Network Layout

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CS 448B: Visualization
Fall 2020

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Last Time: Animation

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Implementing Animation

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Animation Approaches

Frame-based Animation

Redraw scene at regular interval (e.g., 16ms)
Developer defines the redraw function

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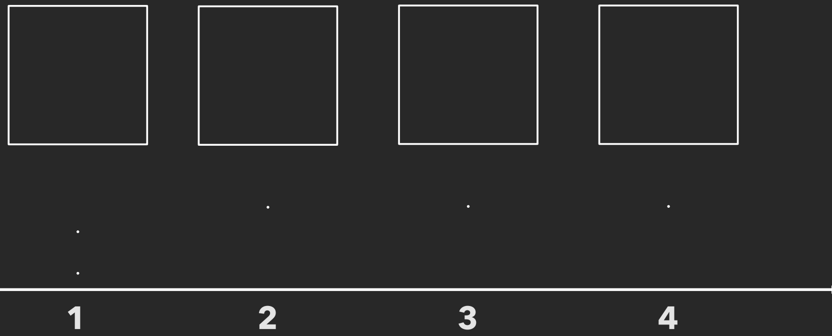
Frame-based Animation



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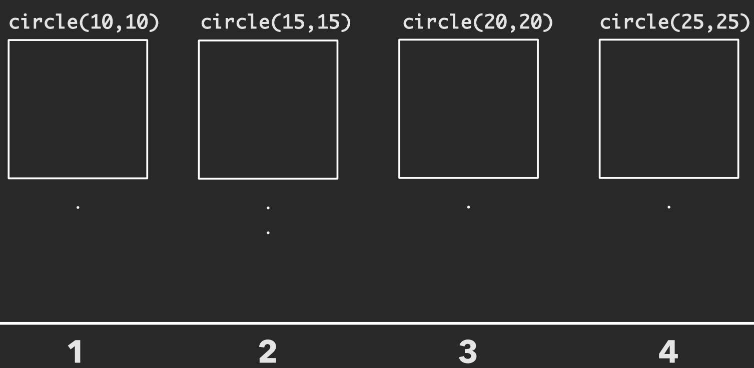

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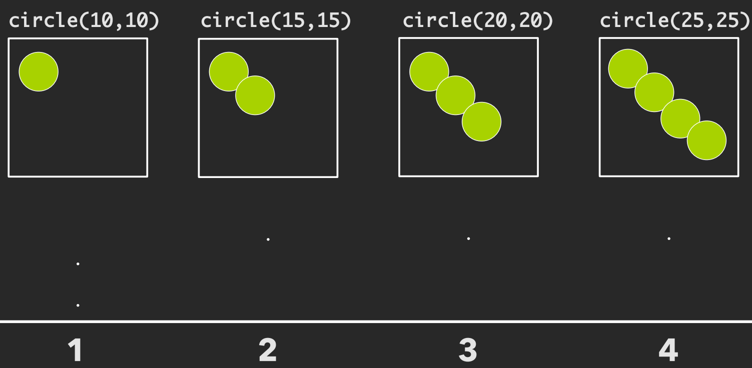

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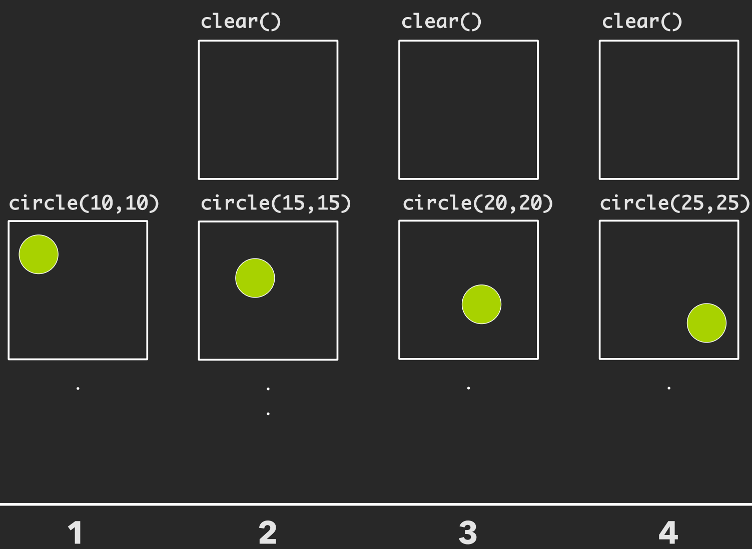

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Transition-based Animation (Hudson & Stasko '93)

Specify property value, duration & easing (tweening)
Typically computed via interpolation

step(*fraction*) { $x_{now} = x_{start} + fraction * (x_{end} - x_{start})$; }

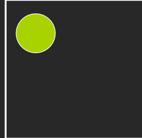
Timing & redraw managed by UI toolkit

Transition-based Animation

from: **(10,10)** to: **(25,25)** duration: **3sec**

dx=25-10

x=10+(t/3)*dx



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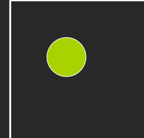

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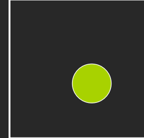

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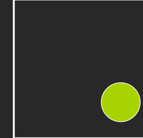

0s **1s** **2s** **3s**

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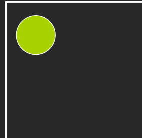
Transition-based Animation

from: **(10,10)** to: **(25,25)** duration: **3sec**
Toolkit handles frame-by-frame updates

dx=25-10

x=10+(t/3)*dx



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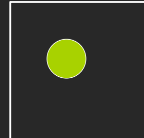

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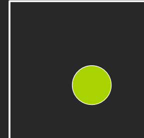

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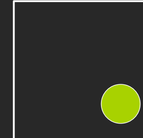

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D3 Transitions

Any d3 *selection* can be used to drive animation.

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```
// Select SVG rectangles and bind them to data values.
var bars = svg.selectAll("rect.bars").data(values);
```

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D3 Transitions

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```
// Select SVG rectangles and bind them to data values.
var bars = svg.selectAll("rect.bars").data(values);
// Static transition: update position and color of bars.
bars
  .attr("x", (d) => xScale(d.foo))
  .attr("y", (d) => yScale(d.bar))
  .style("fill", (d) => colorScale(d.baz));
```

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D3 Transitions

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// Select SVG rectangles and bind them to data values.
var bars = svg.selectAll("rect.bars").data(values);
// Animated transition: interpolate to target values using default timing
bars.transition()
  .attr("x", (d) => xScale(d.foo))
  .attr("y", (d) => yScale(d.bar))
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   .style("fill", (d) => colorScale(d.baz));

   // Animation is implicitly queued to run!
```

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D3 Transitions, Continued

```
bars.transition()
   .duration(500)              // animation duration in ms
   .delay(0)                   // onset delay in ms
   .ease(d3.easeBounce)  // set easing (or "pacing") style
   .attr("x", (d) => xScale(d.foo))
   …
```

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D3 Transitions, Continued

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bars.transition()
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   .ease(d3.easeBounce)        // set easing (or "pacing") style
   .attr("x", (d) => xScale(d.foo))
   ...

bars.exit().transition()  // animate elements leaving display
  .style("opacity", 0)    // fade out to fully transparent
  .remove();              // remove from DOM upon completion
```

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Easing Functions

Goals: **stylize animation, improve perception.**

Basic idea is to warp time: as *duration* goes from start (0%) to end (100%), dynamically adjust the *interpolation fraction* using an easing function**.**

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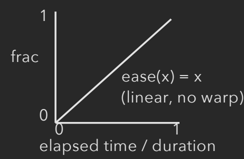

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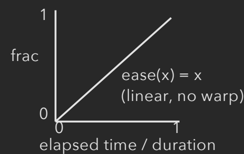

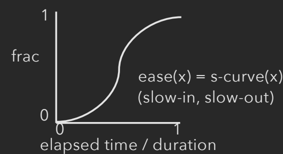

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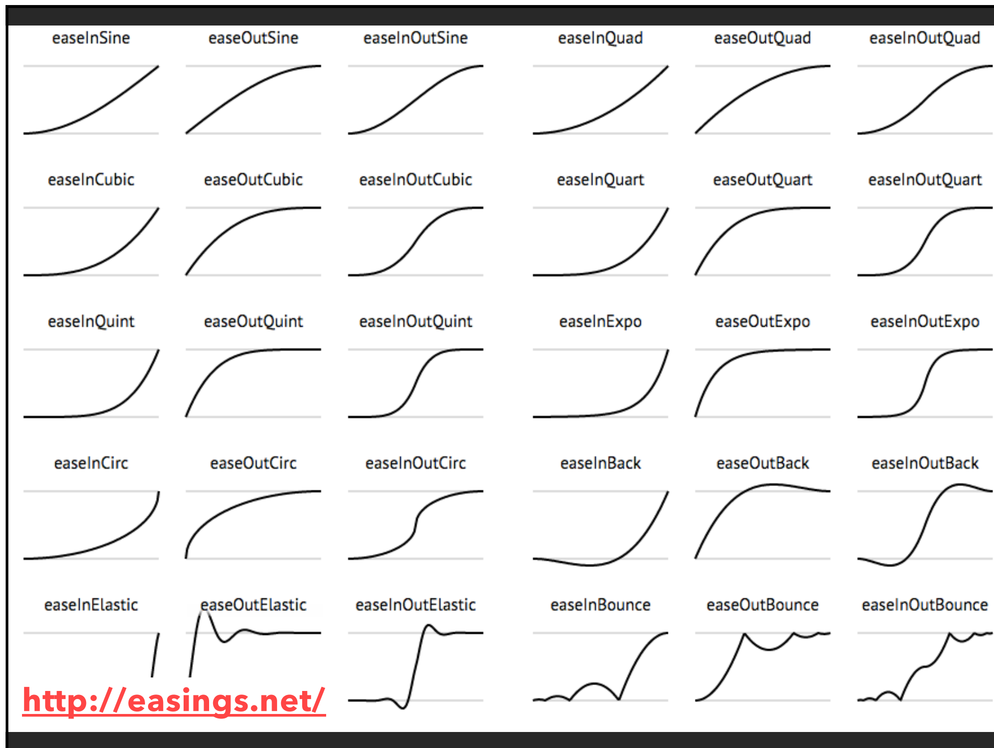

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Summary

Animation is a salient visual phenomenon
Attention, object constancy, causality, timing

Design with care: congruence & apprehension

For processes, static images may be preferable
For transitions, animation has some benefits, but consider task and timing

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Announcements

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Final project

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

Deliverables
- **Data analysis/explainer**: Article with multiple interactive visualizations
- **Research**: Implementation of solution and web-based demo if possible
- **Short video (2 min)** demoing and explaining the project

Schedule
- Project proposal: Thu 10/29
- Design Review and Feedback: Tue 11/17 & Thu 11/19
- Final code and video: Sat 11/21 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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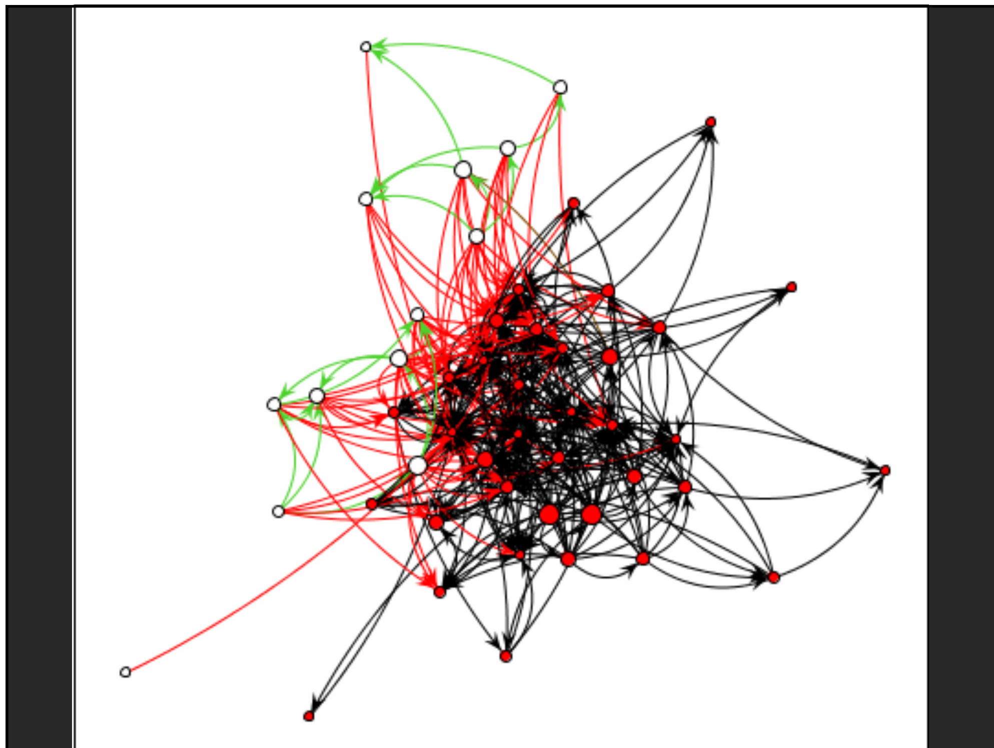

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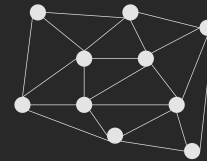
Graphs and Trees

Graphs

Model relations among data

Nodes and edges

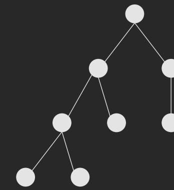


Trees

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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Topics

Tree Layout
Node-Link Graph Layout
- Sugiyama-Style Layout
- Force-Directed Layout

Alternatives to Node-Link Graph Layout
- Matrix Diagrams
- Attribute-Drive Layout

