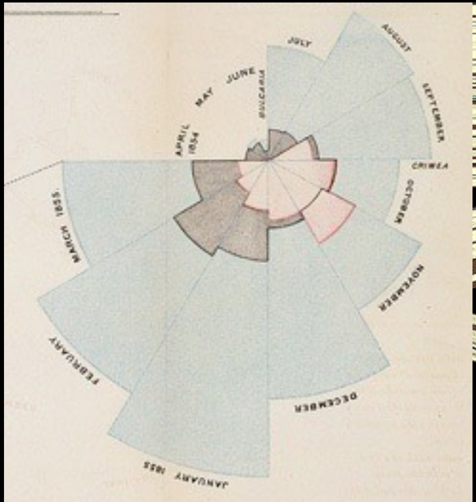
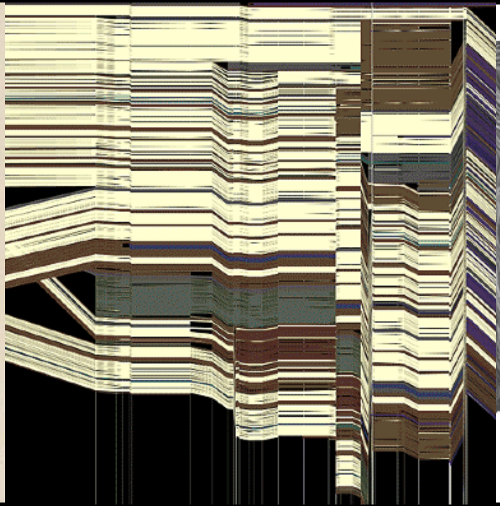
CSE 442 - Data Visualization

Networks





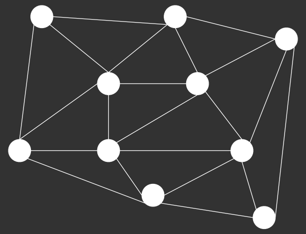
Jeffrey Heer University of Washington

Graphs and Trees

Graphs

Model relations among data

Nodes and *edges*

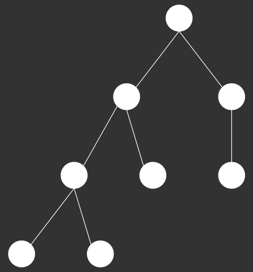


Trees

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:

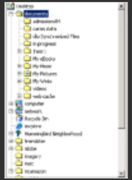
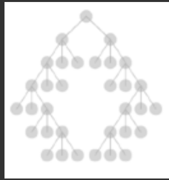
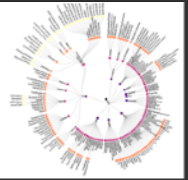
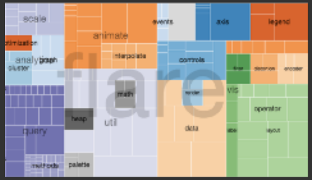
- Connectivity, path-following
- Topological distance
- Clustering / grouping
- Ordering (e.g., hierarchy level)

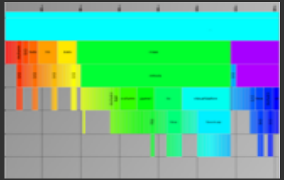
Applications

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

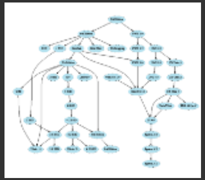
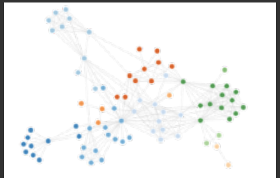
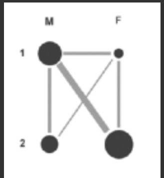
Topics

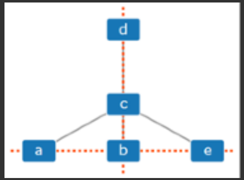
Tree Visualization

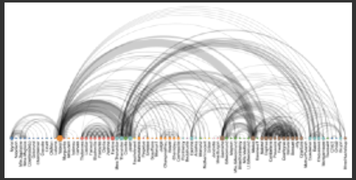







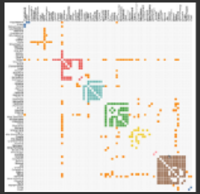

Graph Layout: Node-Link Diagrams





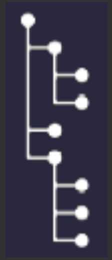
Alternative Visualizations and Techniques

Tree Visualization

Tree Visualization

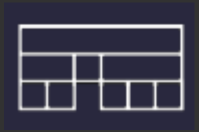
Indentation
Linear list, indentation encodes depth



Node-Link diagrams
Nodes connected by lines/curves

Enclosure diagrams
Represent hierarchy by enclosure

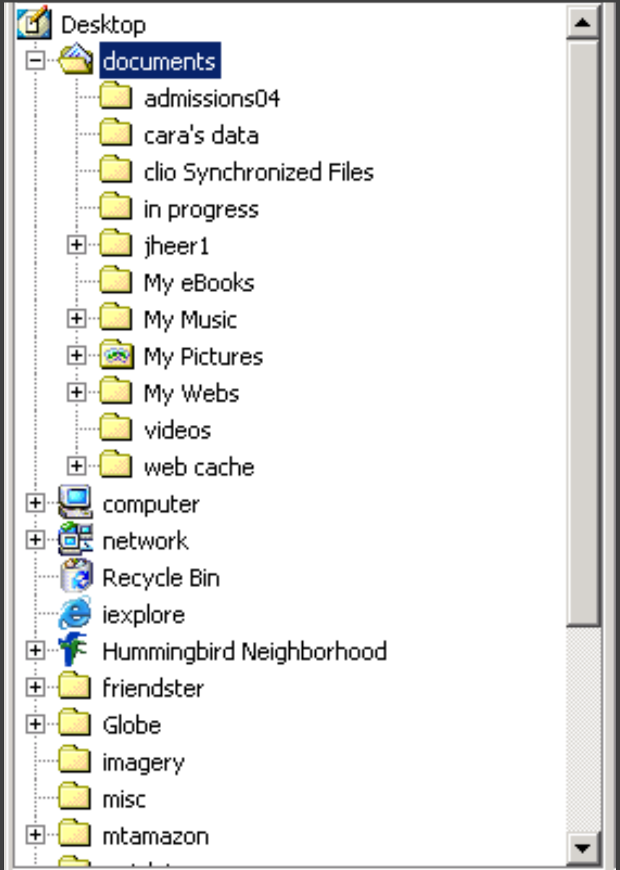
Layering
Relative position and alignment

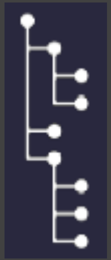


Typically fast: O(n) or O(n log n), interactive layout

Indentation

Indentation





Places all items along vertically spaced rows

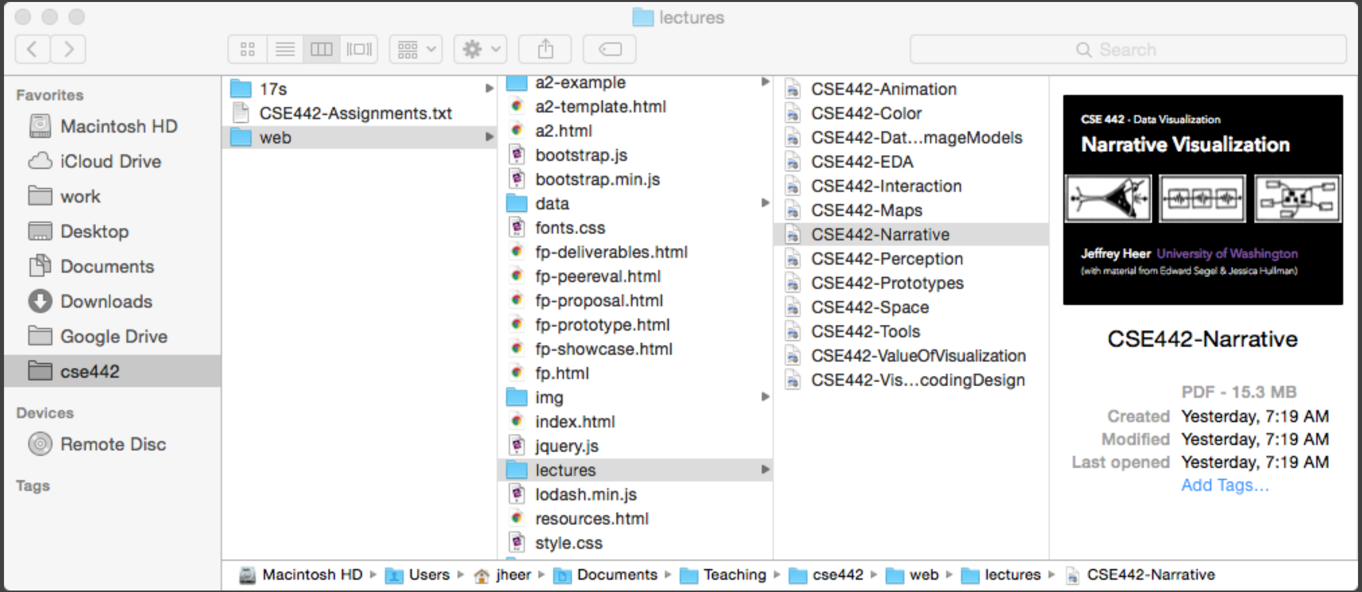
Indentation used to show parent/child relationships

