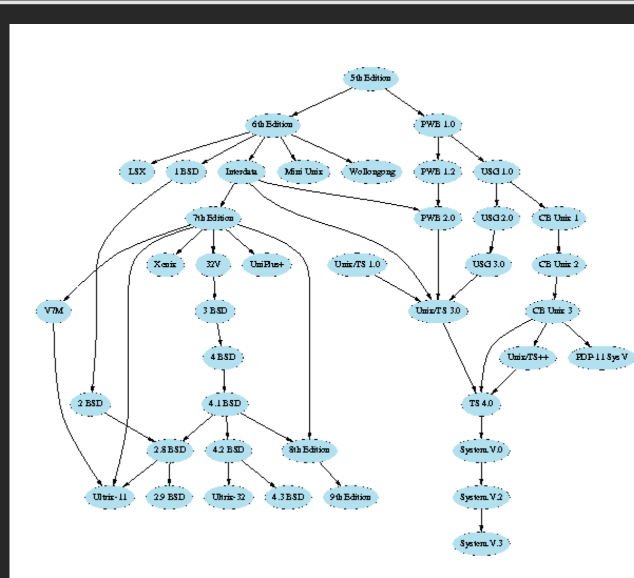
Sugiyama-style graph layout

Evolution of the UNIX operating system

Hierarchical layering based on descent



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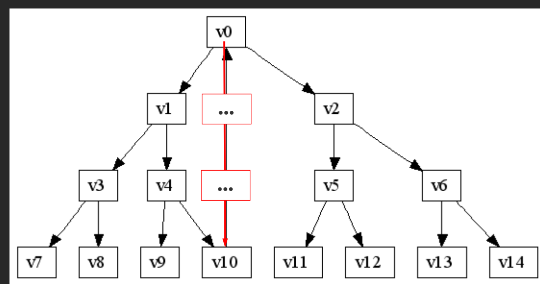
Sugiyama-style graph layout

Layer 1
Layer 2
Layer 3
Layer 4



Reverse some edges to remove cycles
Assign nodes to hierarchy layers → Longest path layering
    Create dummy nodes to "fill in" missing layers
Arrange nodes within layer, minimize edge crossings
    Route edges – layout splines if needed

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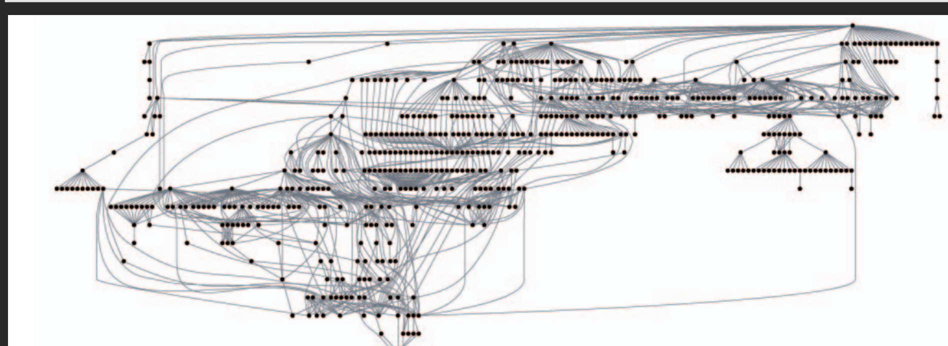
Produces hierarchical layout



Sugiyama-style layout emphasizes hierarchy

However, cycles in the graph may mislead.
Long edges can impede perception of proximity.