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Tree Layout

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Tree Visualization

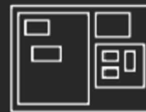
Indentation

- 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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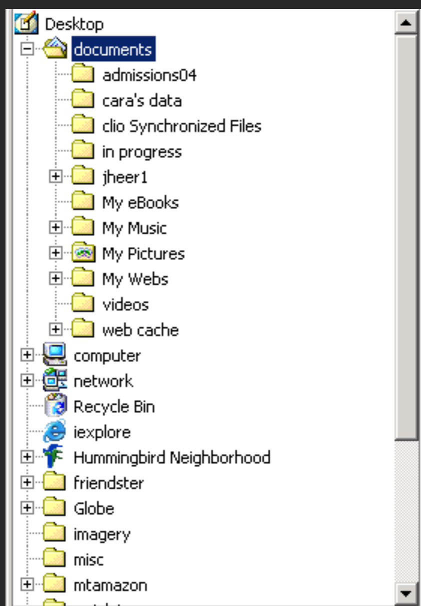
Indentation



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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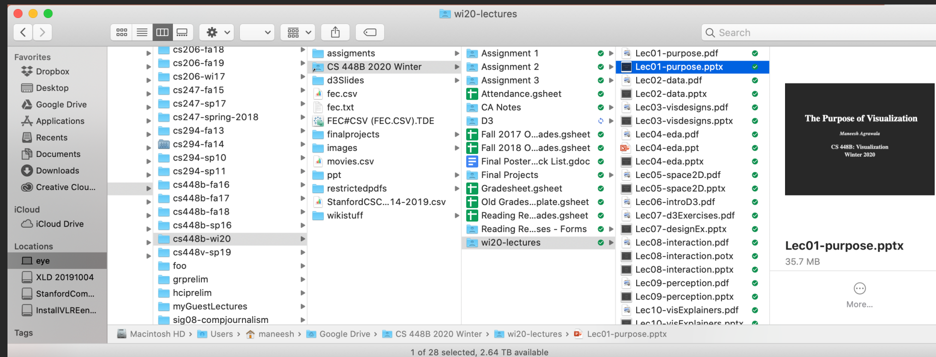
Single-Focus (Accordion) List



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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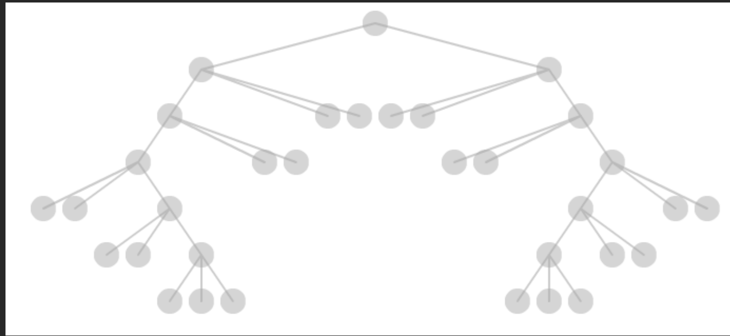
Basic Recursive Approach

Repeatedly divide space for subtrees by leaf count

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



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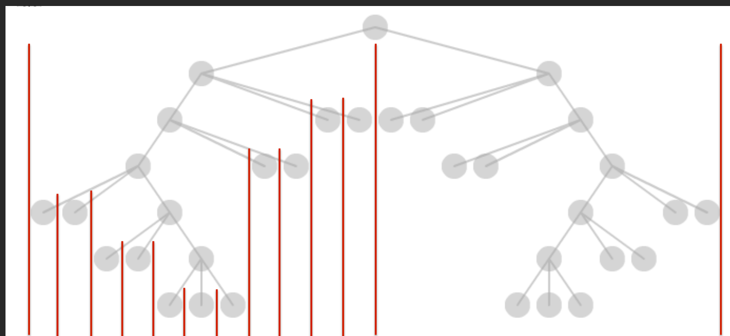

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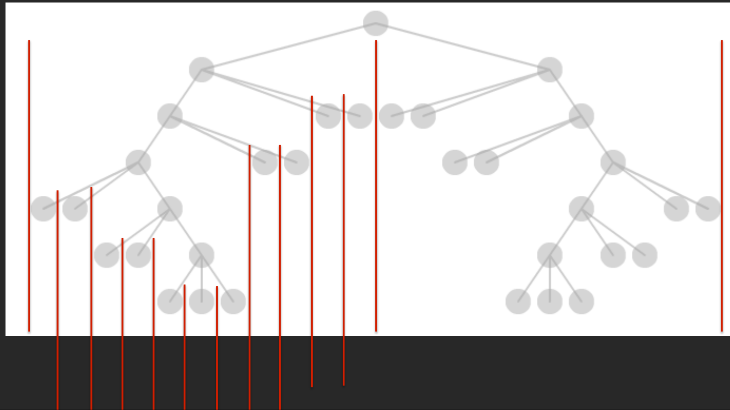
Problem: Exponential growth of breadth



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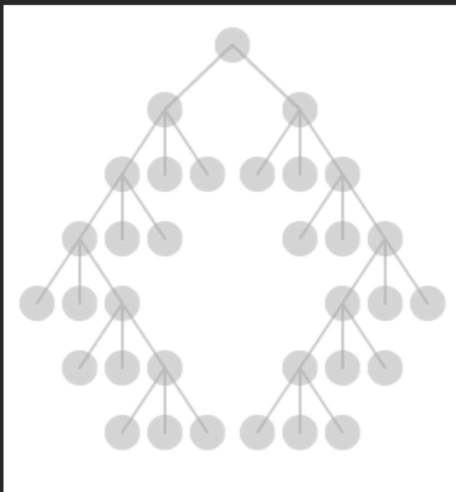
Reingold & Tilford' s Tidier Layout



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)*

Reingold-Tilford Algorithm

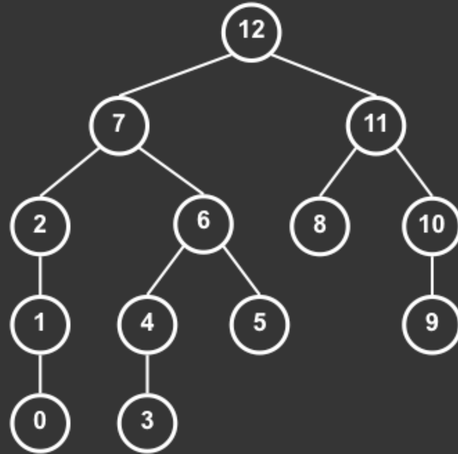
Linear algorithm – starts with bottom-up (postorder) pass
Set Y-coord by depth, arbitrary starting X-coord
Merge left and right subtrees

- 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

Reingold-Tilford Algorithm



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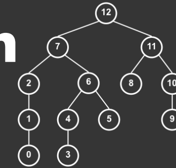

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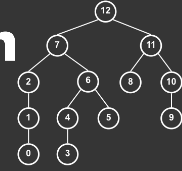

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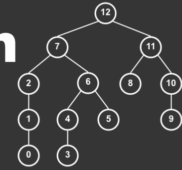

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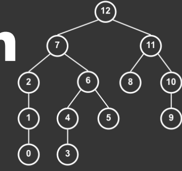

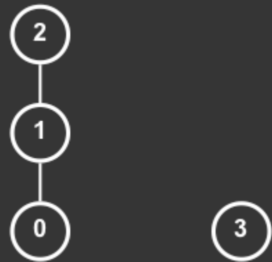

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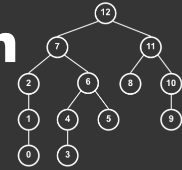

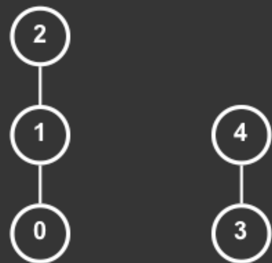

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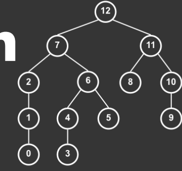

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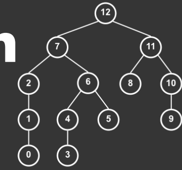

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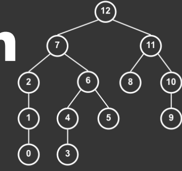

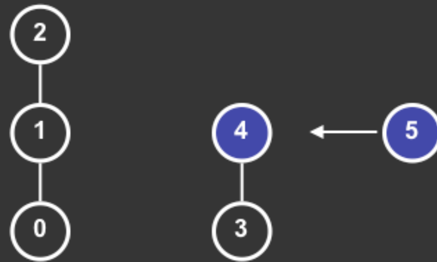

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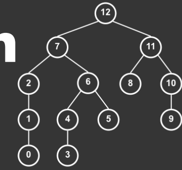

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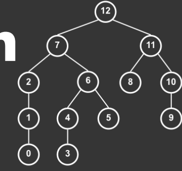

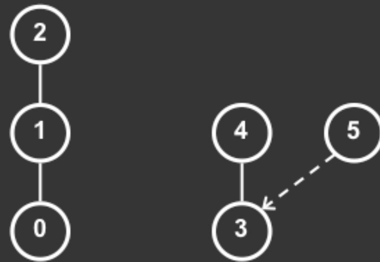

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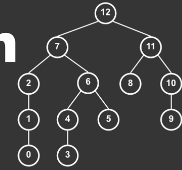

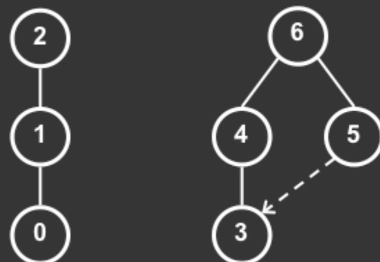

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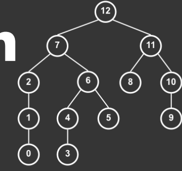
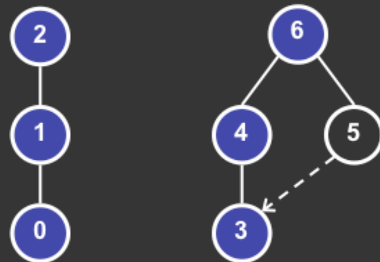
Reingold-Tilford Algorithm





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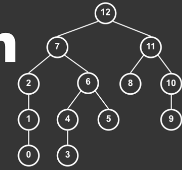

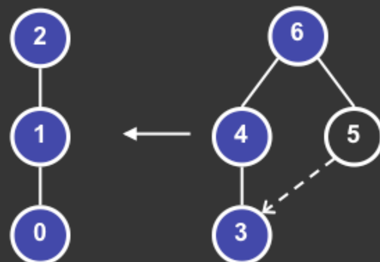

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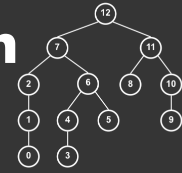

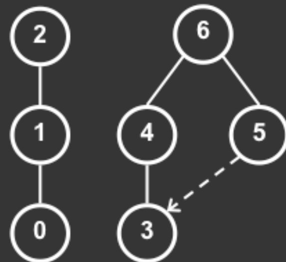

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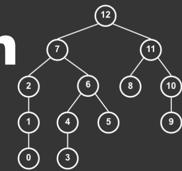

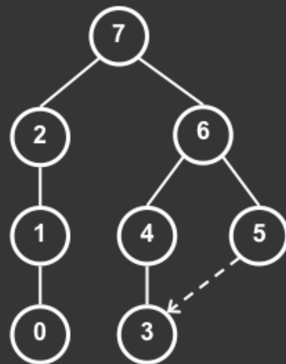

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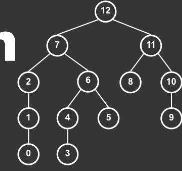

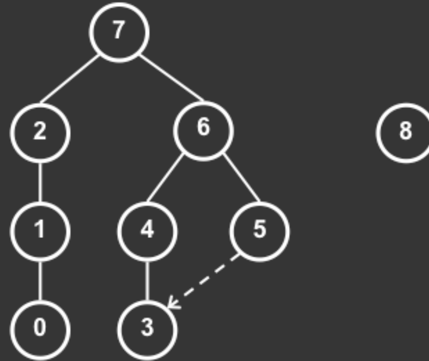

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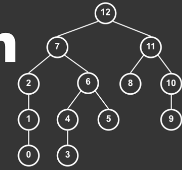

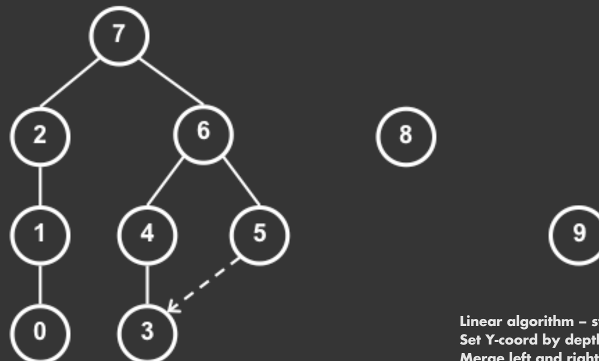

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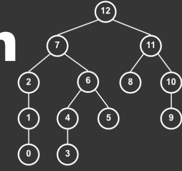

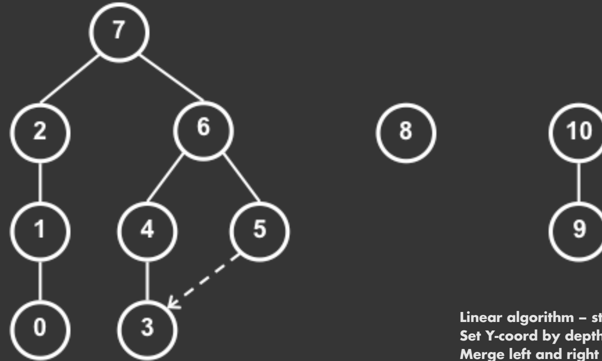

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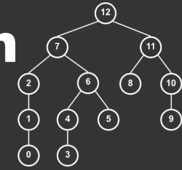

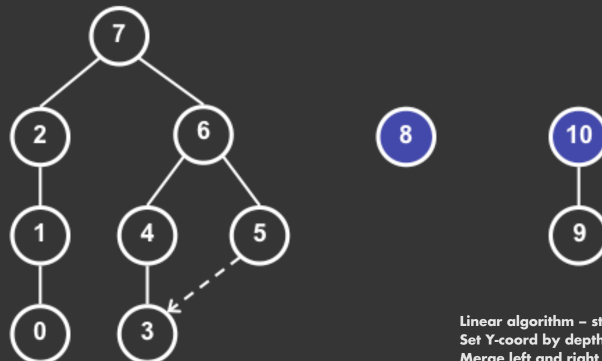

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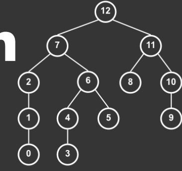