Commonly used as a component in an interface

Breadth and depth contend for space

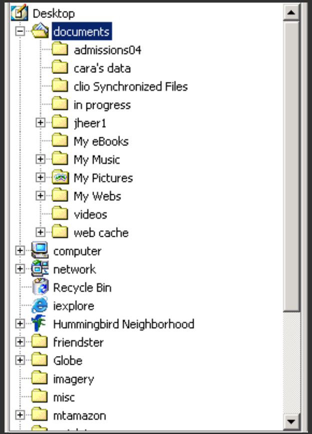
Often requires a great deal of scrolling

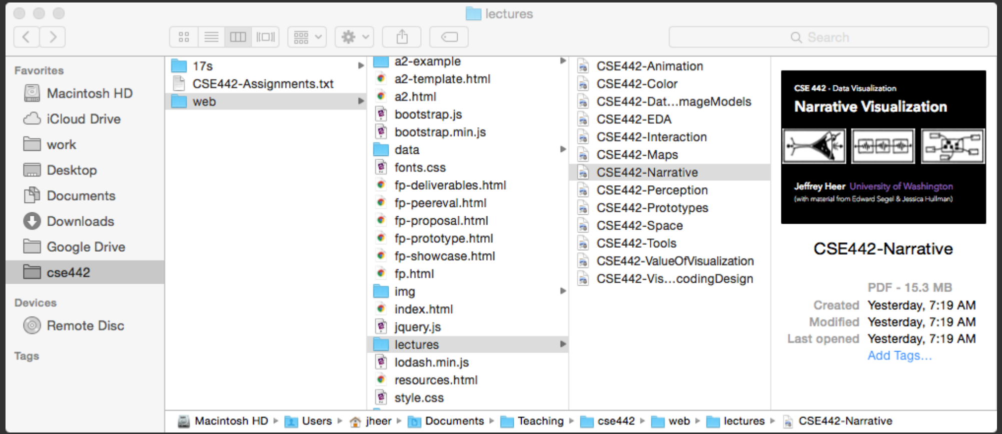
Single-Focus (Accordion) List



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

What tasks are these good for?





Benefits:

Navigation + Browsing, Parent-Child Relationships

Disadvantages:

Estimation, Comparison, Network Overview

Node-Link Diagrams

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

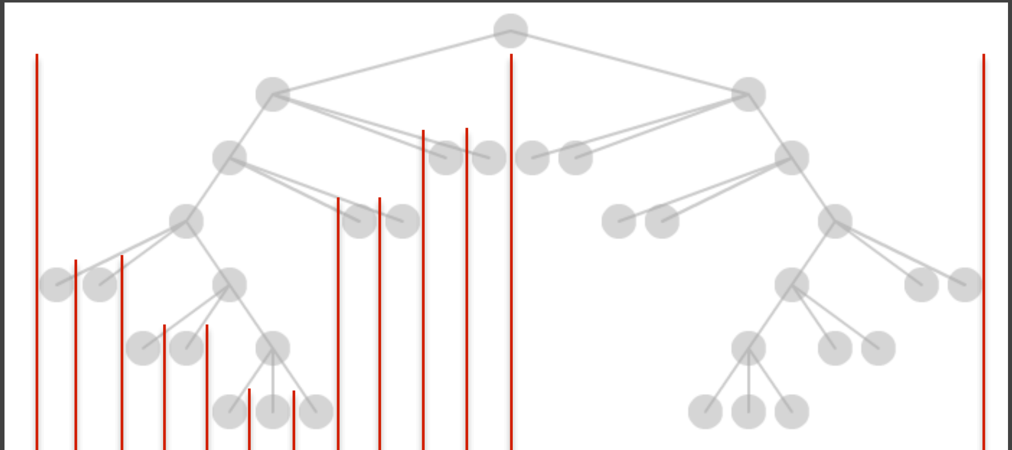
Often space is used to communicate hierarchical orientation (e.g., towards authority or generality)

Naïve Recursive Layout

Repeatedly divide space for subtrees by leaf count

Breadth of tree along one dimension

Depth along the other dimension



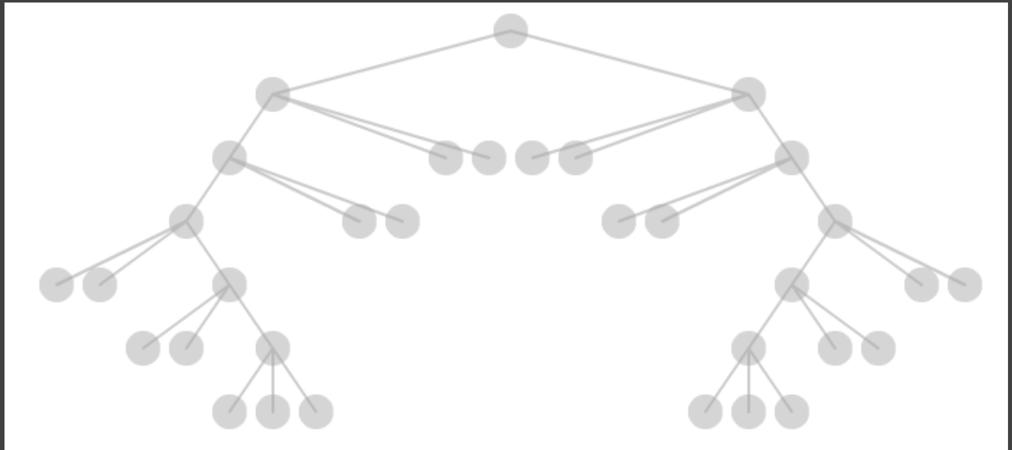
Naïve Recursive Layout

Repeatedly divide space for subtrees by leaf count

Breadth of tree along one dimension

Depth along the other dimension

Problems?