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Hierarchical Edge Bundles

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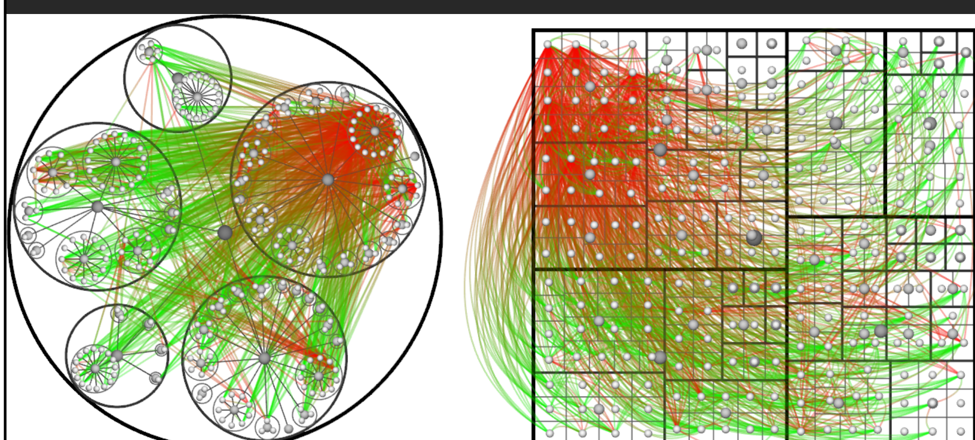
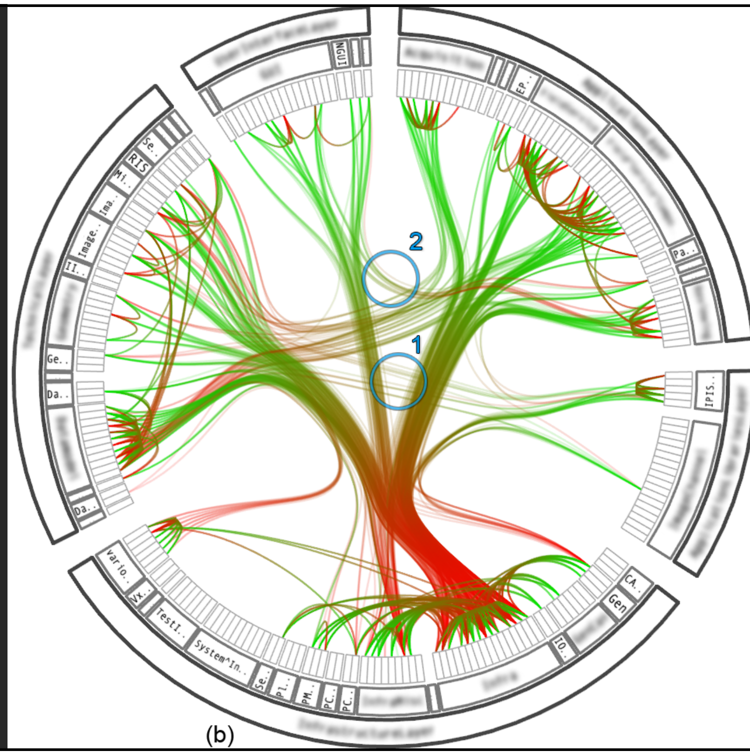
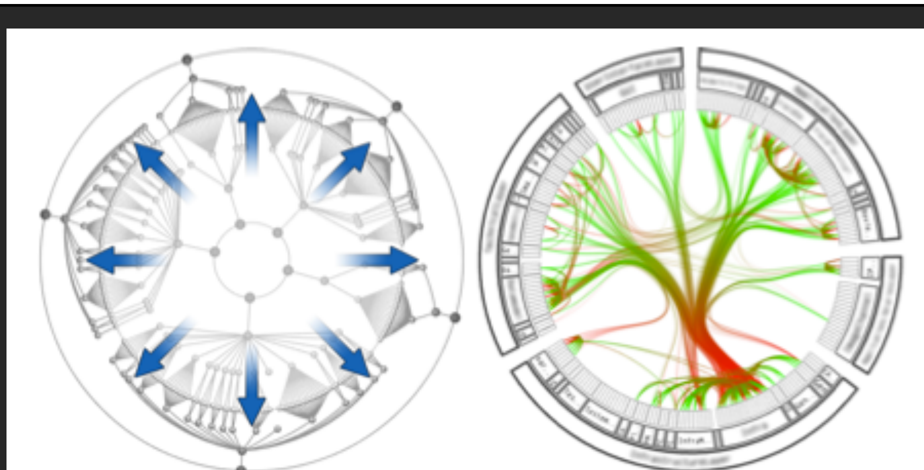
Trees with Adjacency Relations


(a) (b)

93



94



Use radial tree layout for inner circle
Mirror to outside
Replace inner tree with hierarchical edge bundles

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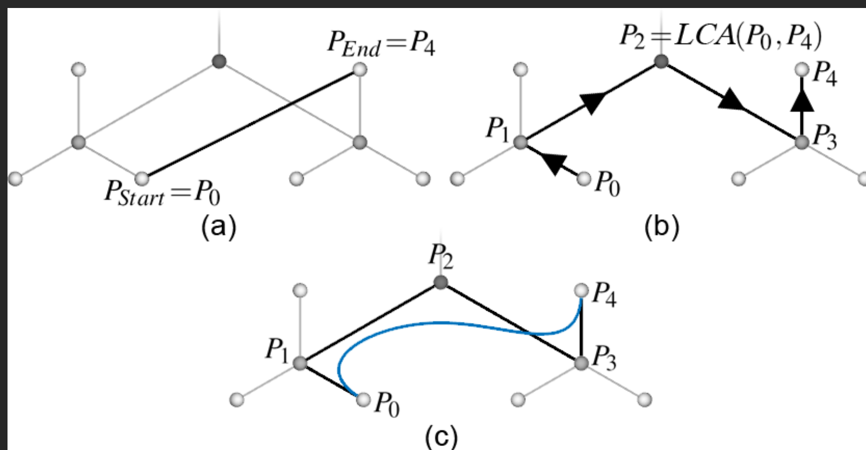
Bundle Edges along Hierarchy