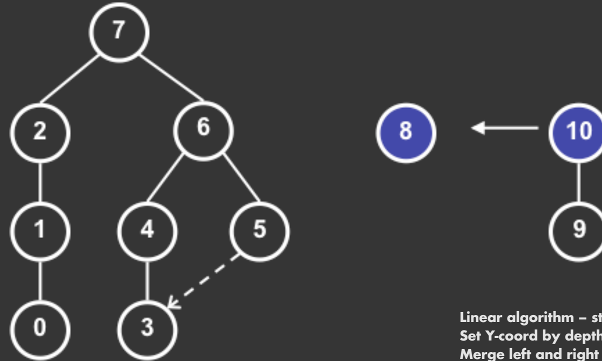

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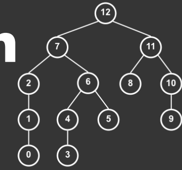

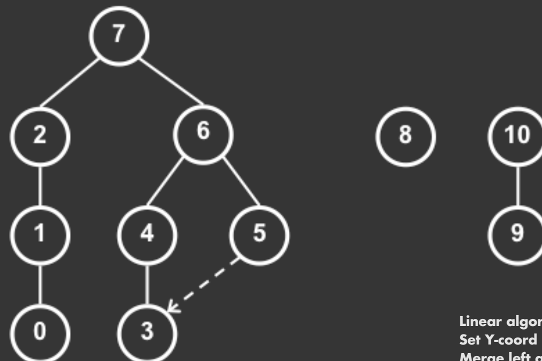

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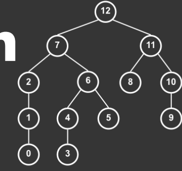

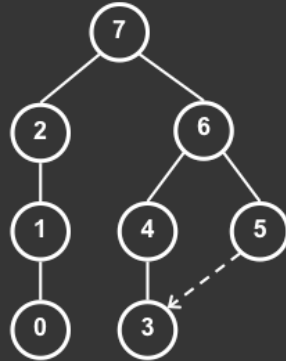

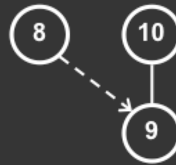

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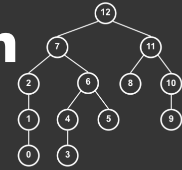

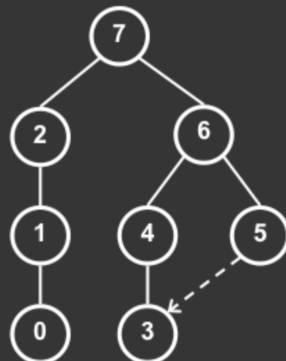

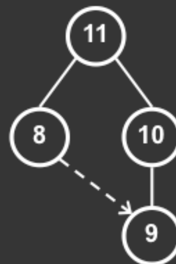

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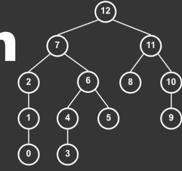

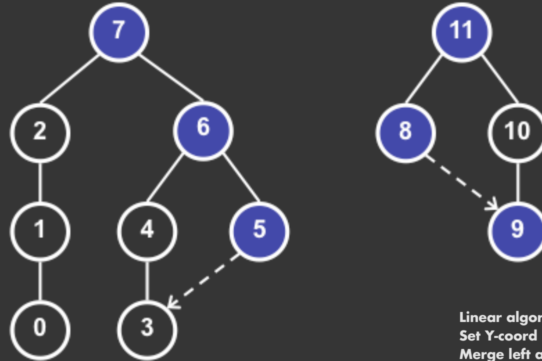

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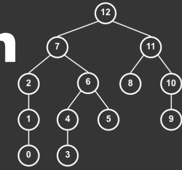

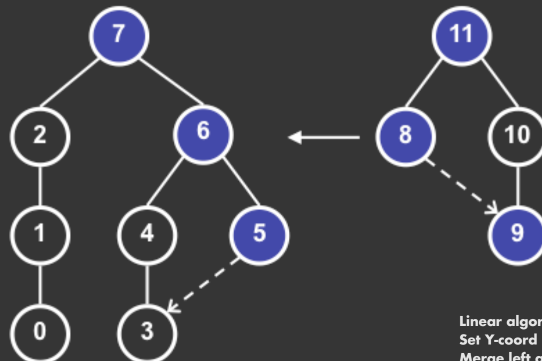

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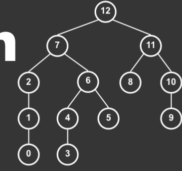

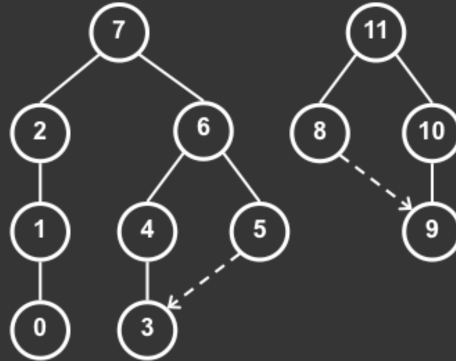

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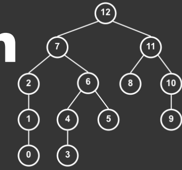

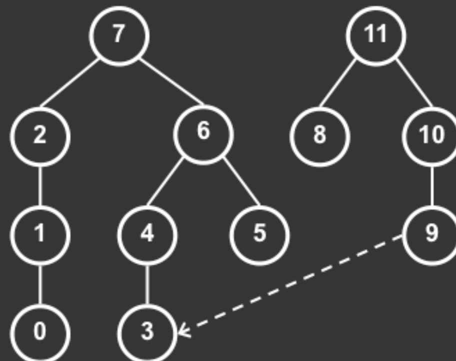

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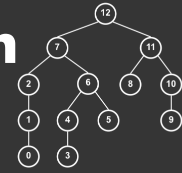

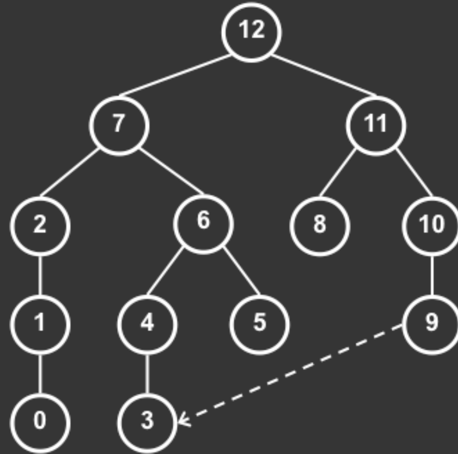

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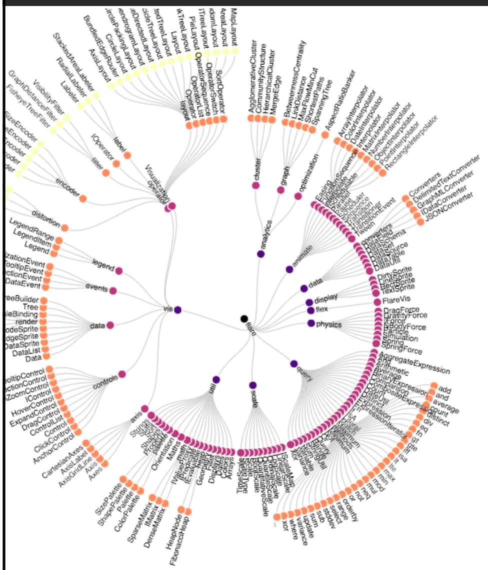
Radial Layout



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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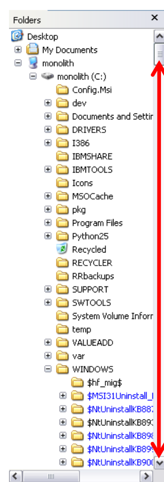
Visualizing Large Hierarchies



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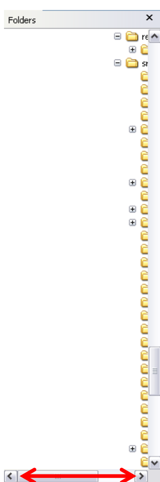

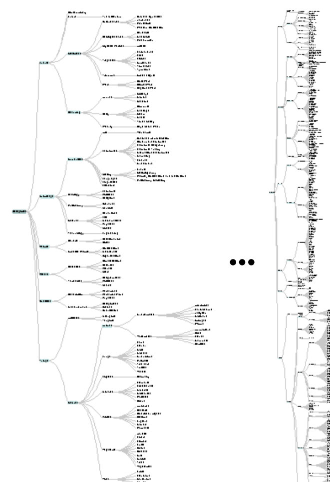

… …

Indented Layout

Reingold-Tilford Layout

83

MC Escher, *Circle Limit IV*

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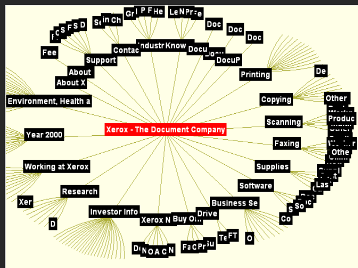
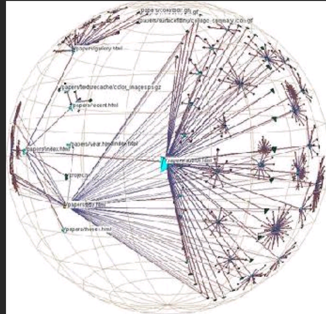
Hyperbolic Layout





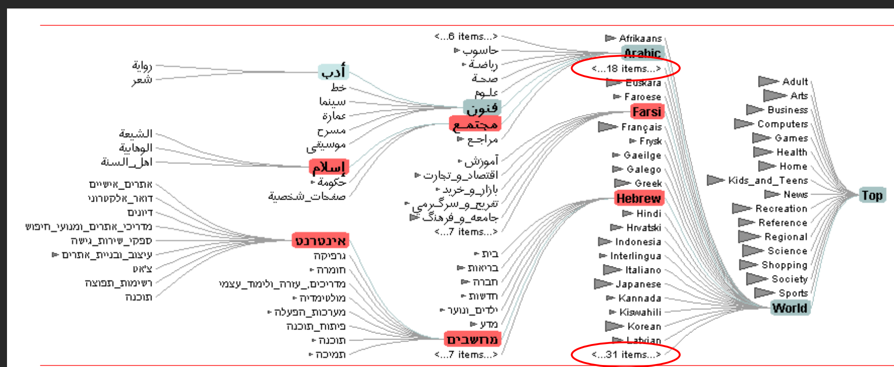
Layout in hyperbolic space, then project on to Euclidean plane

Why? Like tree breadth, the hyperbolic plane expands exponentially

Also computable in 3D, projected into a sphere

85

Degree-of-Interest Trees [AVI 04]

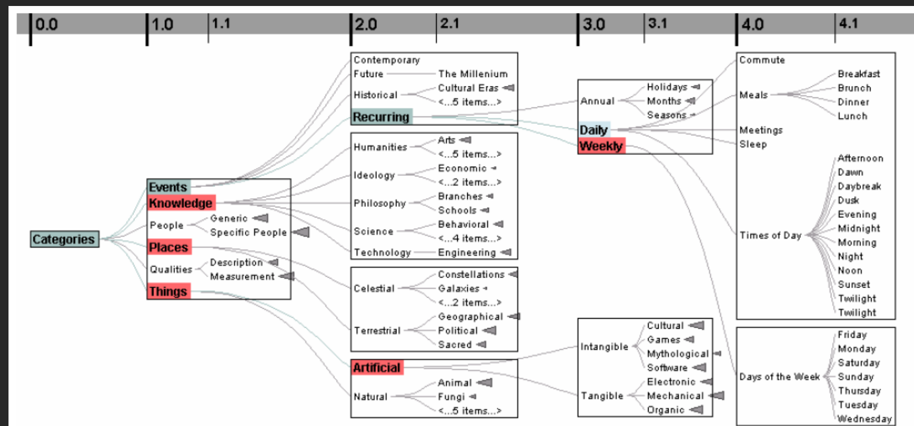


Space-constrained, multi-focal tree layout

https://www.youtube.com/watch?v=RTQ0N4QY0vc
https://observablehq.com/@d3/collapsible-tree

86

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=RTQ0N4QY0vc
https://observablehq.com/@d3/collapsible-tree

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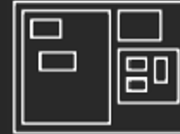
Enclosure Diagrams

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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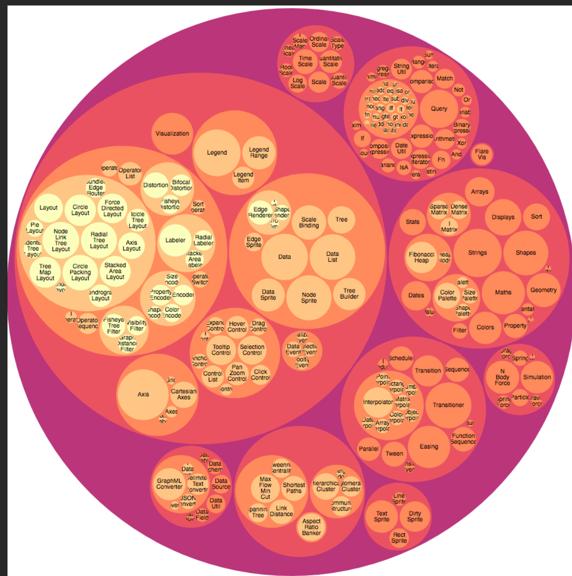
Circle Packing Layout



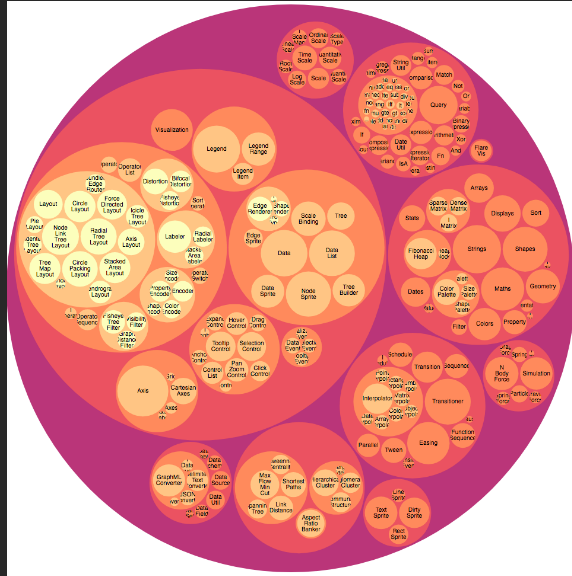
Nodes represented as sized circles

Nesting to show parent-child relationships

Problems:

89

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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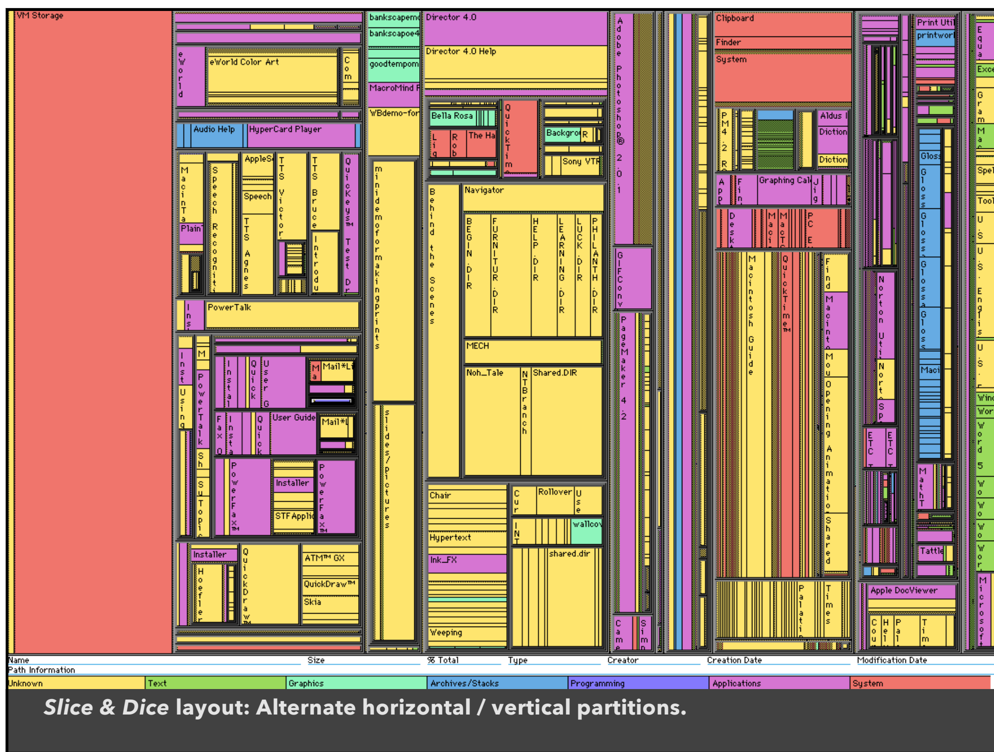

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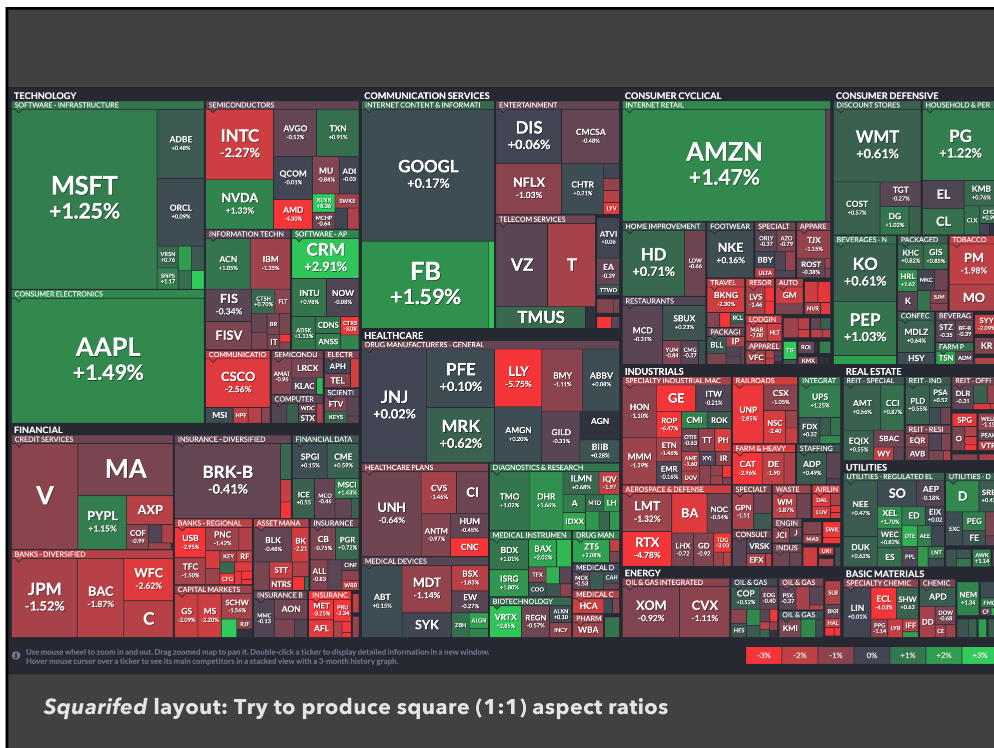

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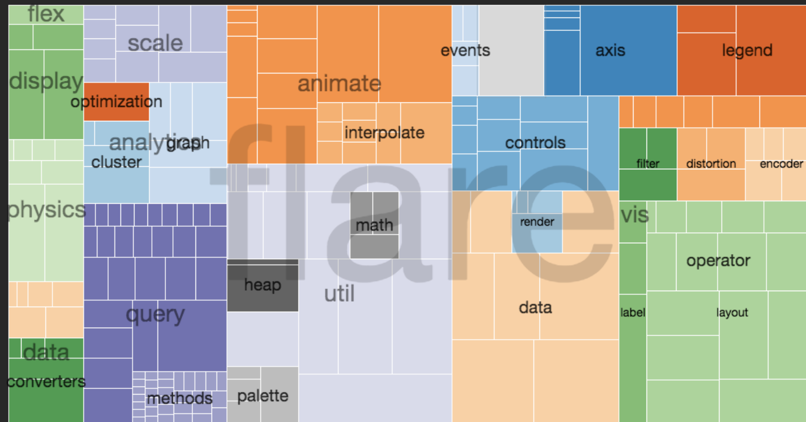
Squarified Treemaps [Bruls 00]

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



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

95

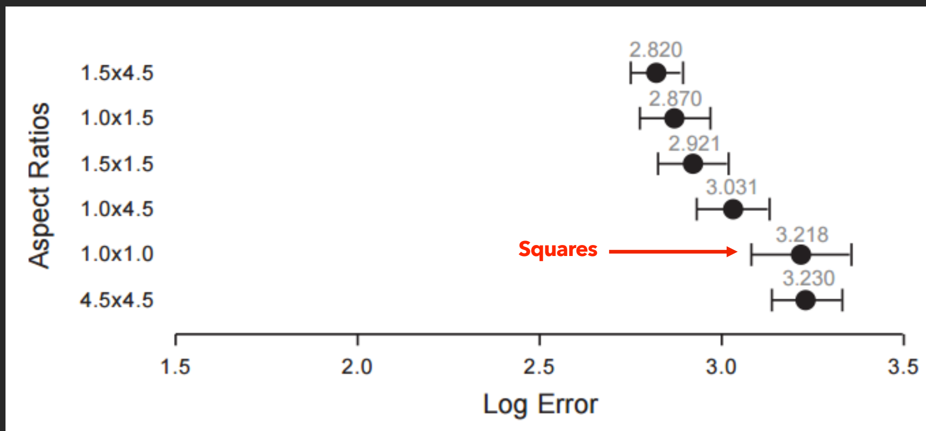
Why Squares

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?

96

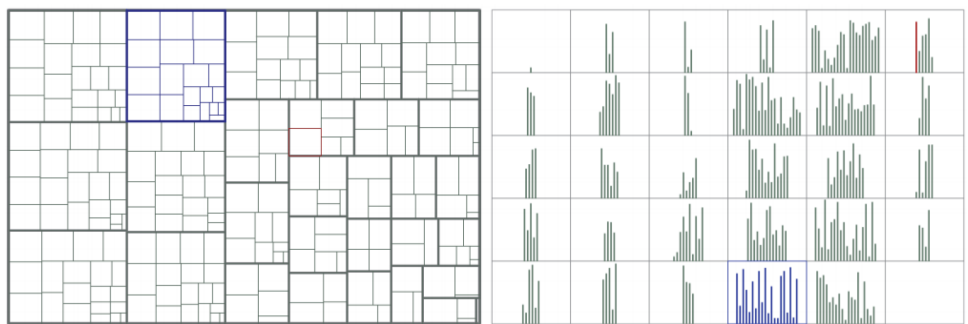
Error vs. Aspect Ratio [Kong 10]



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

97

Treemaps vs. Bar Charts [Kong 10]

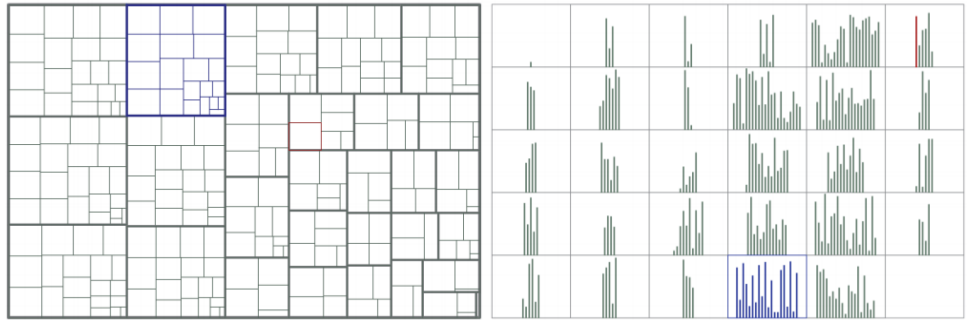


Height more perceptually effective than area

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

99

Treemaps vs. Bar Charts [Kong 10]



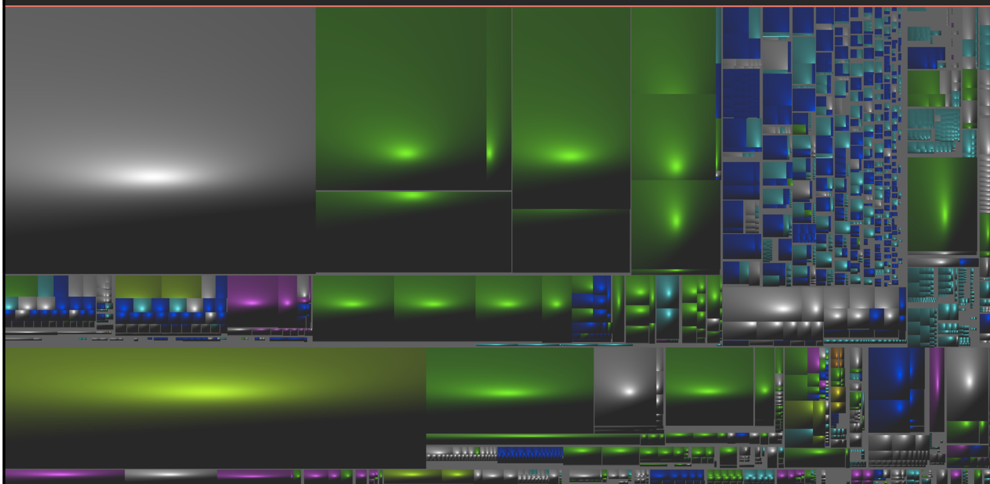
At low densities (< 4k elements), bar charts more accurate than treemaps for leaf-node comparisons.

At higher density, treemaps led to faster judgments.

Treemaps better for group-level comparisons.

100

Cushion Treemaps [van Wijk 99]



Use shading to emphasize hierarchical structure

101

Cascaded Treemaps [Lü 08]

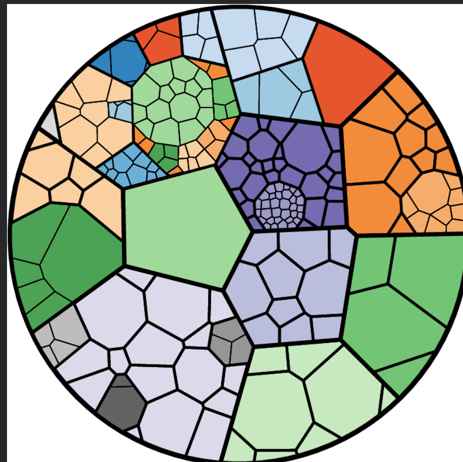
Use 2.5D effect emphasize hierarchical structure

102

Voronoi Treemaps [Balzer 05]

Treemaps with arbitrary polygonal shape and boundary

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



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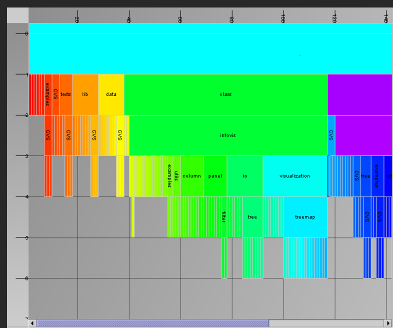
Layered Diagrams

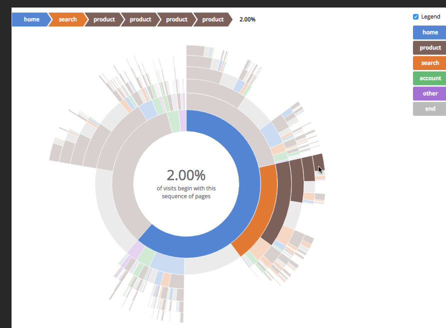
Signify tree structure using
Layering
Adjacency
Alignment

Involves recursive sub-division of space
Can apply the same set of approaches as in node-link layout