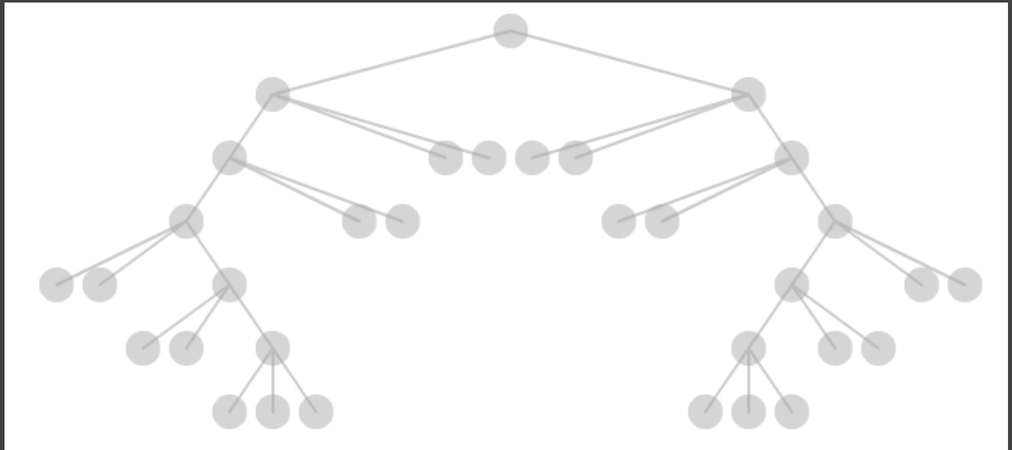
Naïve Recursive Layout

Repeatedly divide space for subtrees by leaf count

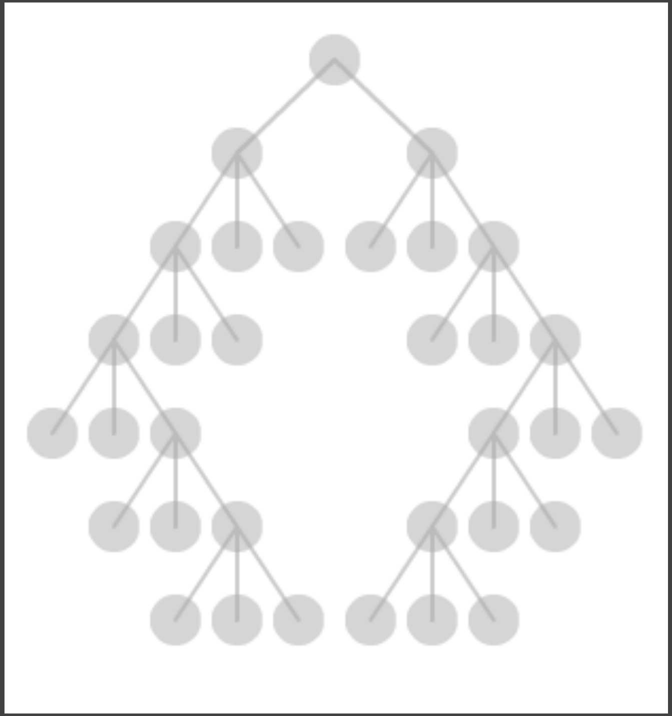
Breadth of tree along one dimension

Depth along the other dimension

Problem: exponential growth of breadth



Reingold & Tilford's "Tidy" Layout

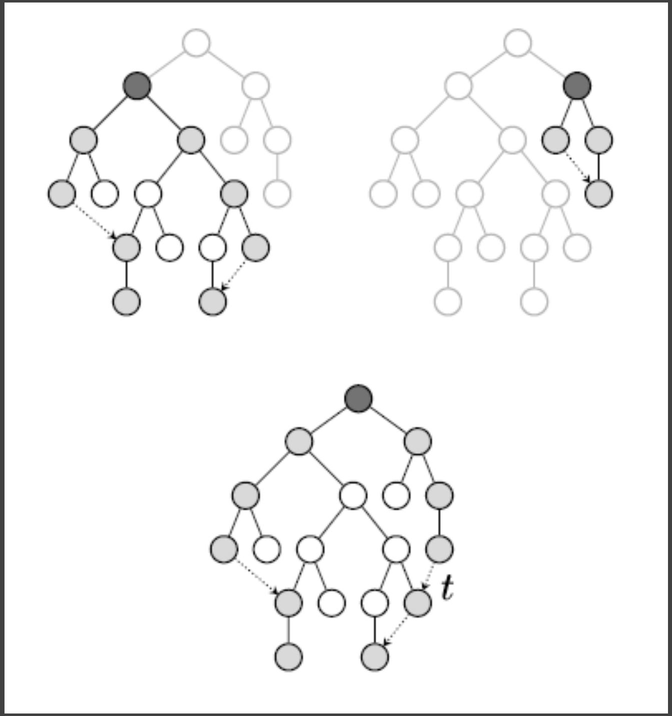


Goal: make smarter use of space, maximize density and symmetry.

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

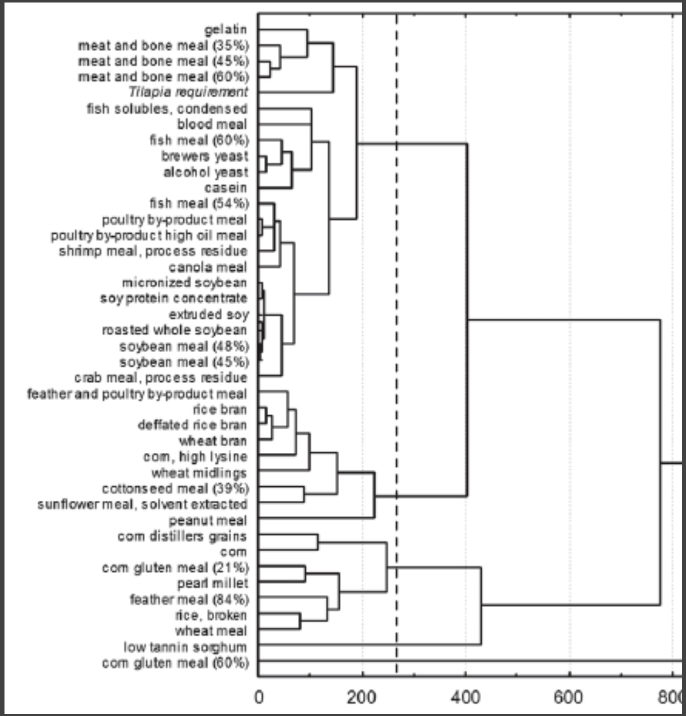
No edge crossings

Draw isomorphic subtrees identically (same shape)

Preserve layout ordering and symmetry

Compact, space-saving layout (don't waste space)

Cluster Dendrograms

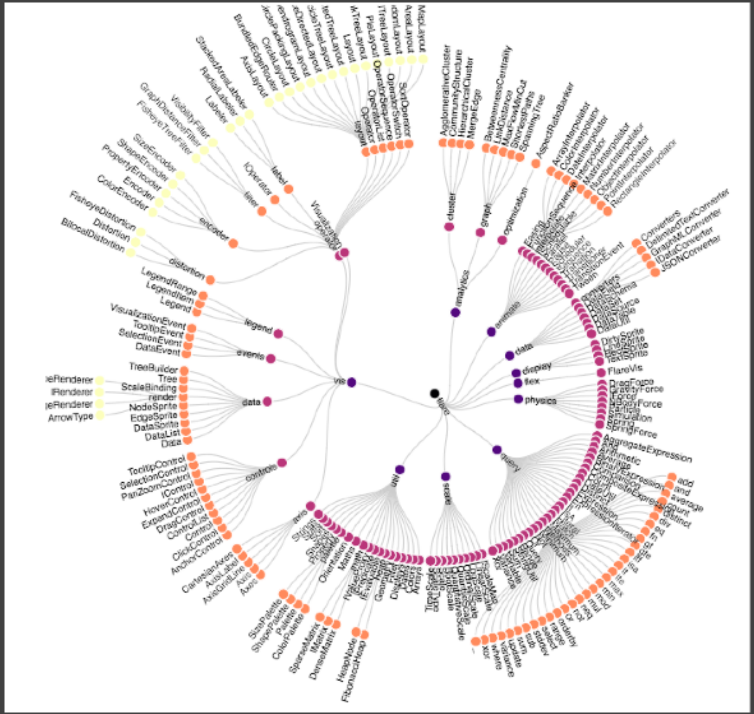


Depicts cluster trees produced by hierarchical clustering algorithms.

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.

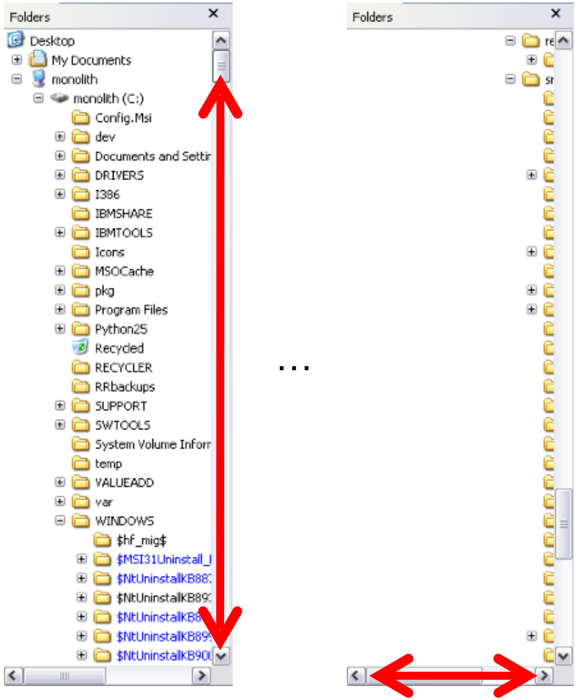
Angular sectors assigned to subtrees (often with naïve recursive layout).

Reingold-Tilford method can also be applied here.