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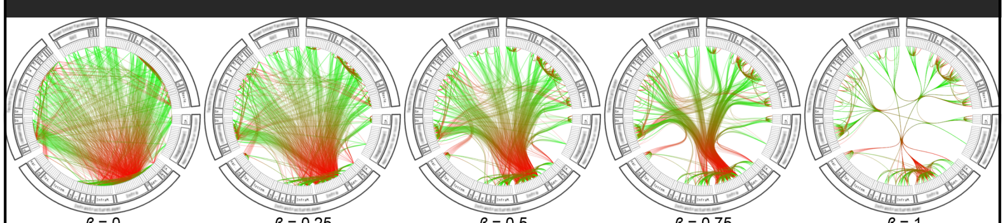
Increasing Edge Tension



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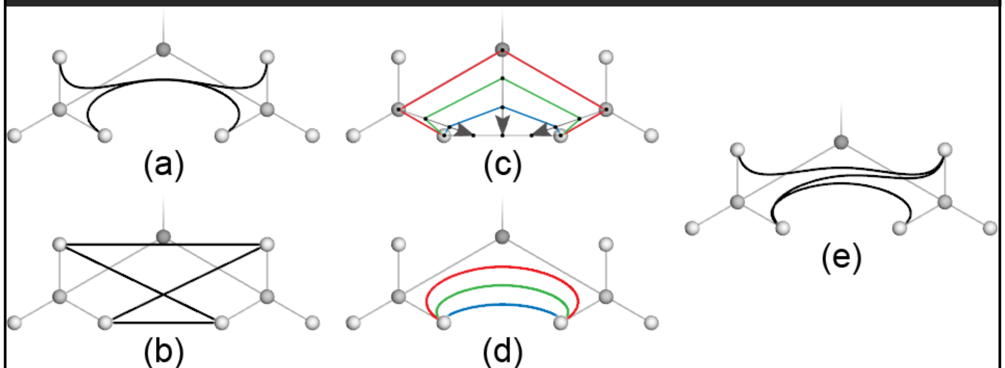
Configuring Edge Tension



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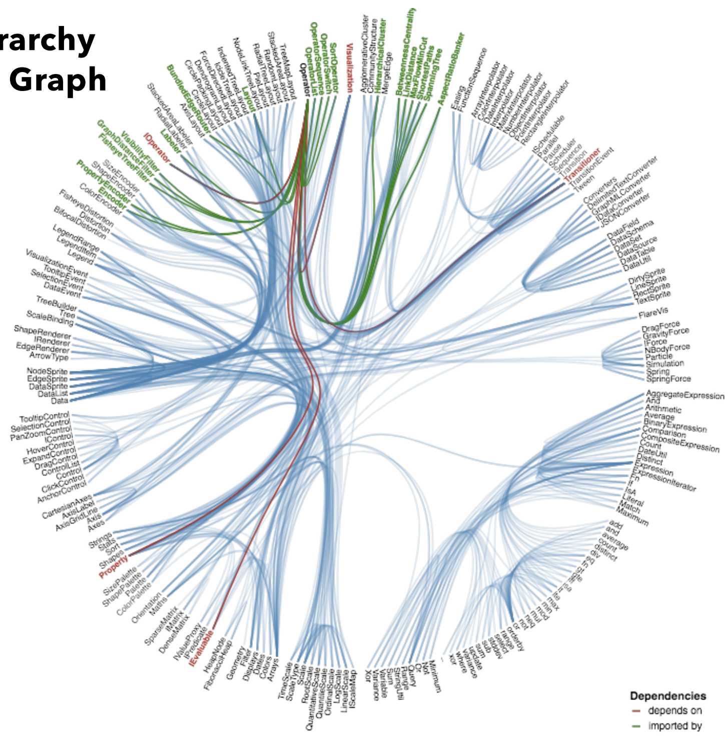
Flare Class Hierarchy & Dependency Graph



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Force-Directed Layout

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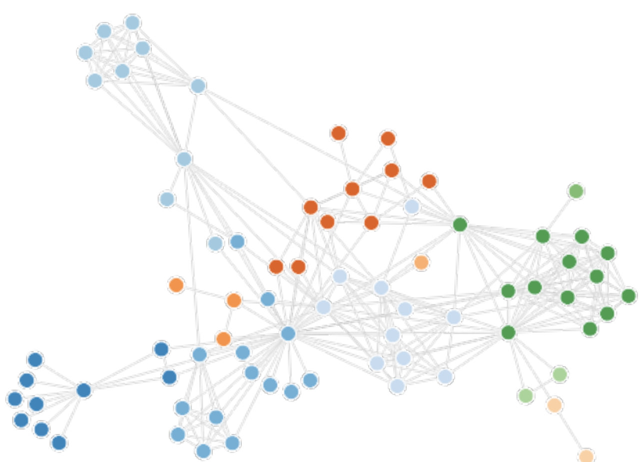