105

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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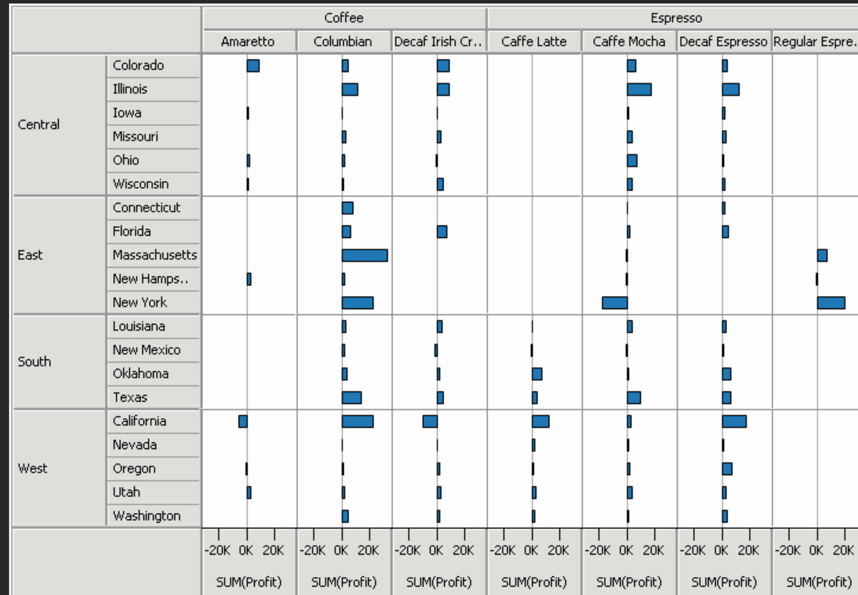
Layered Tree Drawing



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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

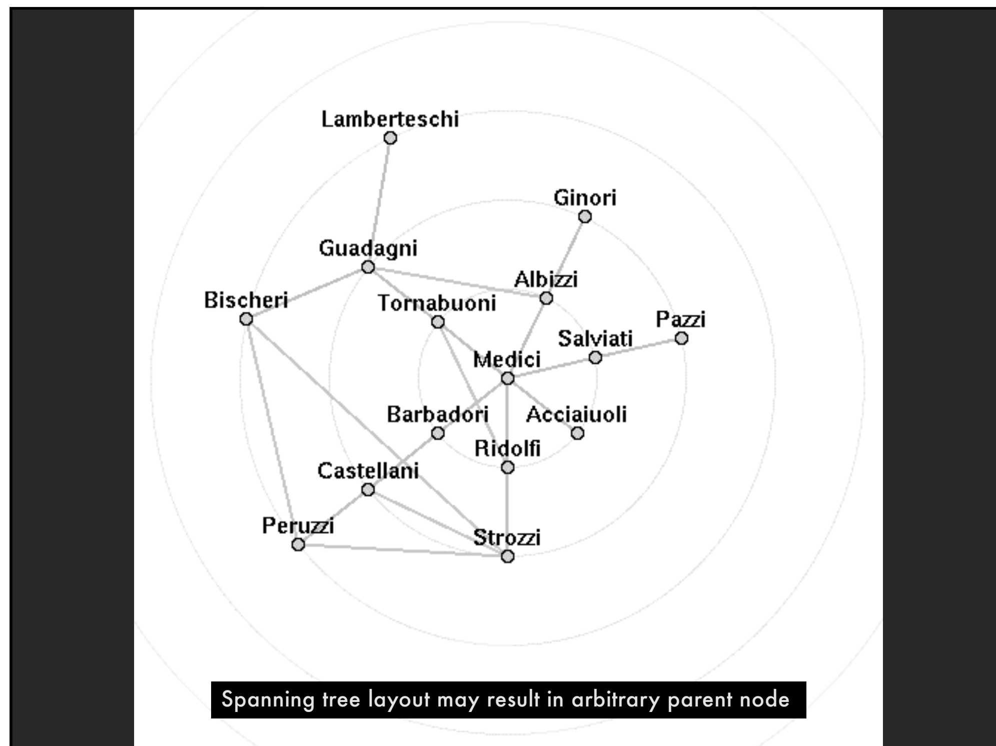
Trees created by BFS / DFS

Min/max spanning trees

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

Heuristics may further improve layout

111



Spanning tree layout may result in arbitrary parent node

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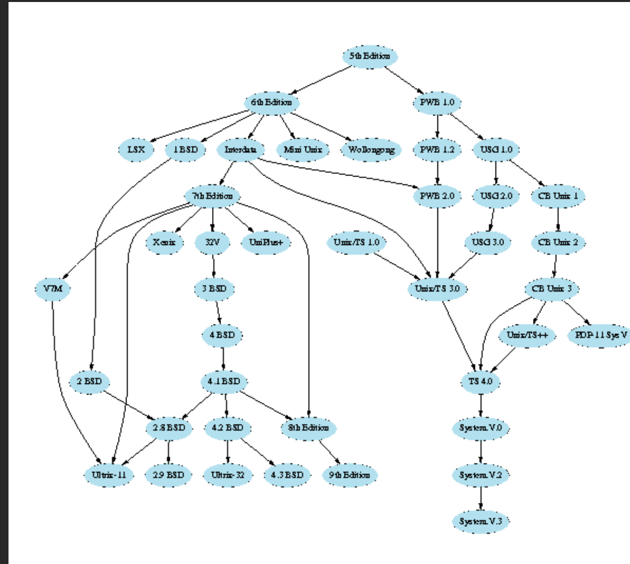
Sugiyama-style graph layout

Evolution of the UNIX operating system

Hierarchical layering based on descent



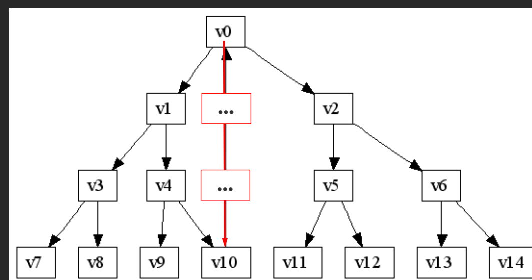
Sugiyama-style graph layout

Layer 1

Layer 2

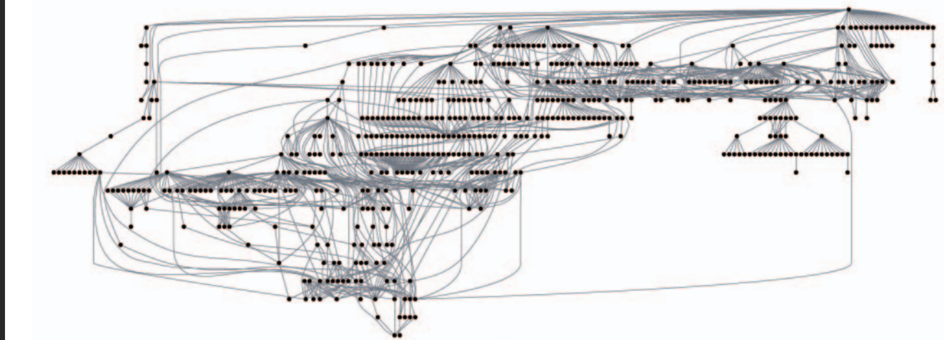
Layer 3

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

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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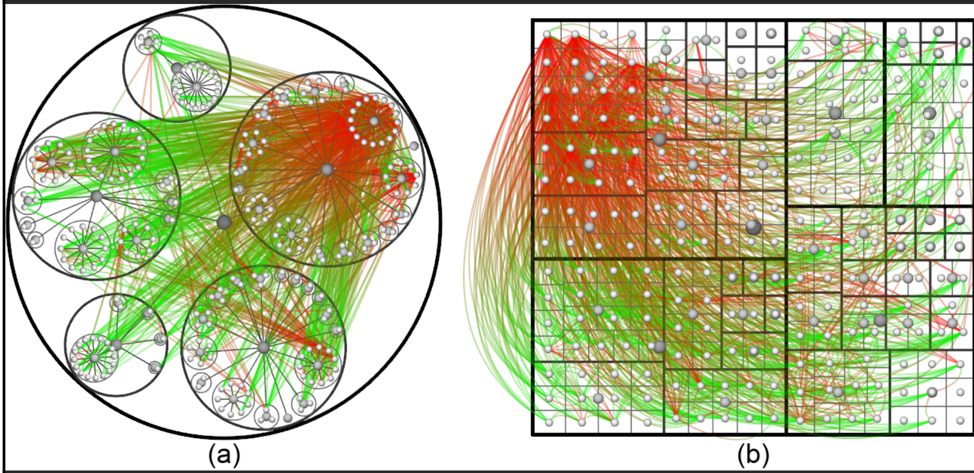
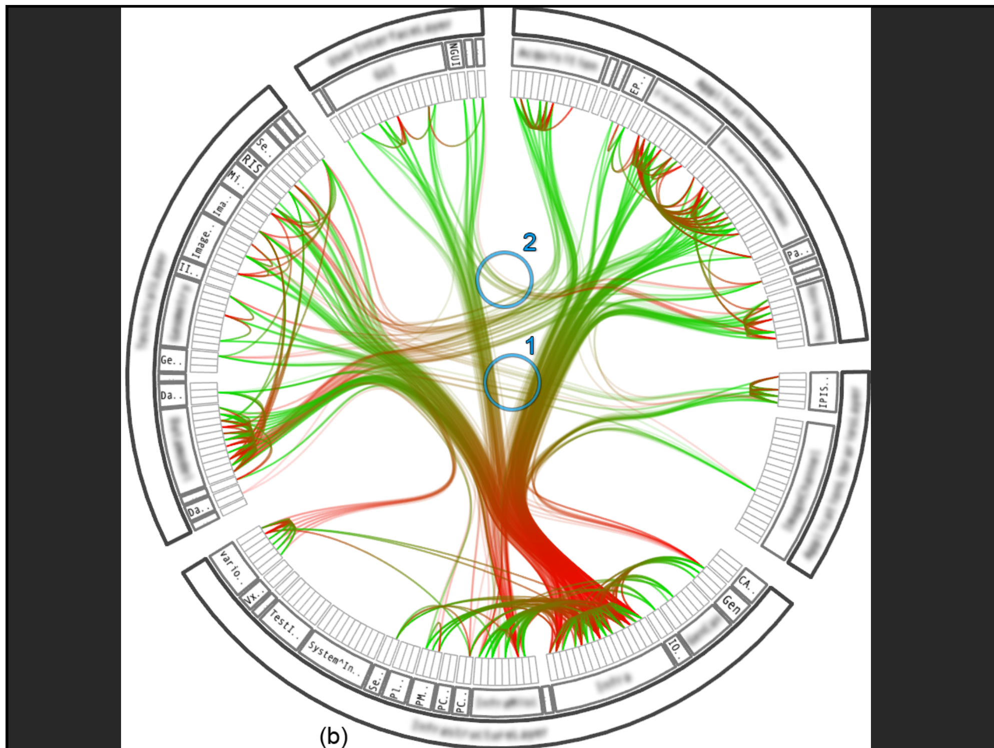
Trees with Adjacency Relations



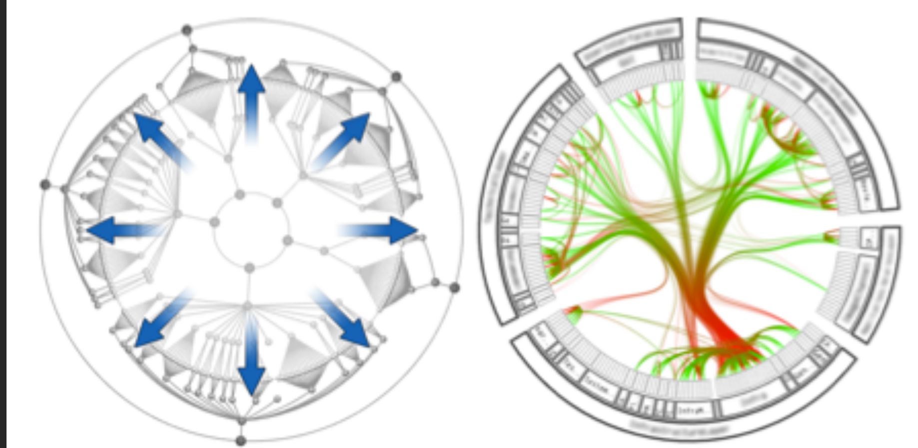
(a) (b)

118



(b)

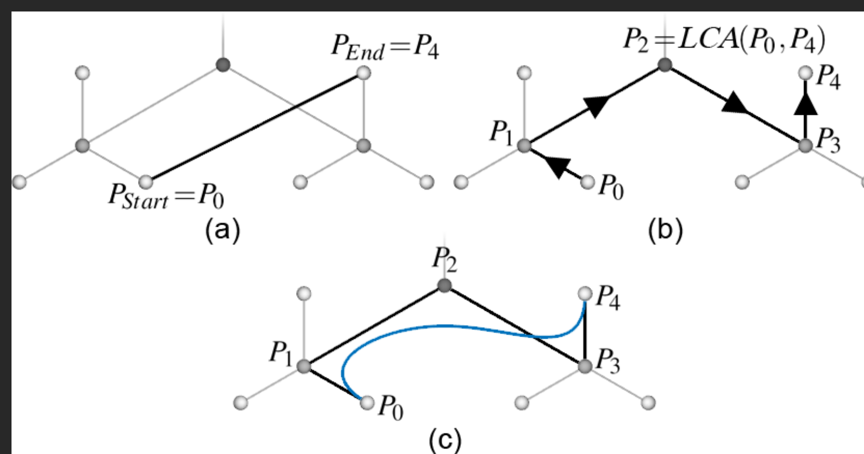
119



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

120

Bundle Edges along Hierarchy



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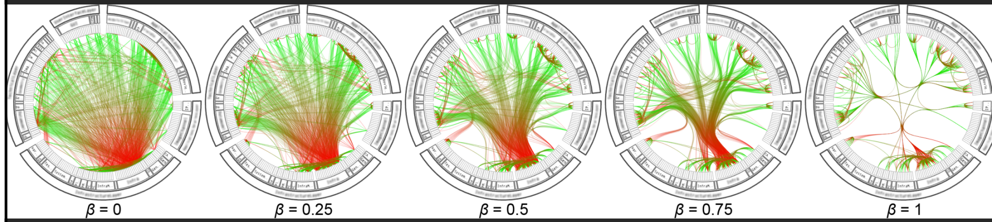
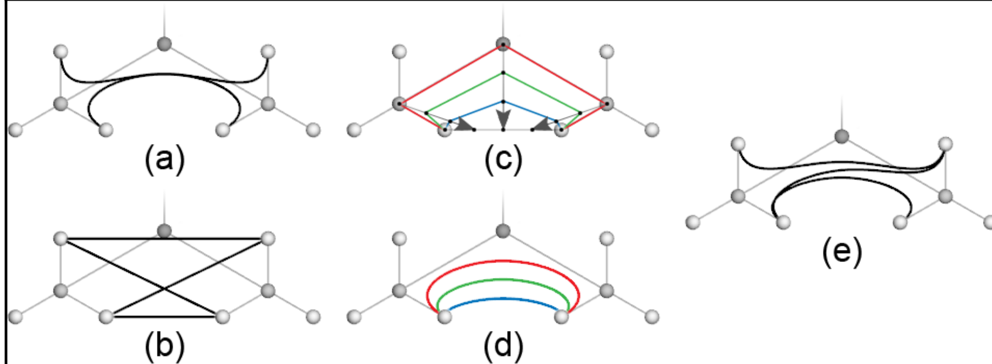
Increasing Edge Tension