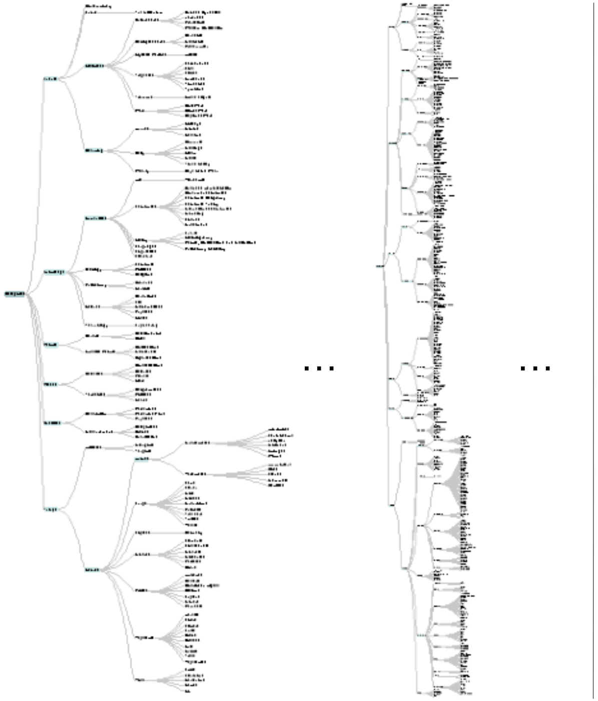
Analysis Tasks:

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

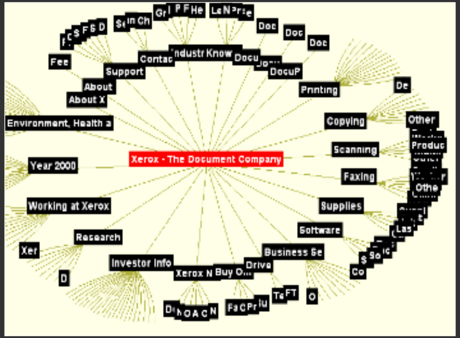
Scrolling or Panning

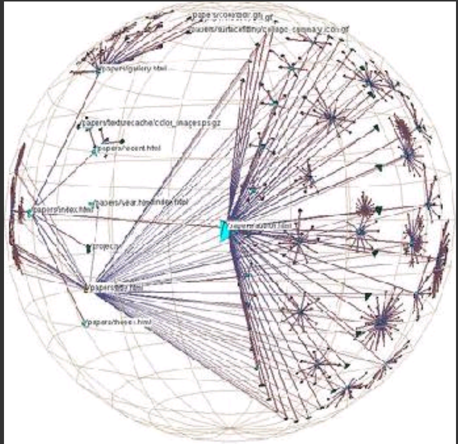
Zooming

Aggregation

MC Escher, *Circle Limit IV*

Hyperbolic Layout



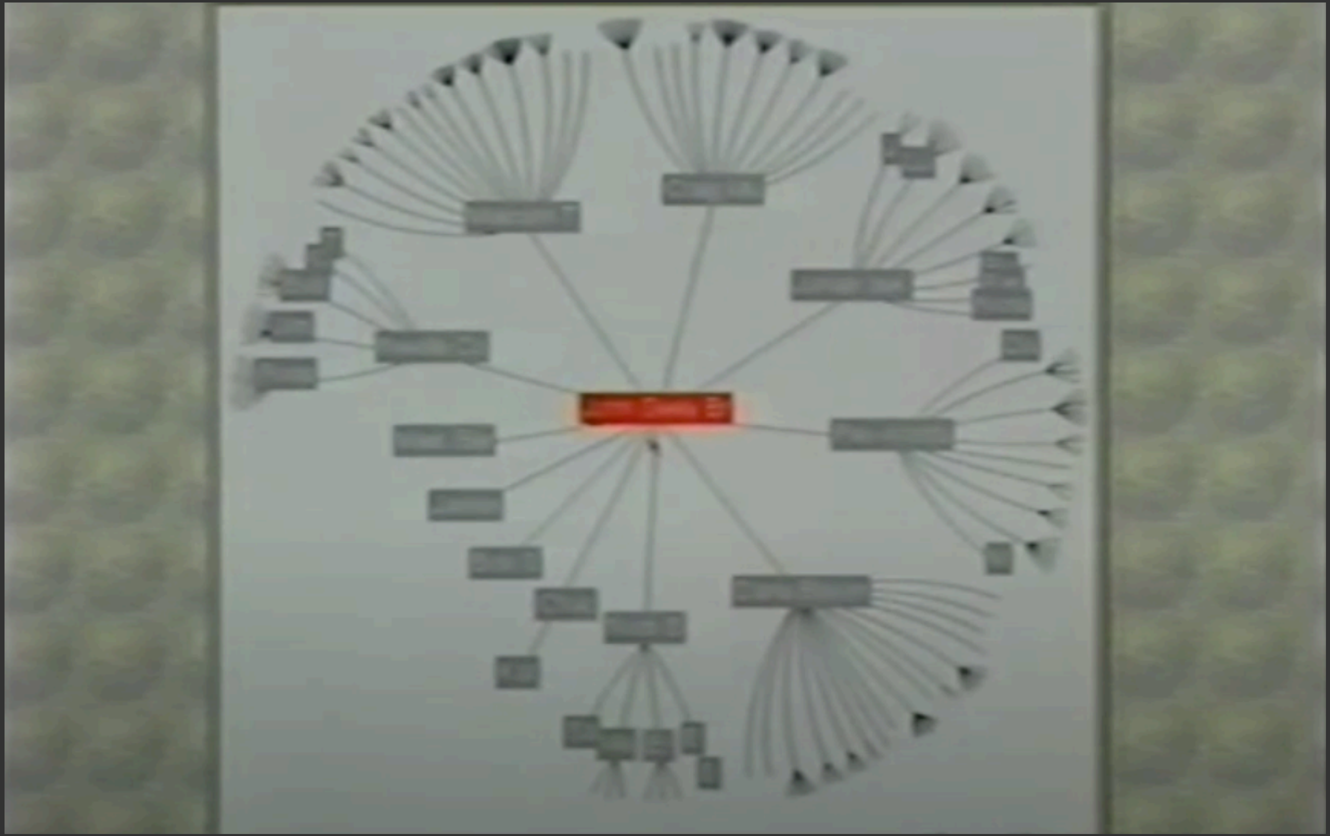


Perform tree layout in hyperbolic geometry, project the result on to the Euclidean plane.

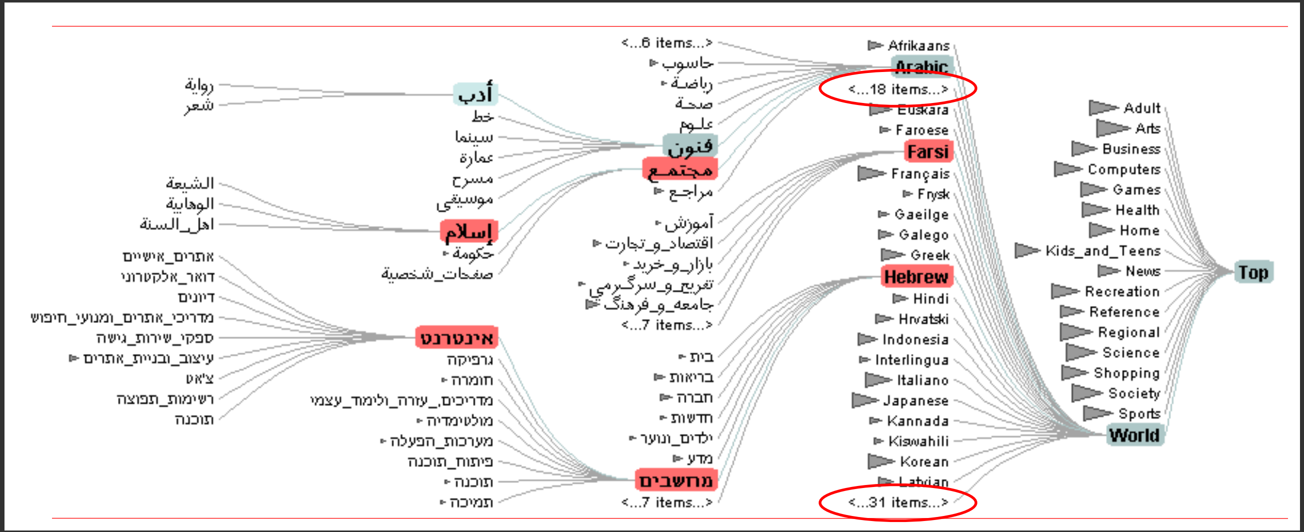
Why? Like tree breadth, the hyperbolic plane expands exponentially!