Interactive Example: Configurable Force Layout

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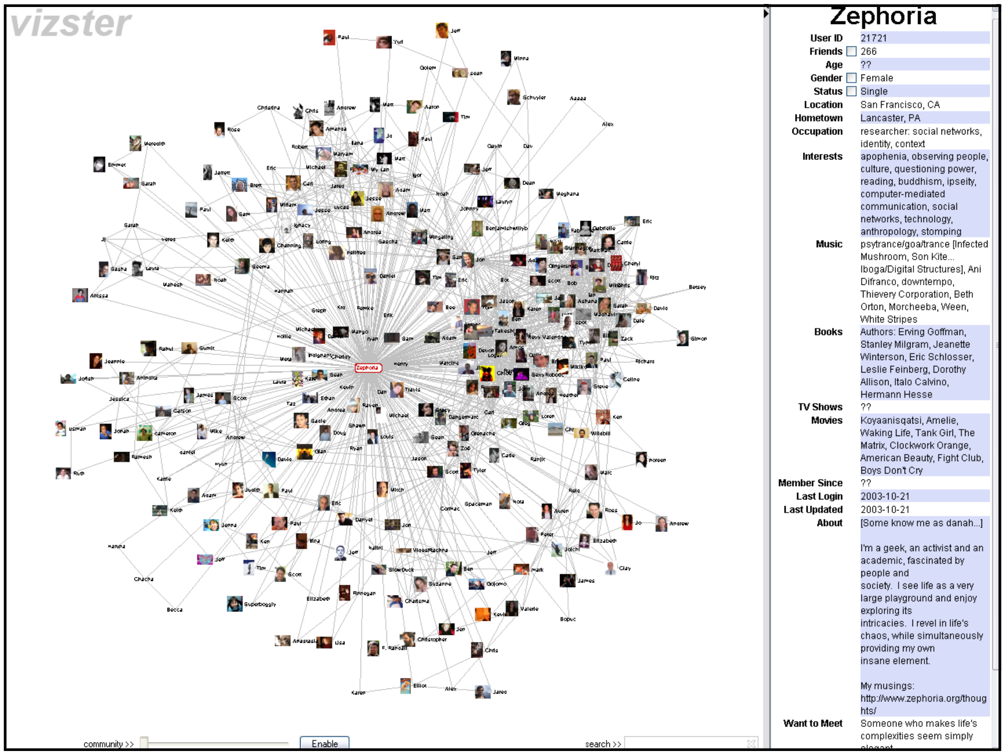

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Use the Force!

http://mbostock.github.io/d3/talk/20110921/

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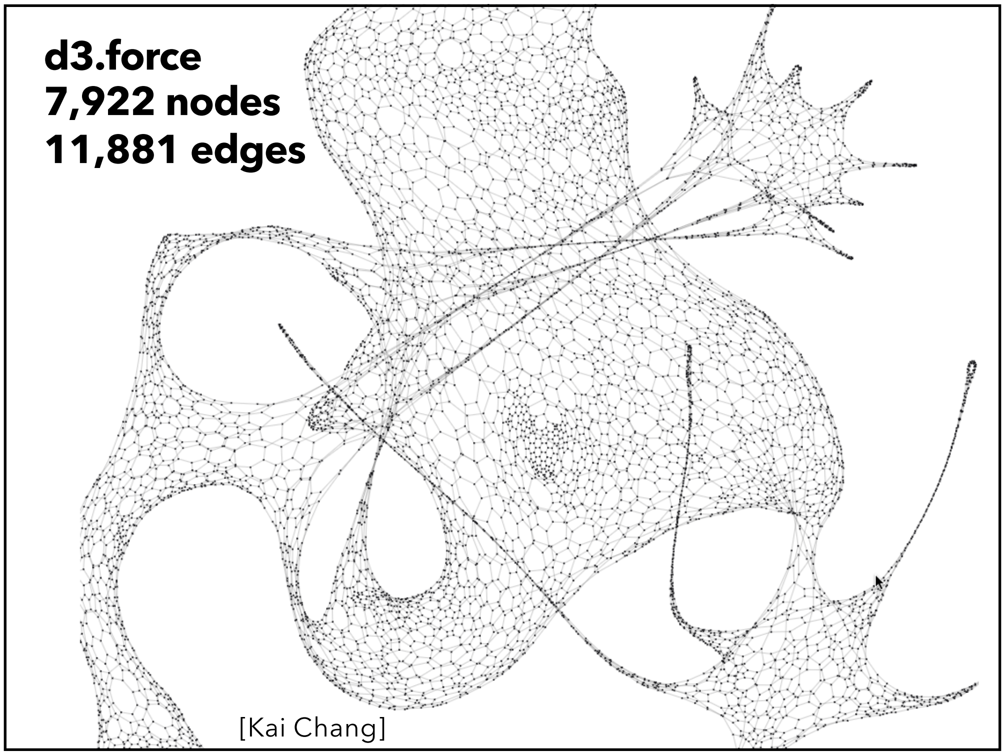