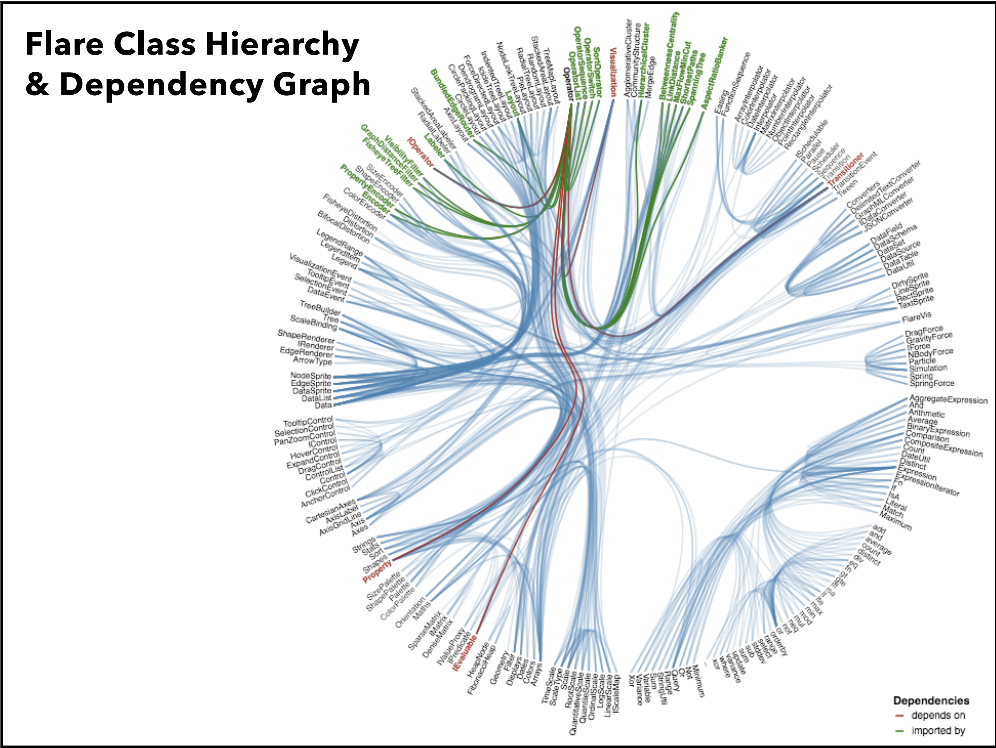


122

Configuring Edge Tension



123



124

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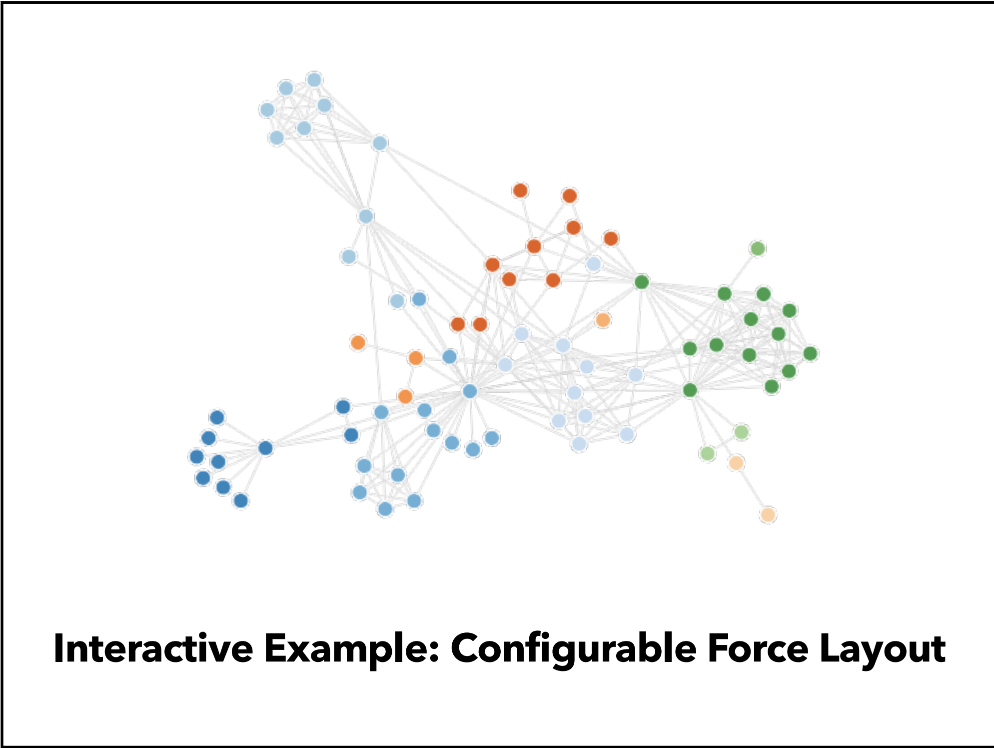

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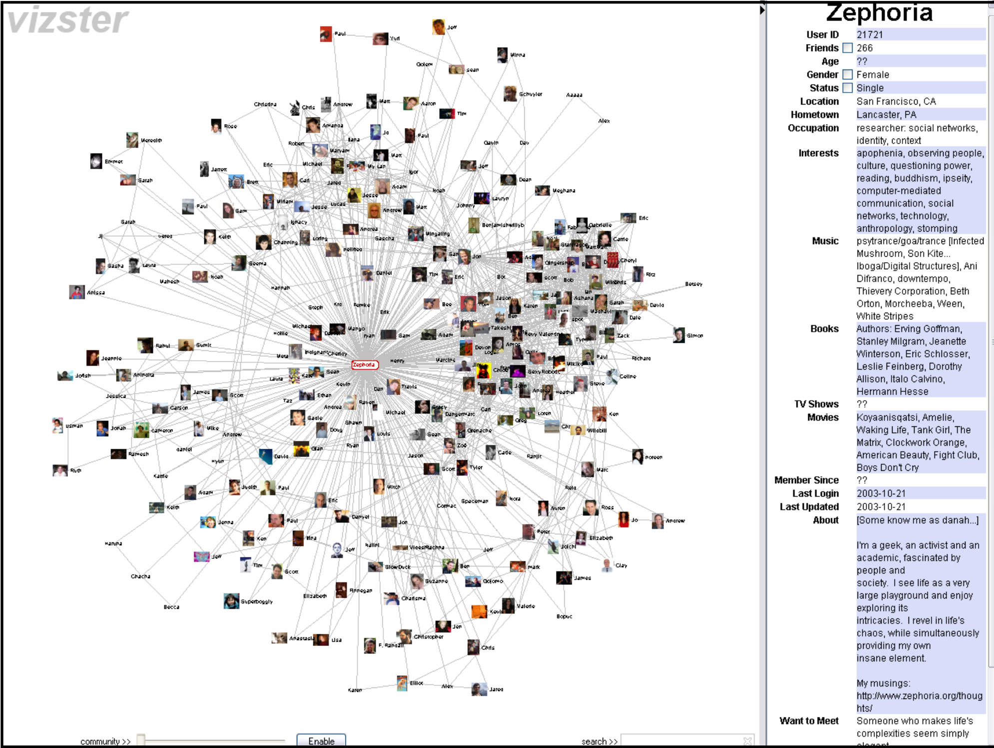

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Use the Force!

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

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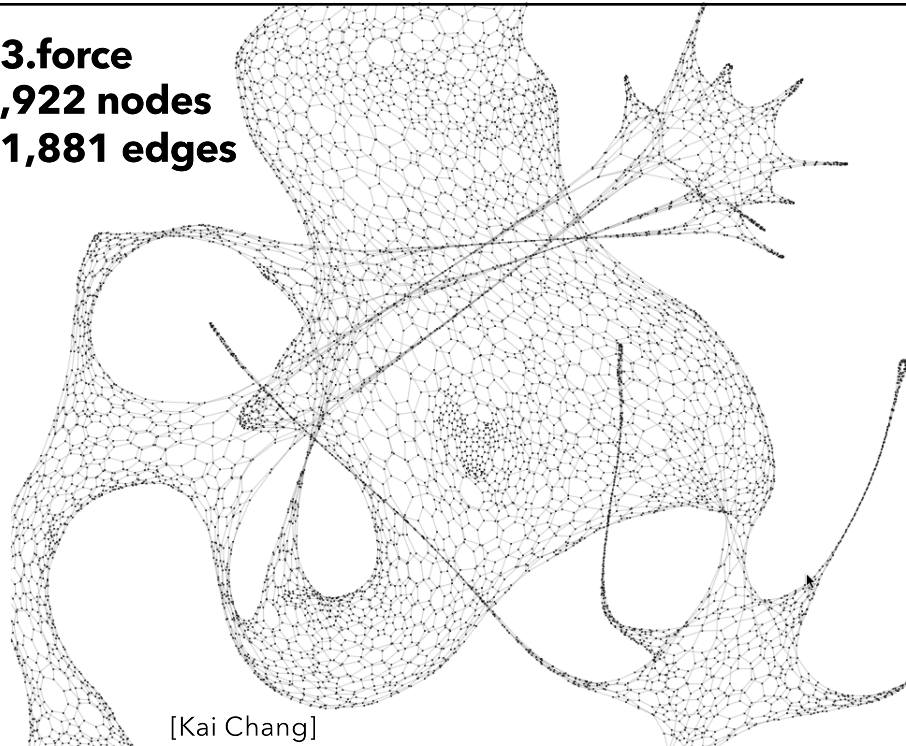

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Force-Directed Layout

Nodes = charged particles $F = q_i * q_j / d_{ij}^2$
with air resistance $F = -b * v_i$
Edges = springs $F = k * (L - d_{ij})$

D3's force layout uses velocity Verlet integration

Assume uniform mass *m* and timestep *Δt*:

F = ma → F = a → F = Δv / Δt → F = Δv

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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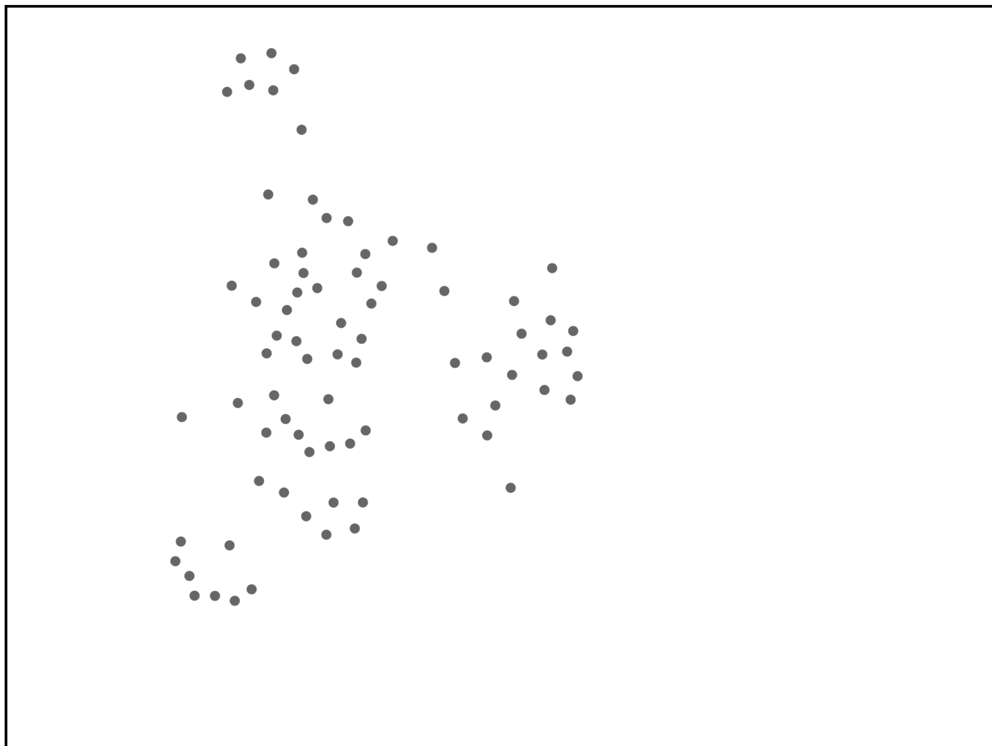