Also computable in 3D, projected into a sphere.

Hyperbolic Layout

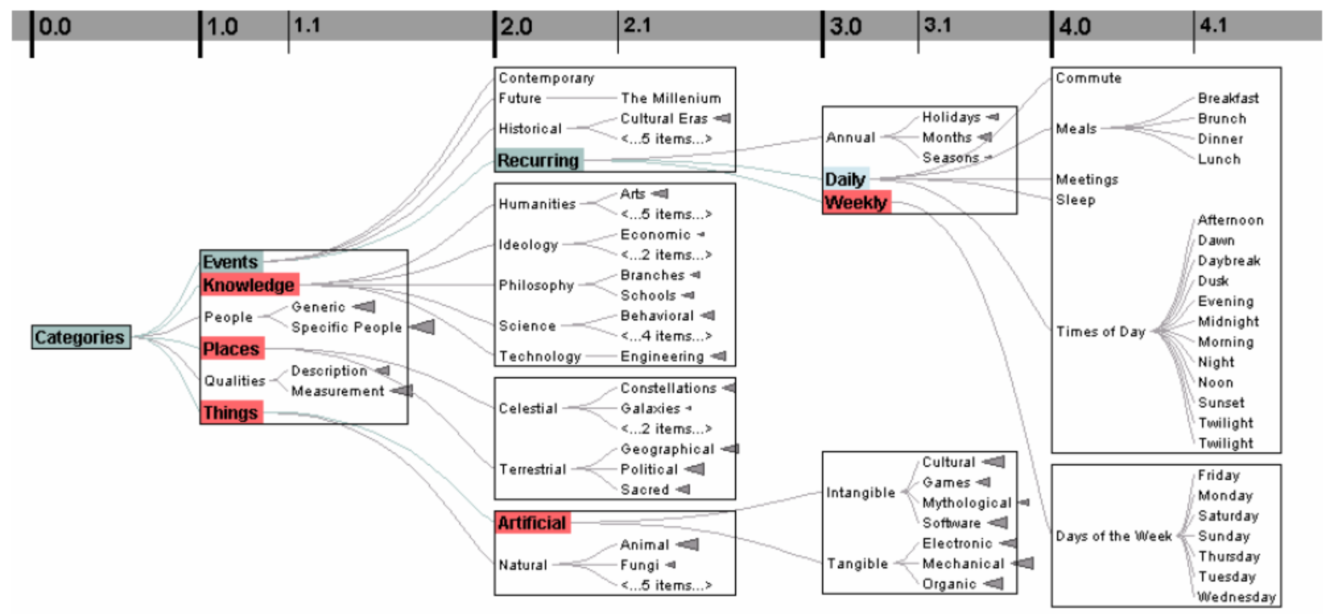


Degree-of-Interest Trees



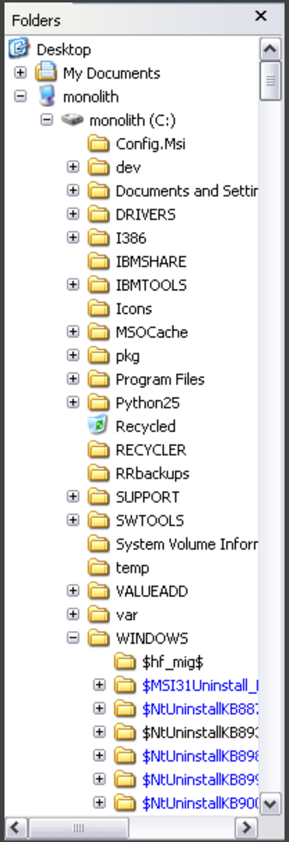
Space-constrained, multi-focal tree layout

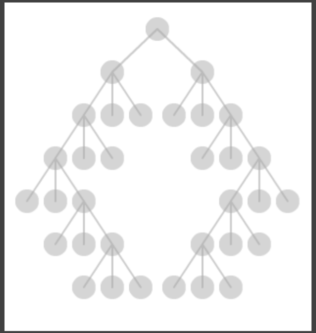
Degree-of-Interest Trees

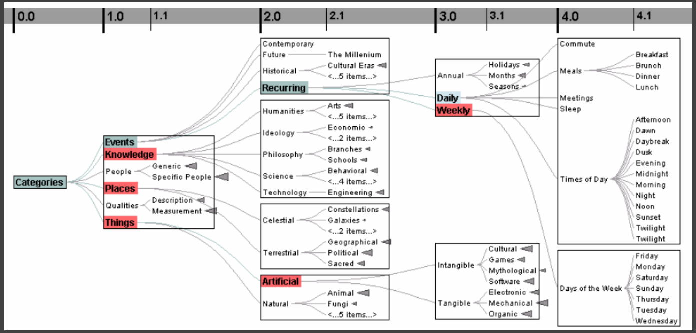


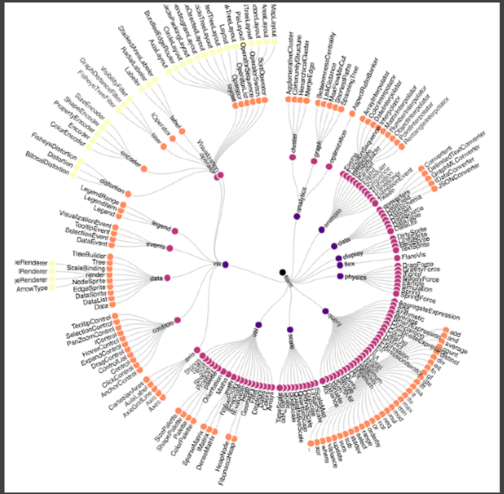
Remove “low interest” nodes at a given depth level until all blocks on a level fit within bounds.
Attempt to center child blocks beneath parents.

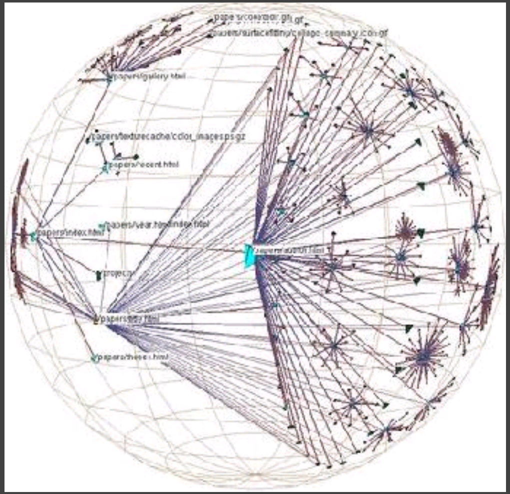
What tasks are supported/missing?











Indentation & Node-Link Diagrams

Encode structure in **2D space** (breadth/depth)

Benefits

Clearly depicts node relationships / structure

Structure-based or browsing tasks

Problems

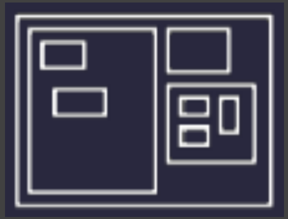
Even with tidy layout, quickly run out of space

Missing

Attribute-based encodings

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

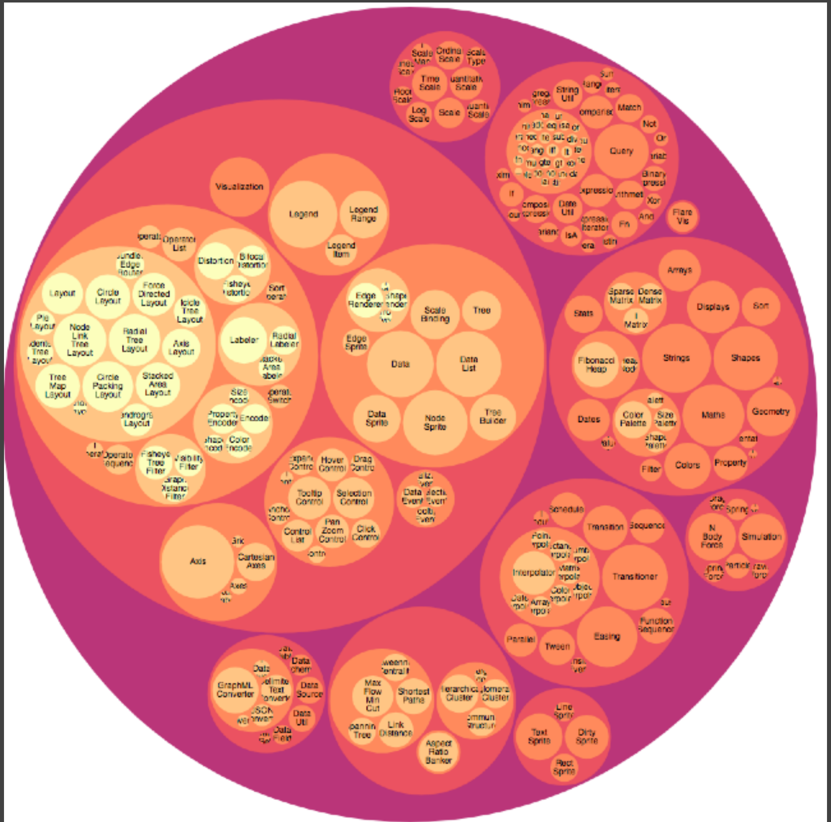
Problems
Difficult to accurately read structure / depth

Circle Packing Layout

Nodes are represented as sized circles.