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Force-Directed Layout

Nodes = charged particles with air resistance — $F = q_i * q_j / d_{ij}^2$, $F = -b * v_i$

Edges = springs — $F = k * (L - d_{ij})$

D3's force layout uses velocity Verlet integration

- Assume uniform mass *m* and timestep *Δt*:
- $F = ma \rightarrow F = a \rightarrow F = \Delta v / \Delta t \rightarrow F = \Delta v$
- *Forces simplify to velocity offsets!*

Repeatedly calculate forces, update node positions

- Naïve approach $O(N^2)$
- Speed up to $O(N \log N)$ using quadtree or k-d tree
- Numerical integration of forces at each time step

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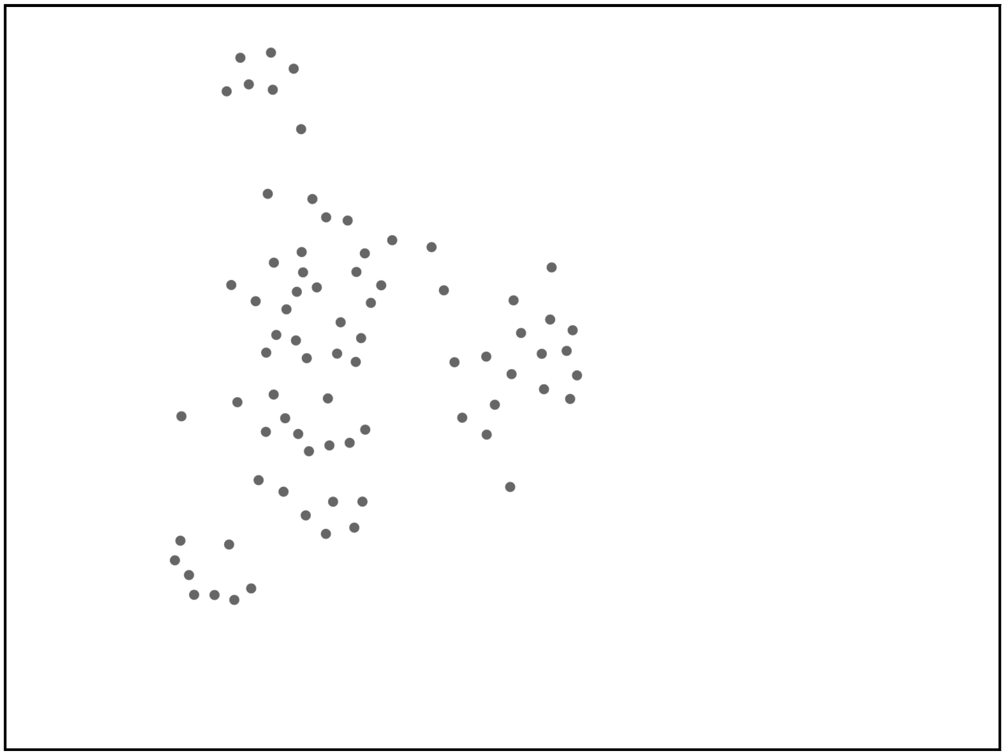
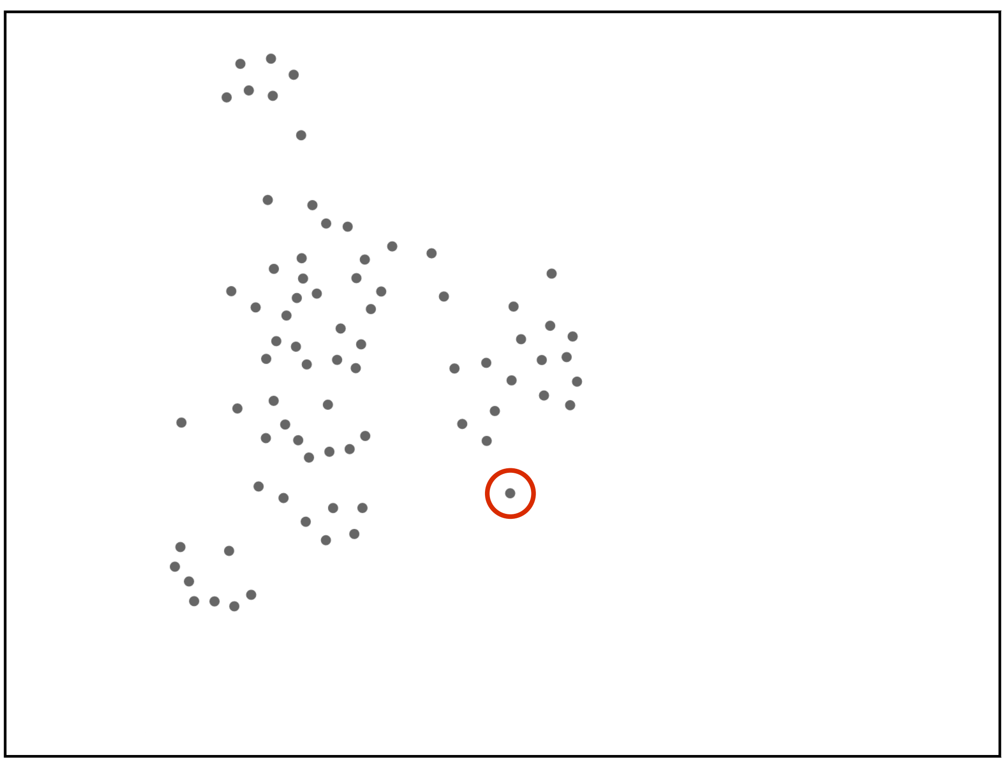
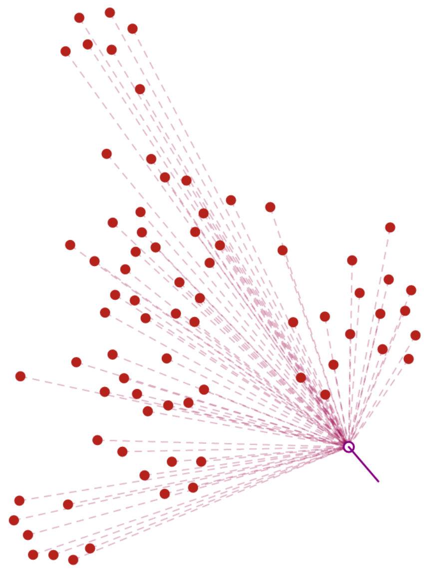