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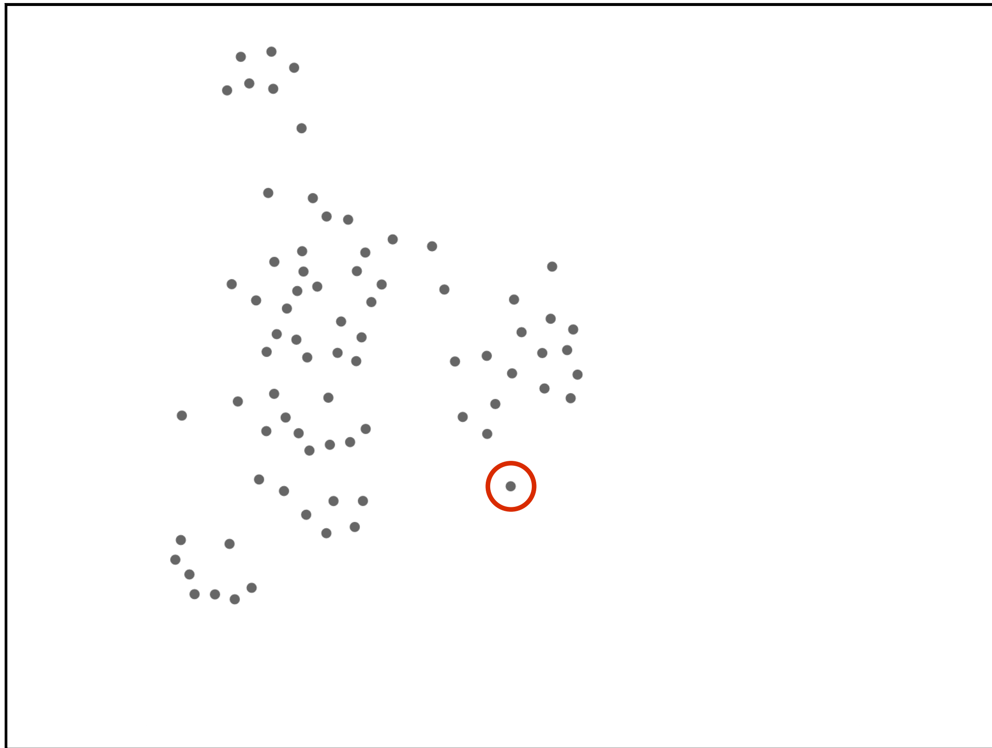

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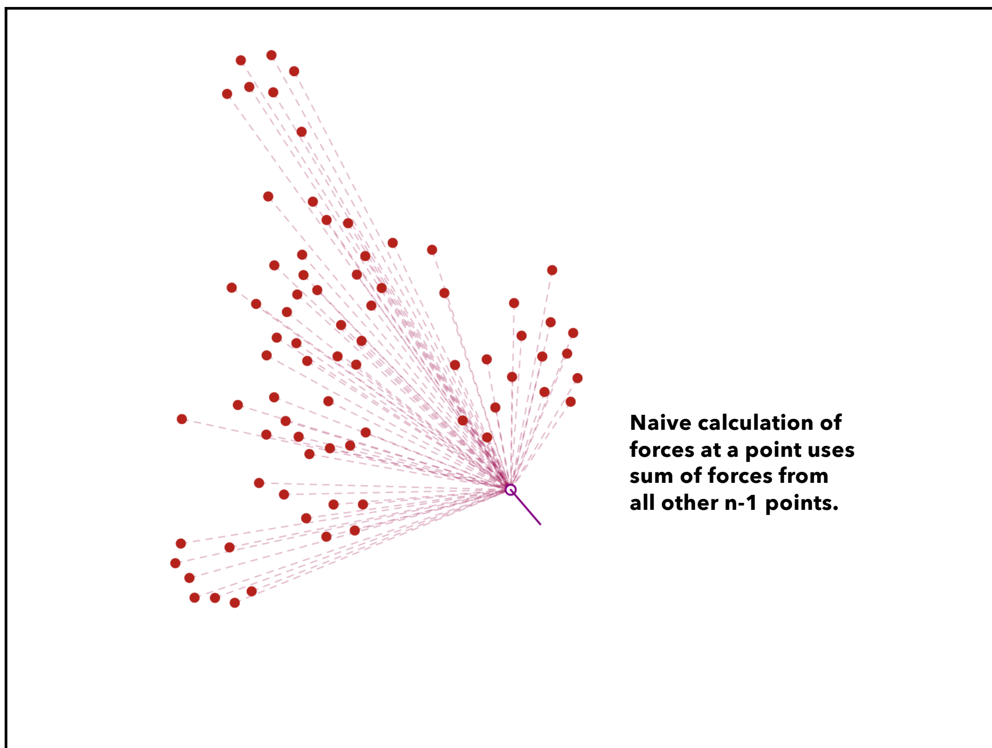

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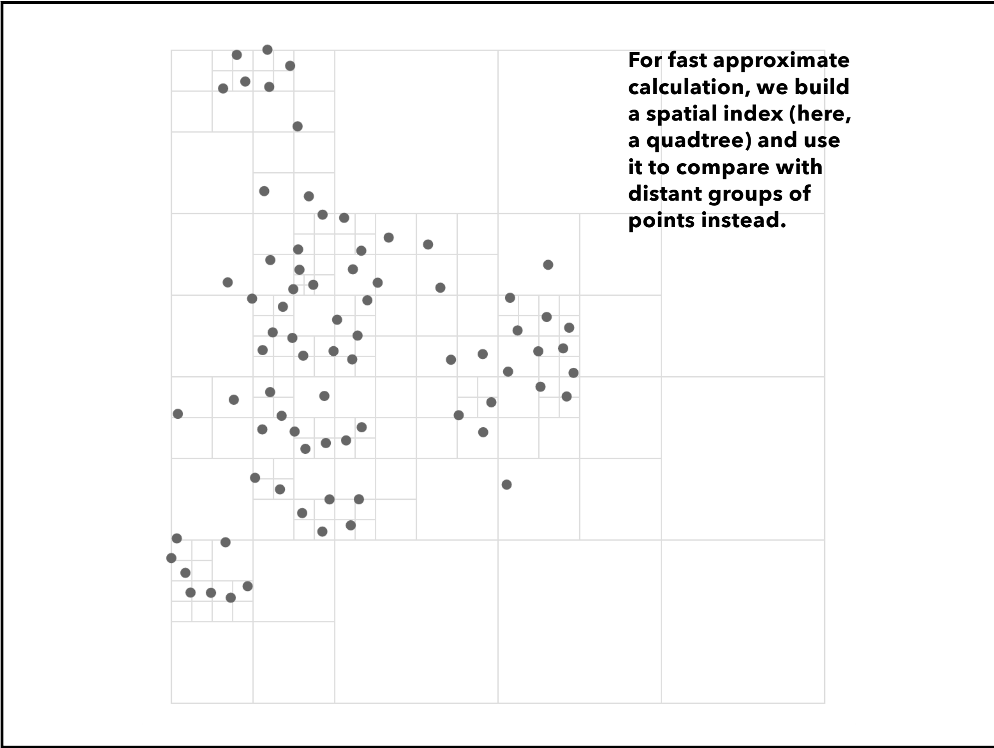

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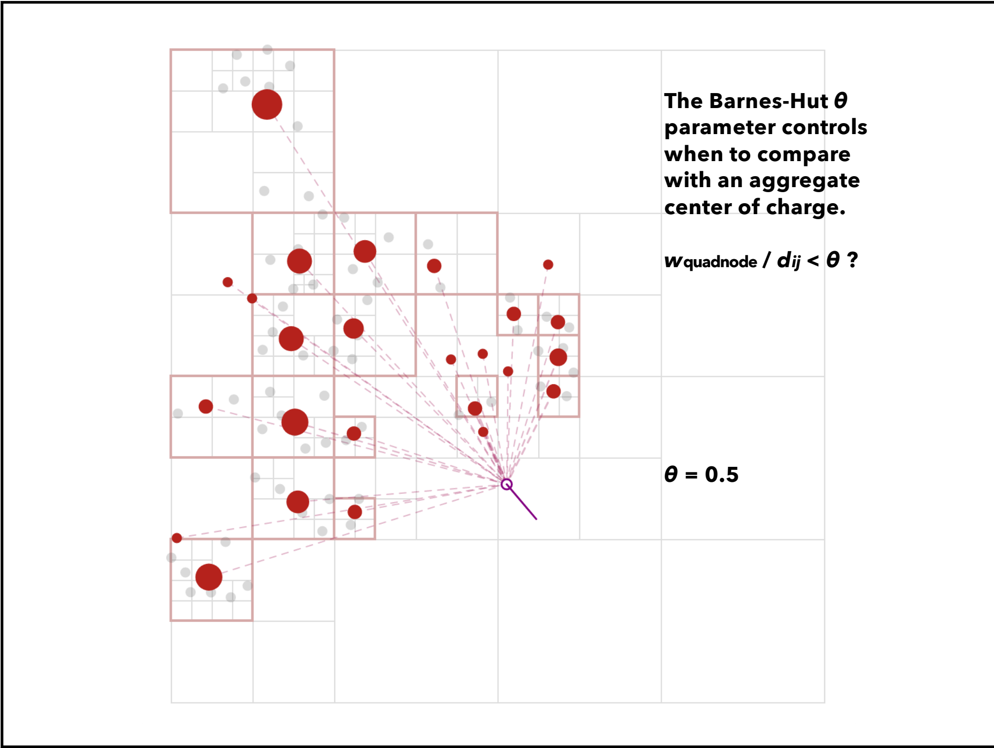

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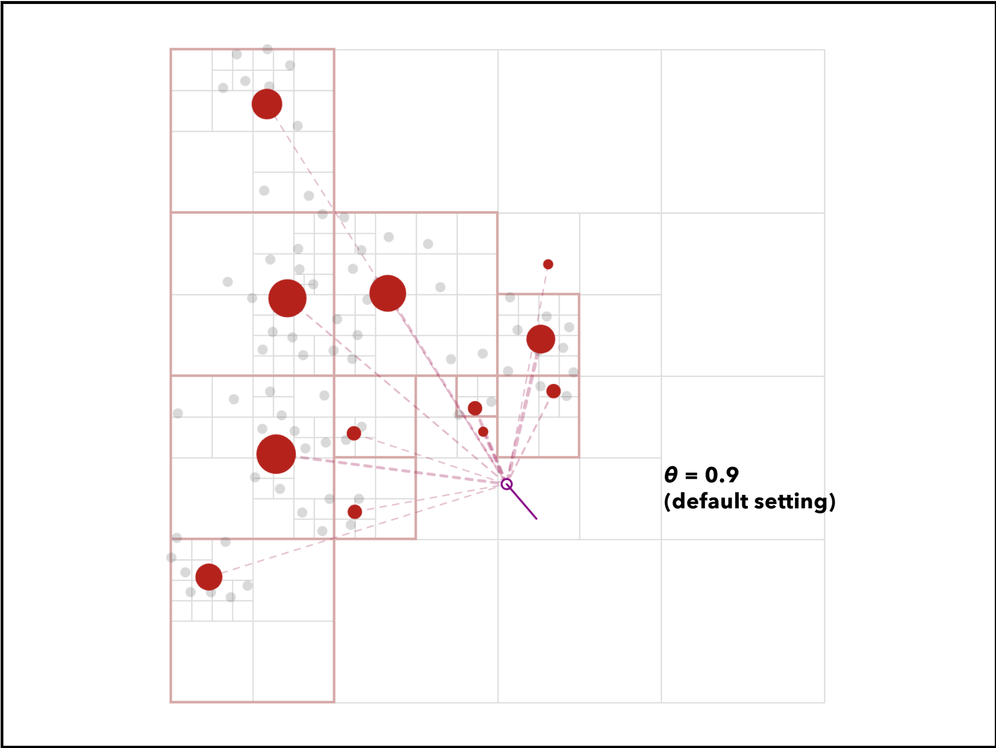

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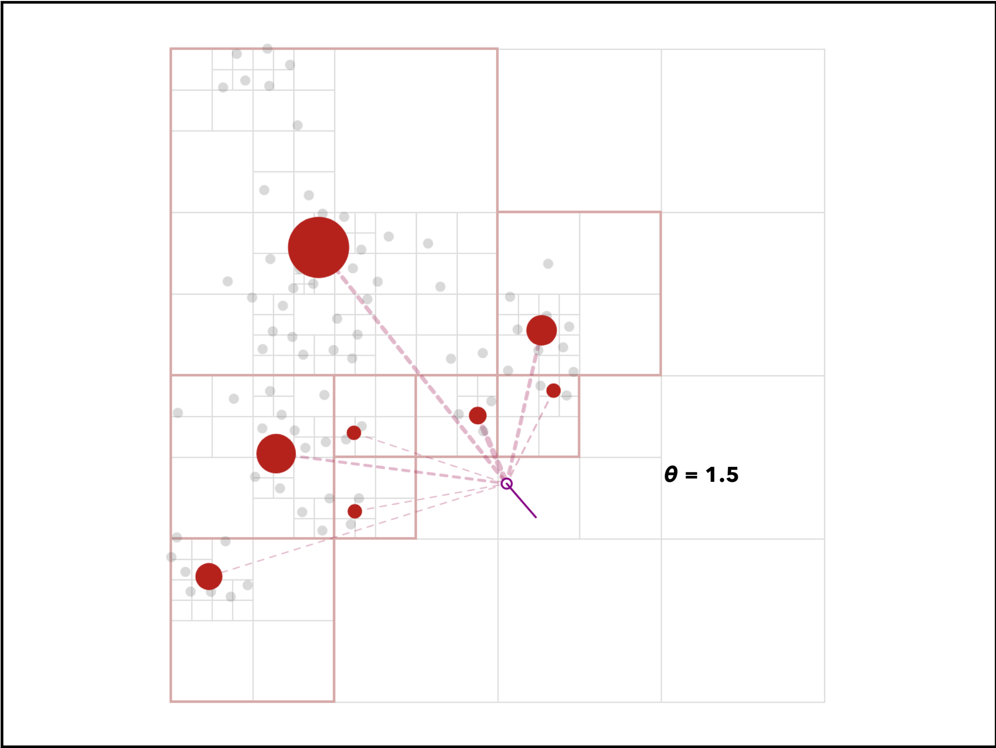