Nesting shows parent-child relationships.

Issues?
Inefficient use of space.
Parent size misleading?

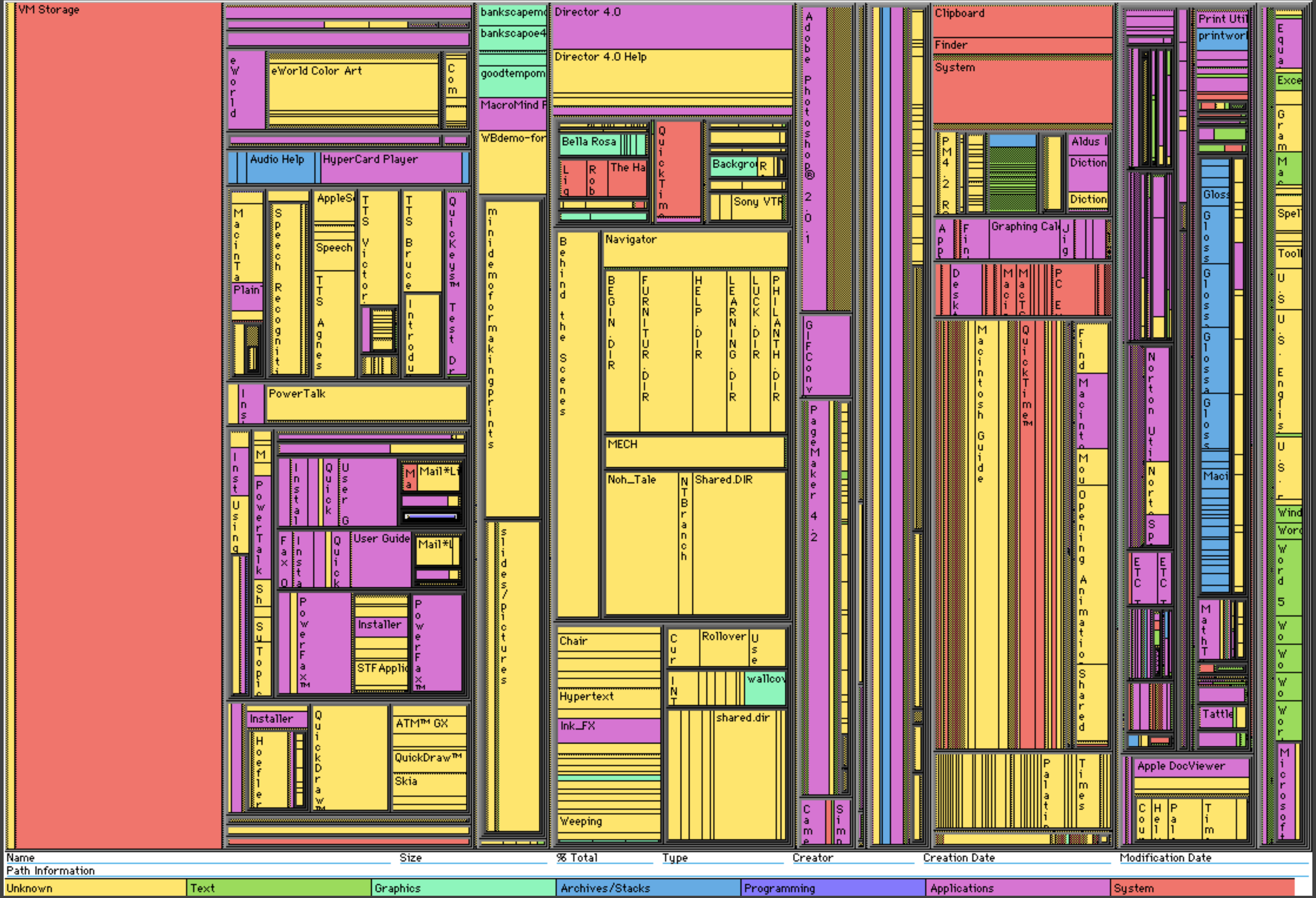


Treemaps

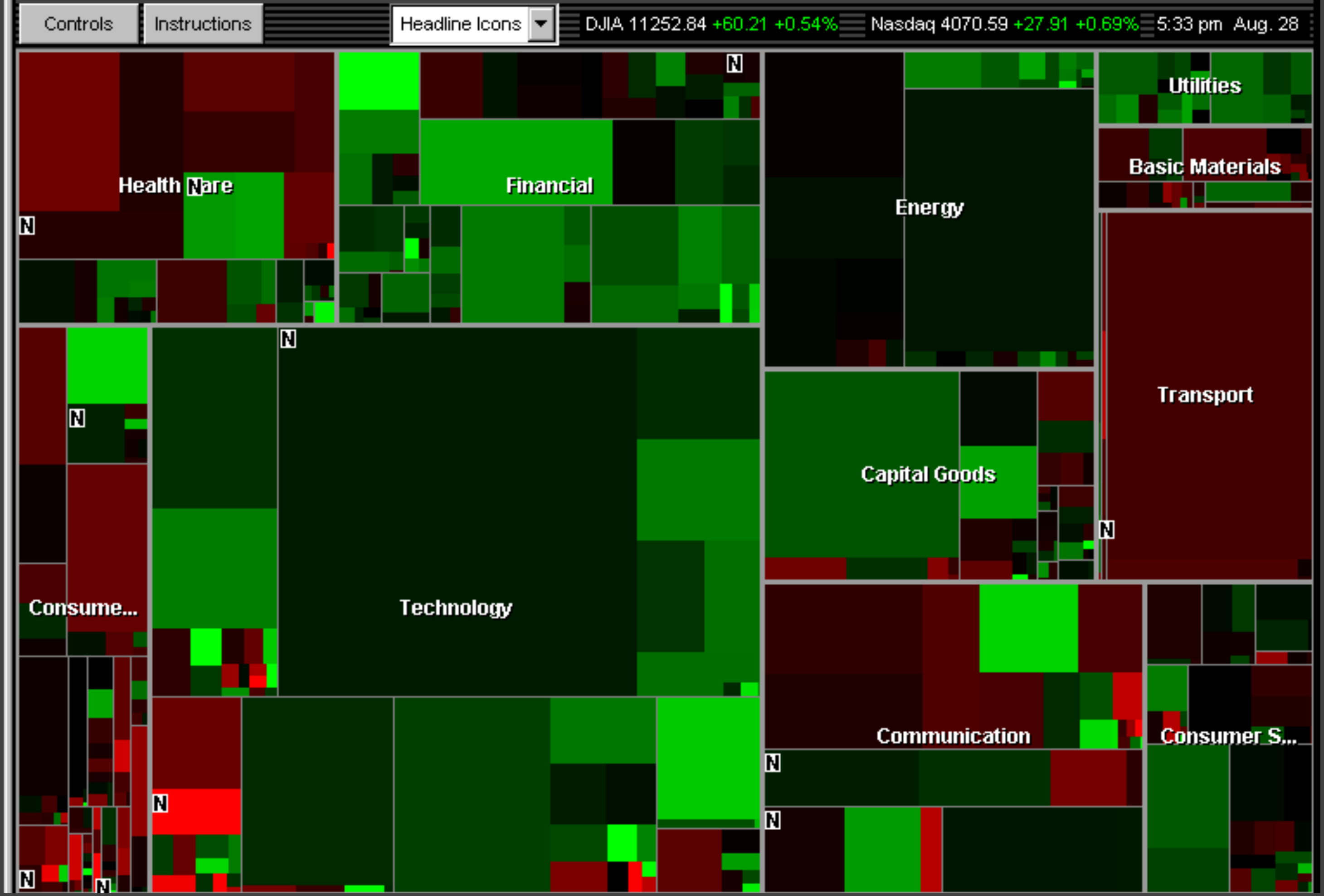
Hierarchy visualization that emphasizes values of nodes via area encoding.