106



107



Naive calculation of forces at a point uses sum of forces from all other n-1 points.

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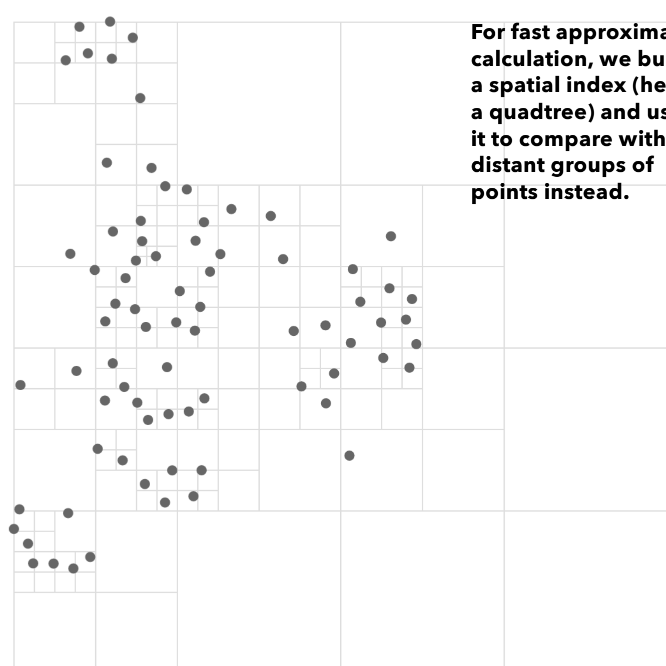

For fast approximate calculation, we build a spatial index (here, a quadtree) and use it to compare with distant groups of points instead.