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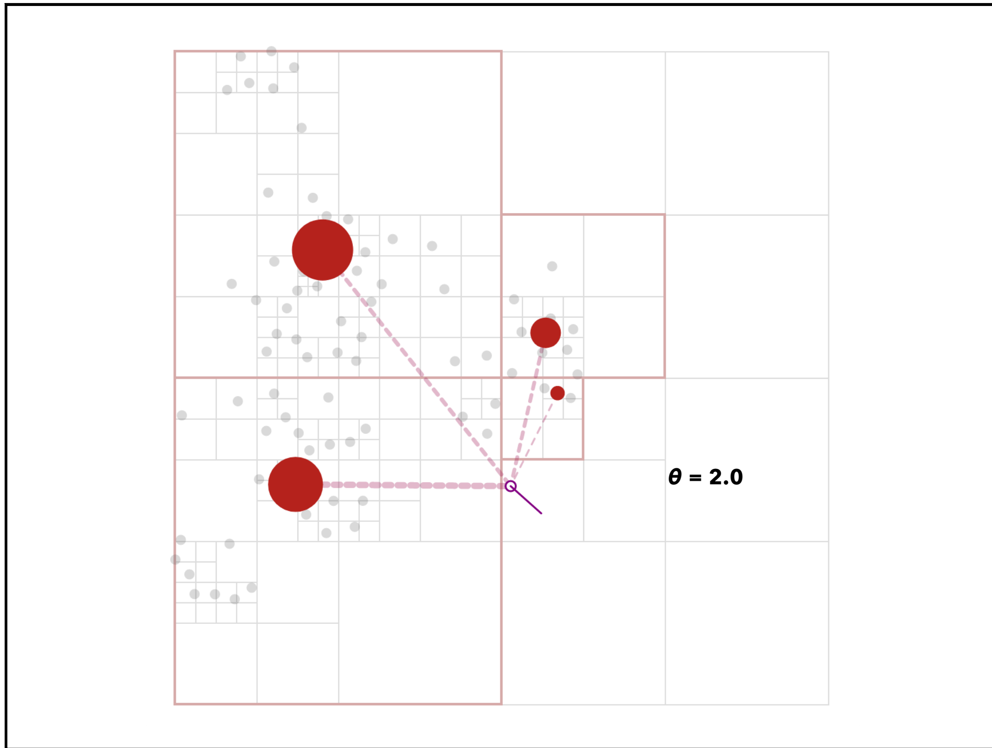

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Alternative Layouts

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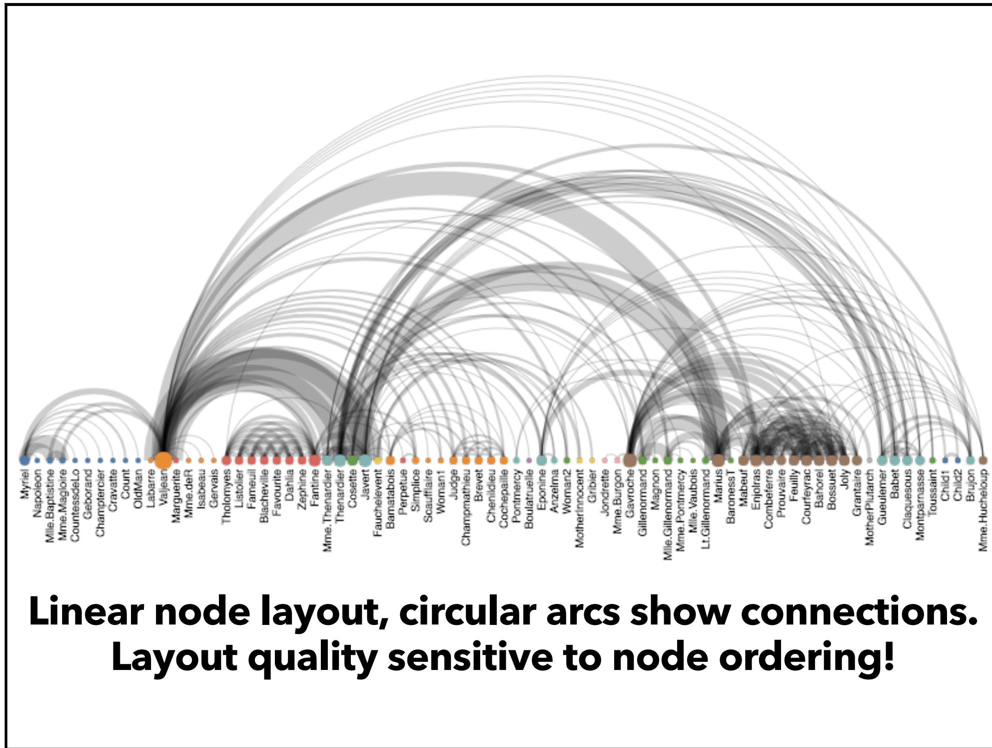
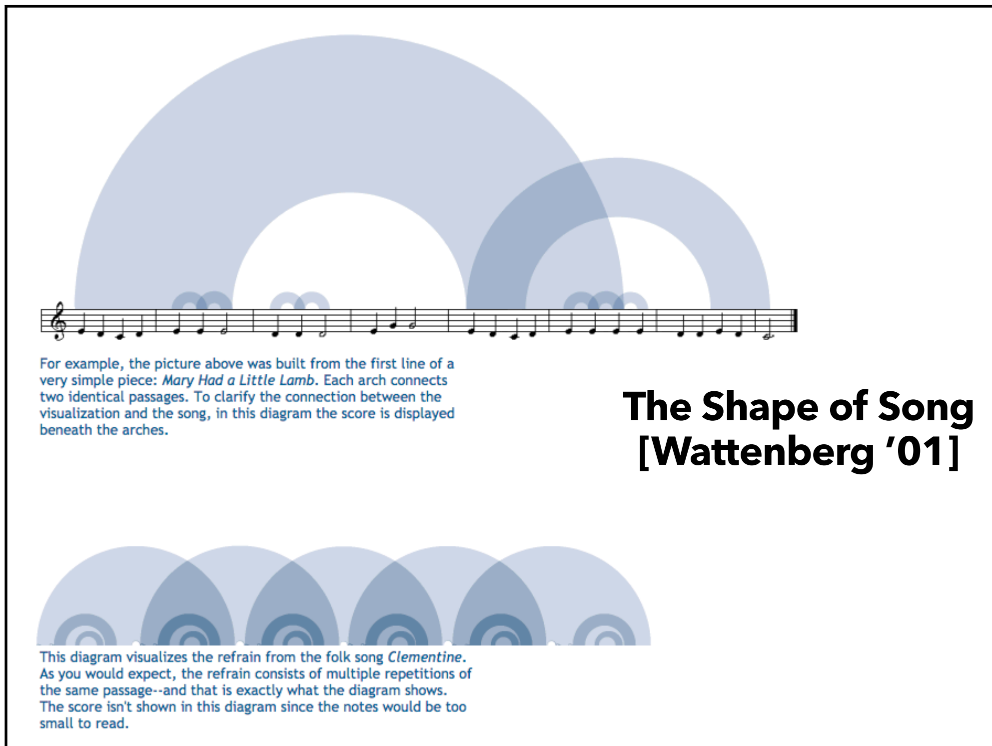


141



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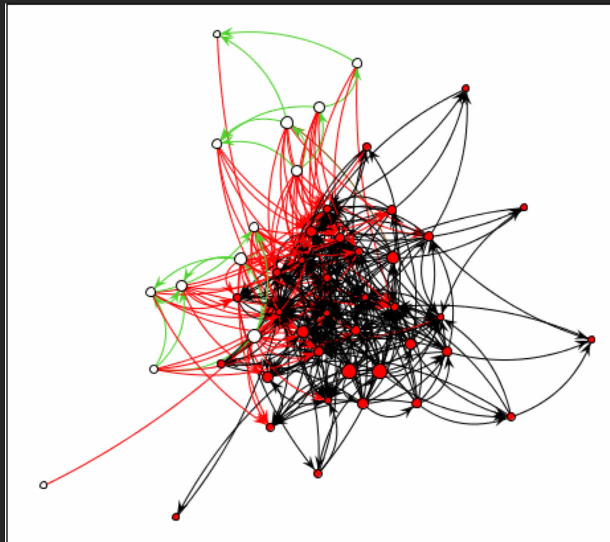
Limitations of Node-Link Layout



Edge-crossings and occlusion

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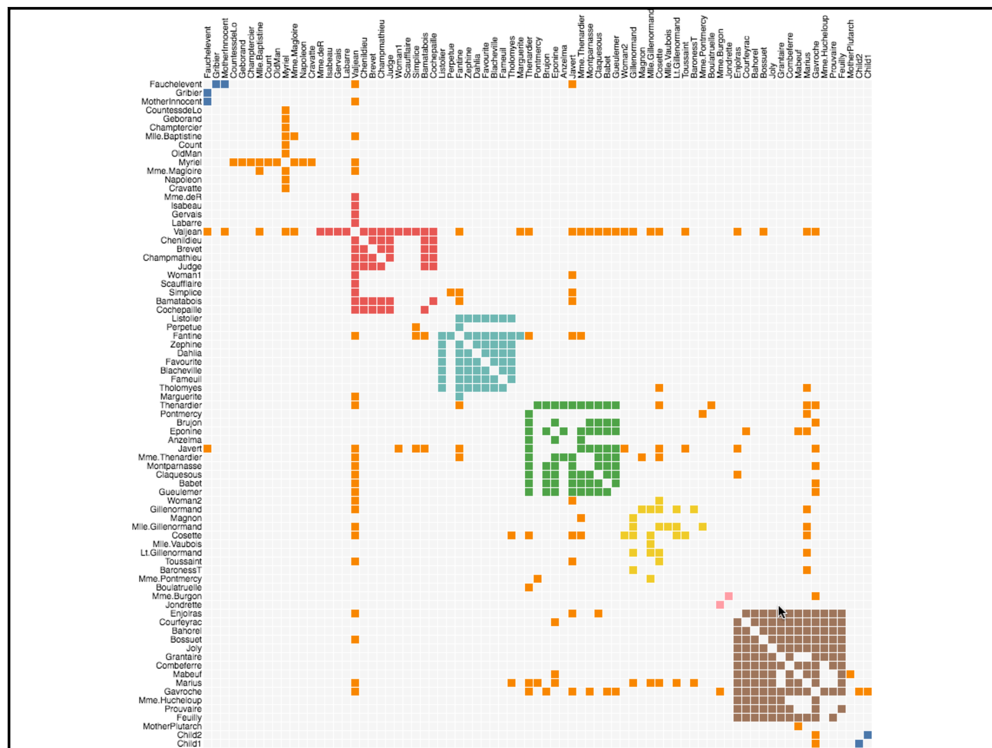

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Attribute-Driven Layout

Large node-link diagrams get messy!
Is there additional structure we can exploit?

Idea: Use data attributes to perform layout

- e.g., scatter plot based on node values

Dynamic queries and/or brushing can be used to explore connectivity

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Attribute-Driven Layout

The "Skitter" Layout

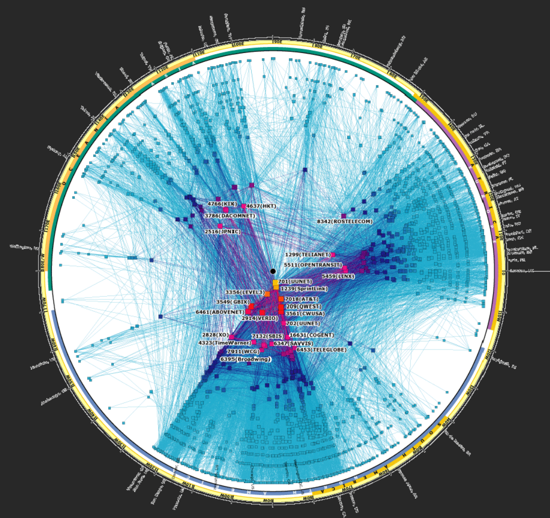
- Internet Connectivity
- Radial Scatterplot

Angle = Longitude

- Geography

Radius = Degree

- # of connections
- (a statistic of the nodes)



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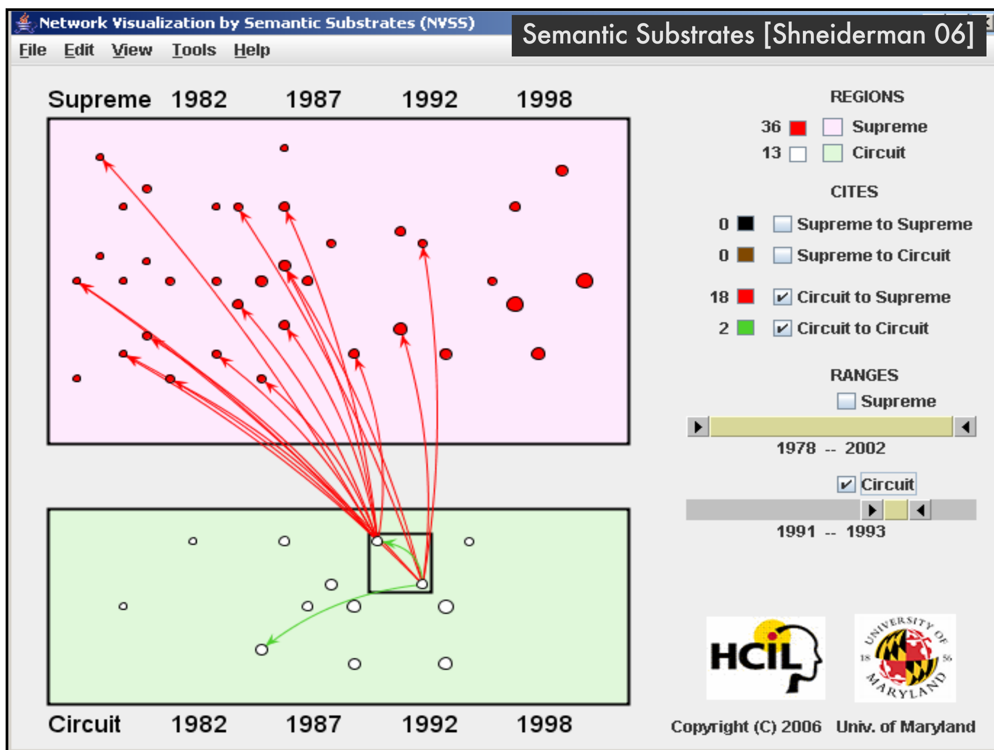

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Summary

Tree Layout

Indented / Node-Link / Enclosure / Layers

How to address issues of scale?

- Filtering and Focus + Context techniques

Graph Layout

Tree layout over spanning tree

Hierarchical "Sugiyama" Layout

Optimization (Force-Directed Layout)

Attribute-Driven Layout

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