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.

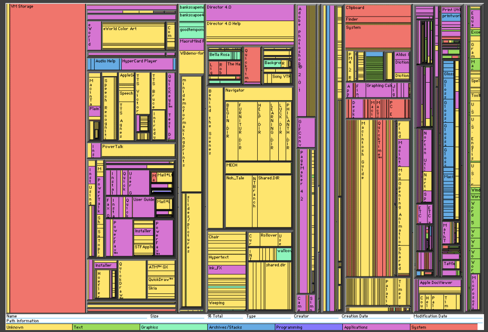


Squarifed layout: Try to produce square (1:1) aspect ratios

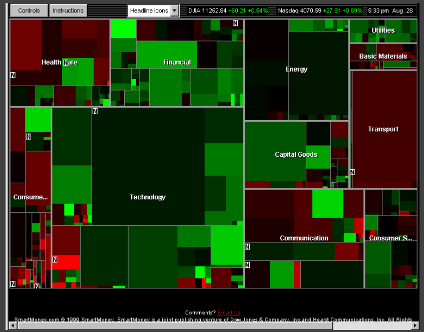
Squarified Treemaps [Bruls et al. ’00]

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.



Why Squares? [Bruls et al. ’00]

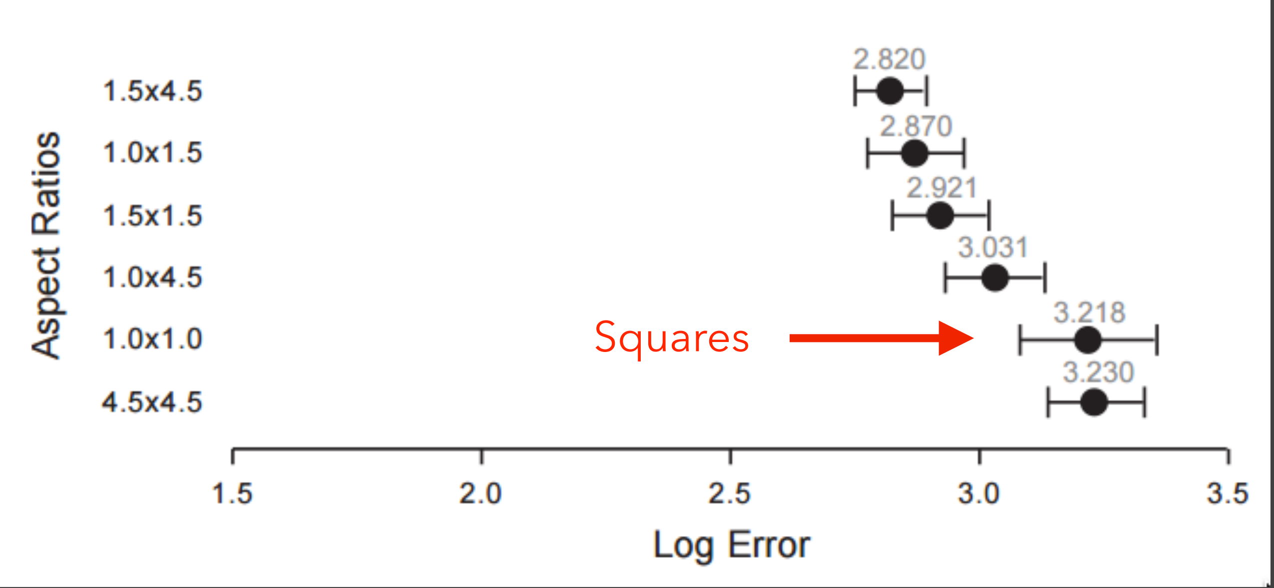
Posited Benefits of 1:1 Aspect Ratios

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?

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?

Why Squares? [Bruls et al. ’00]