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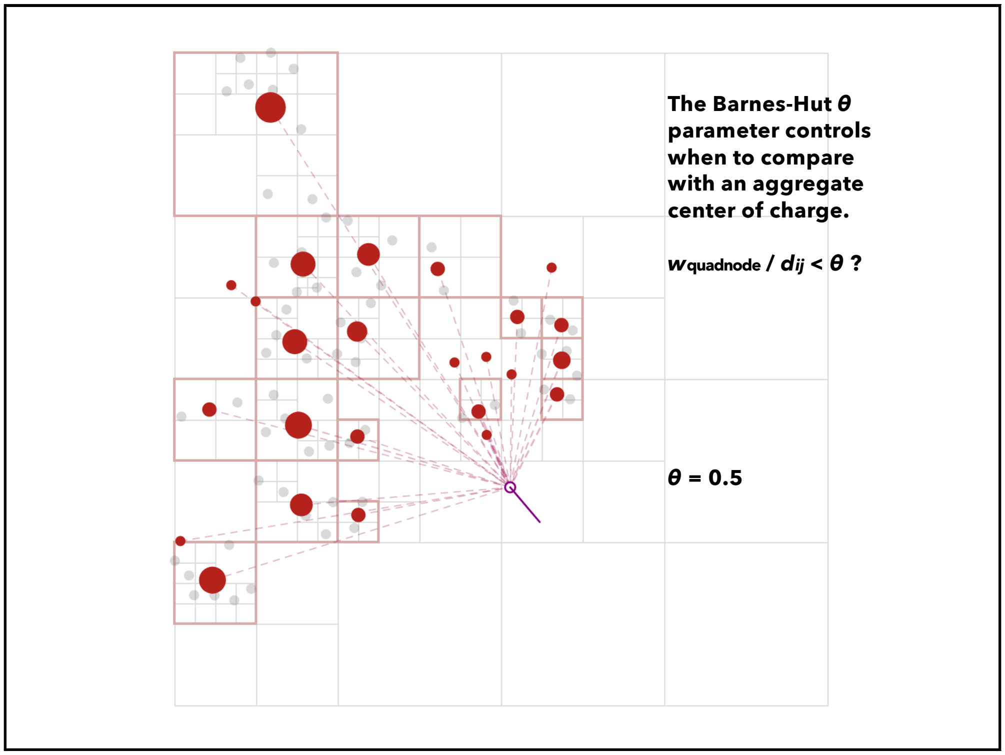
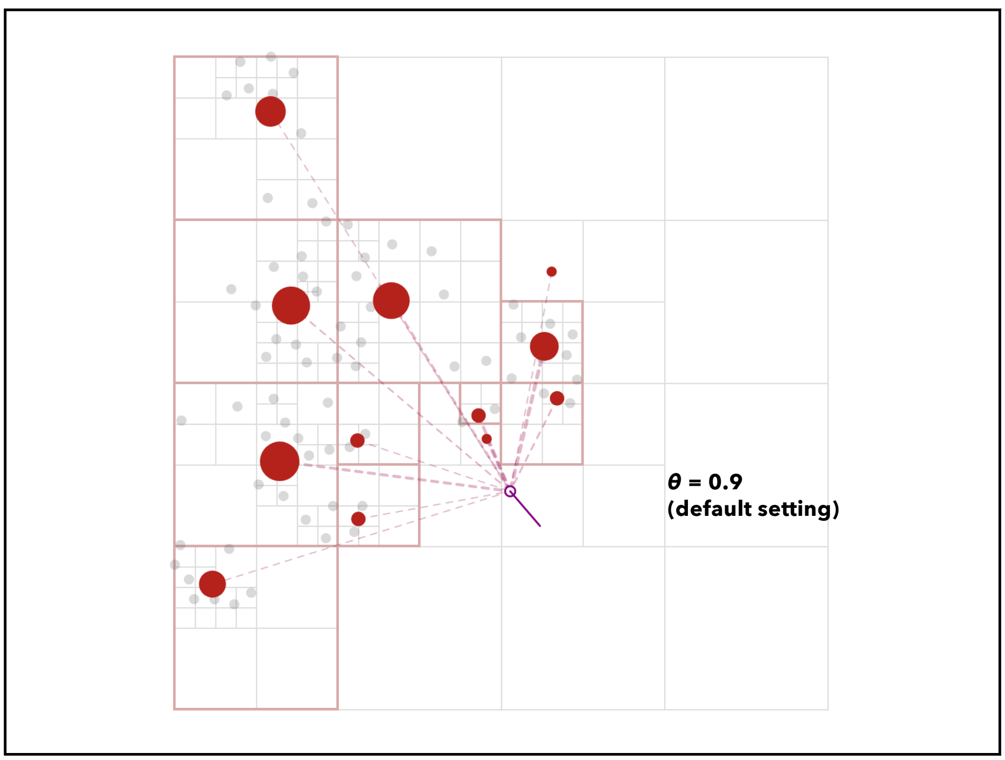
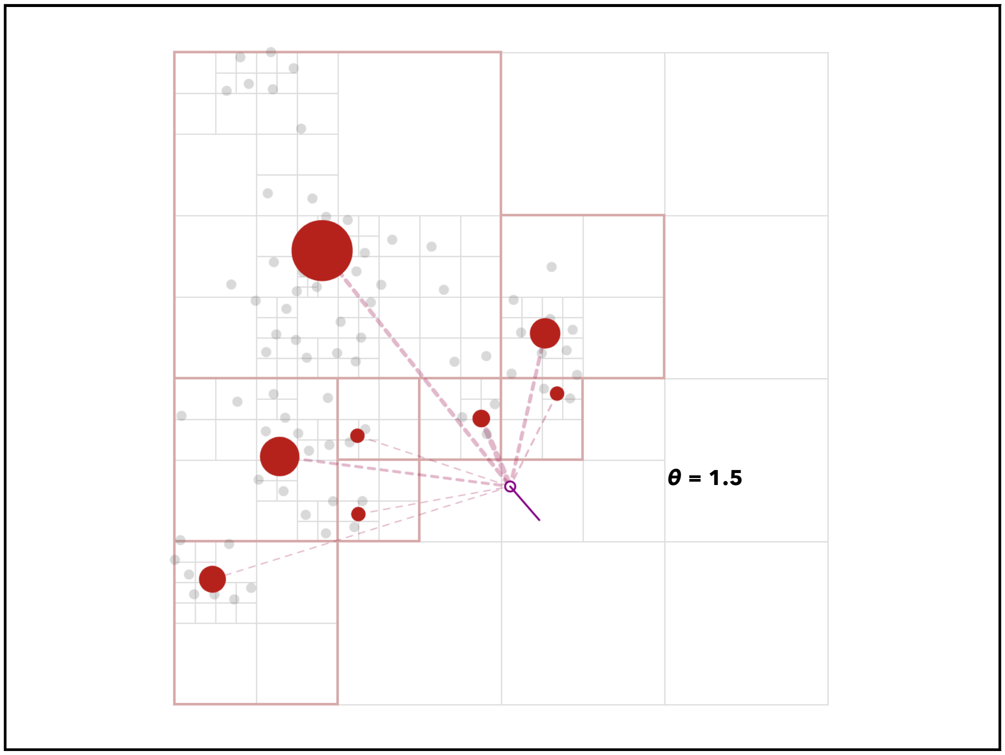

The Barnes-Hut θ parameter controls when to compare with an aggregate center of charge.
$w_{quadnode} / d_{ij} < \theta$?
θ = 0.5

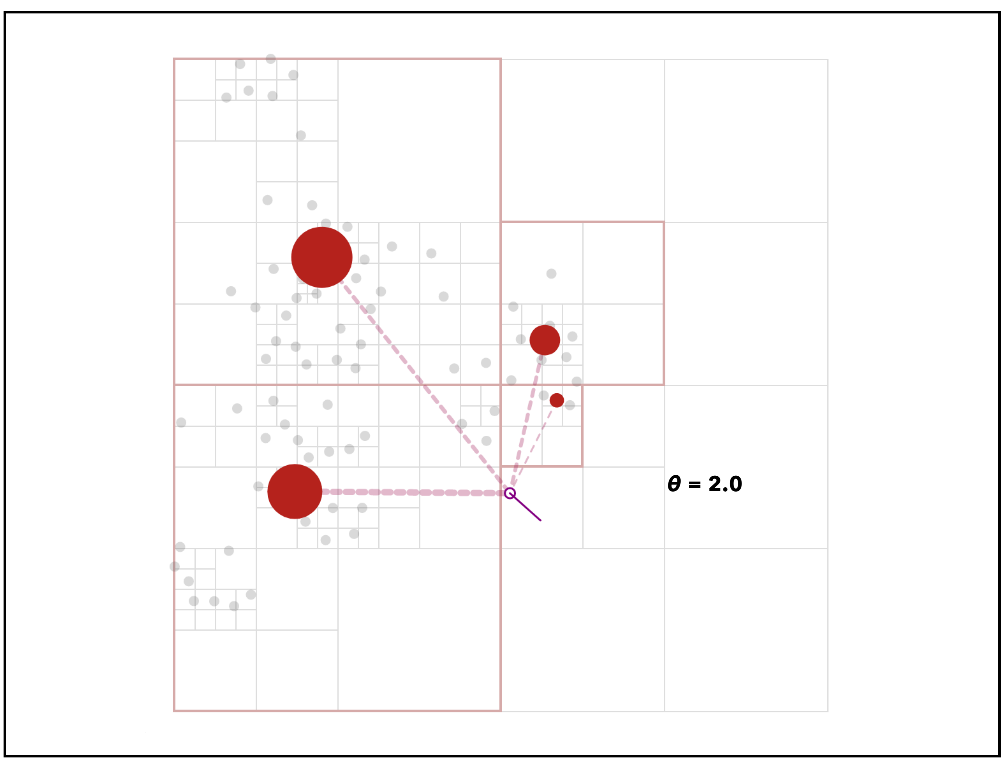
110


θ = 0.9
(default setting)

111



112



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