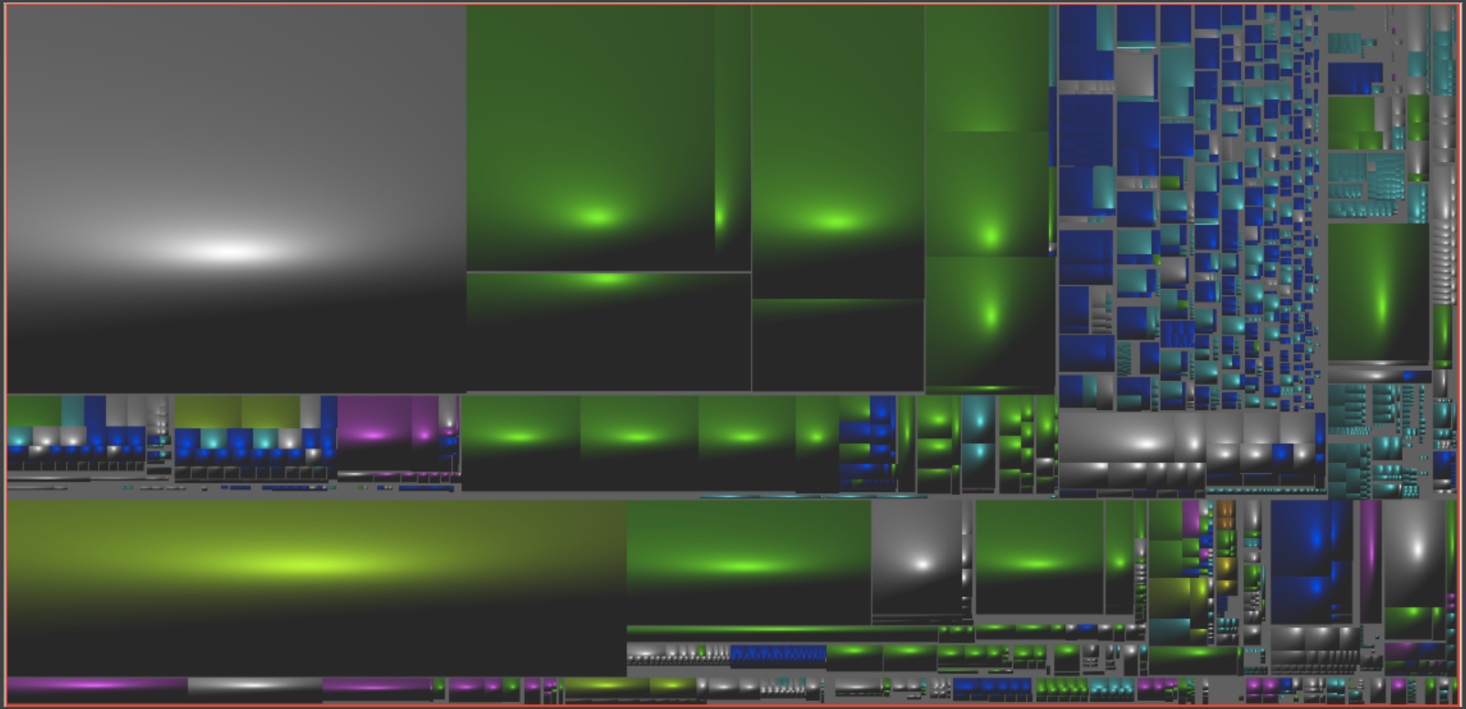
Posited Benefits of 1:1 Aspect Ratios

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

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

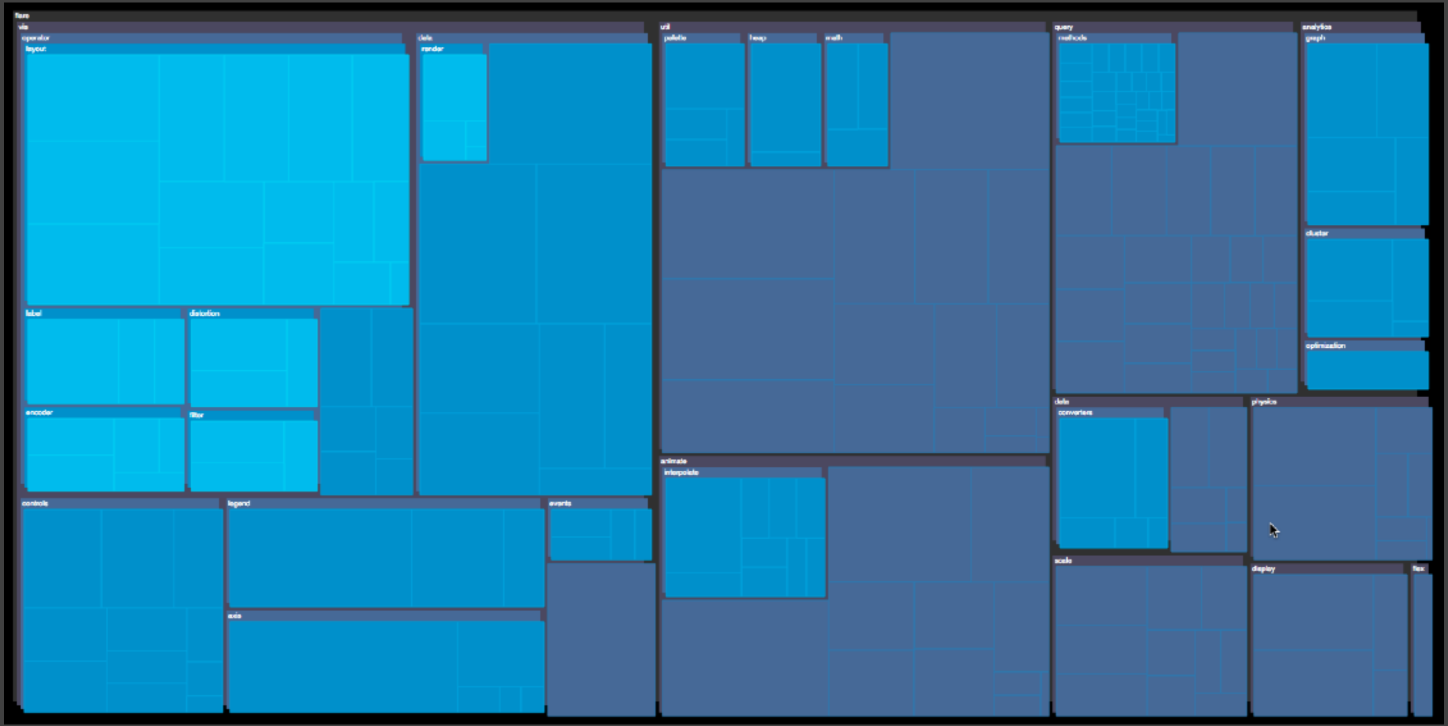
3. ~~Similar aspect ratios are easier to compare.~~
   Extreme ratios & squares-only more inaccurate.
   Balanced ratios better? Target golden ratio?

Cushion Treemaps [van Wijk & Wetering ’99]



Uses shading to emphasize hierarchal structure.

Cascaded Treemaps [Lü & Fogarty '08]

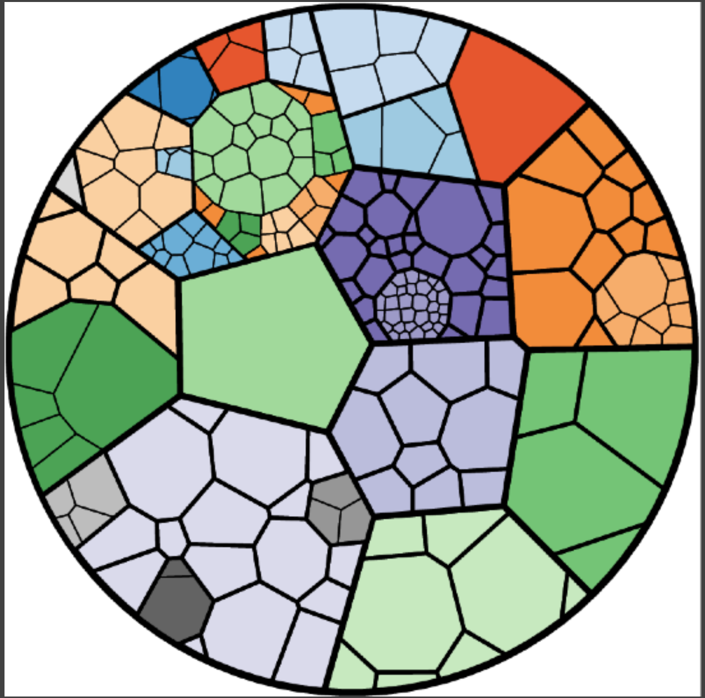


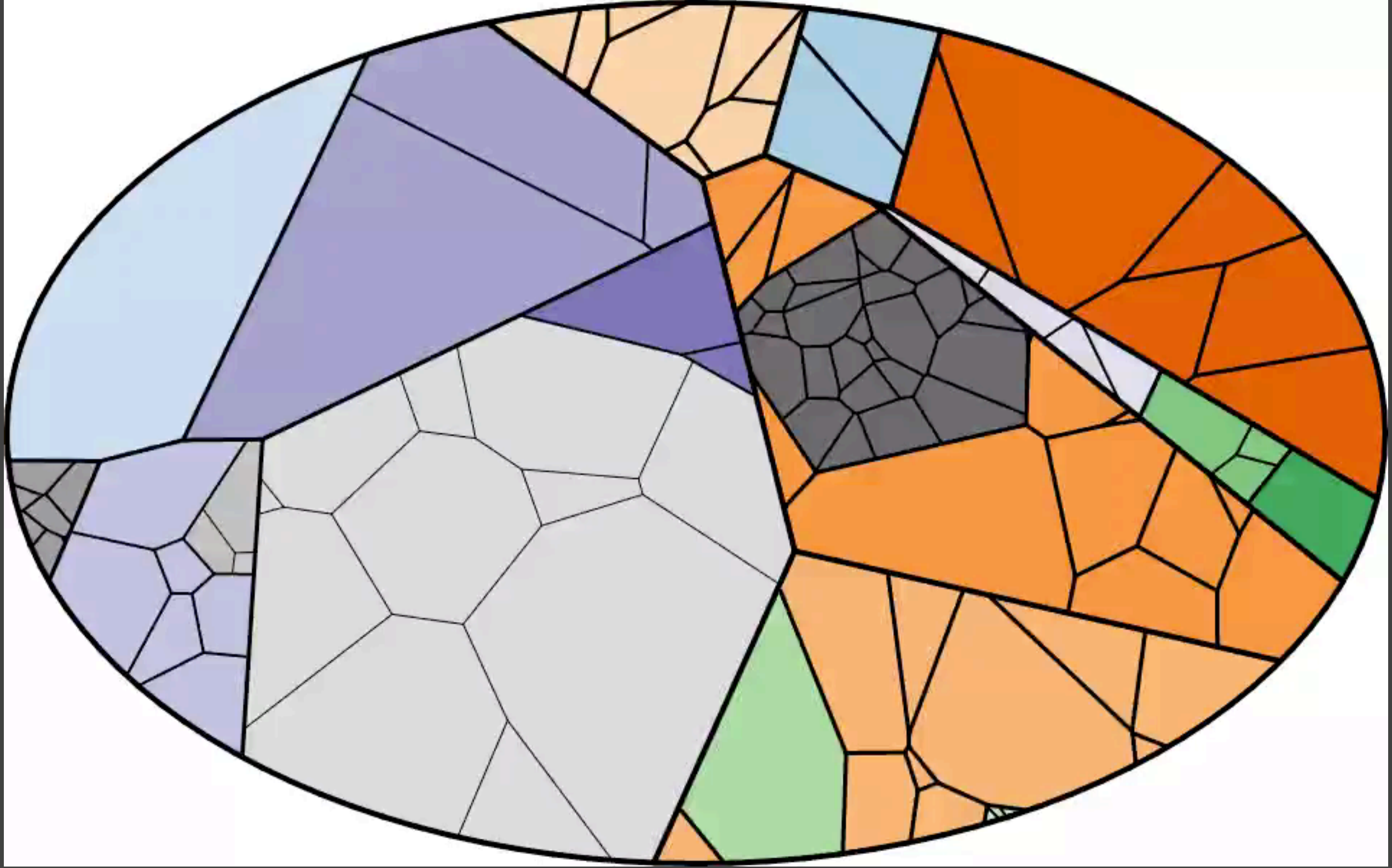
Uses 2.5D effect to emphasize hierarchy relations.

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.

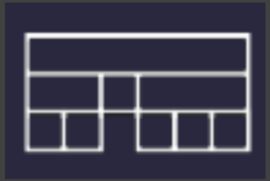




Iterative Voronoi Tesselations [Jason Davies]

Layering

Layered Diagrams

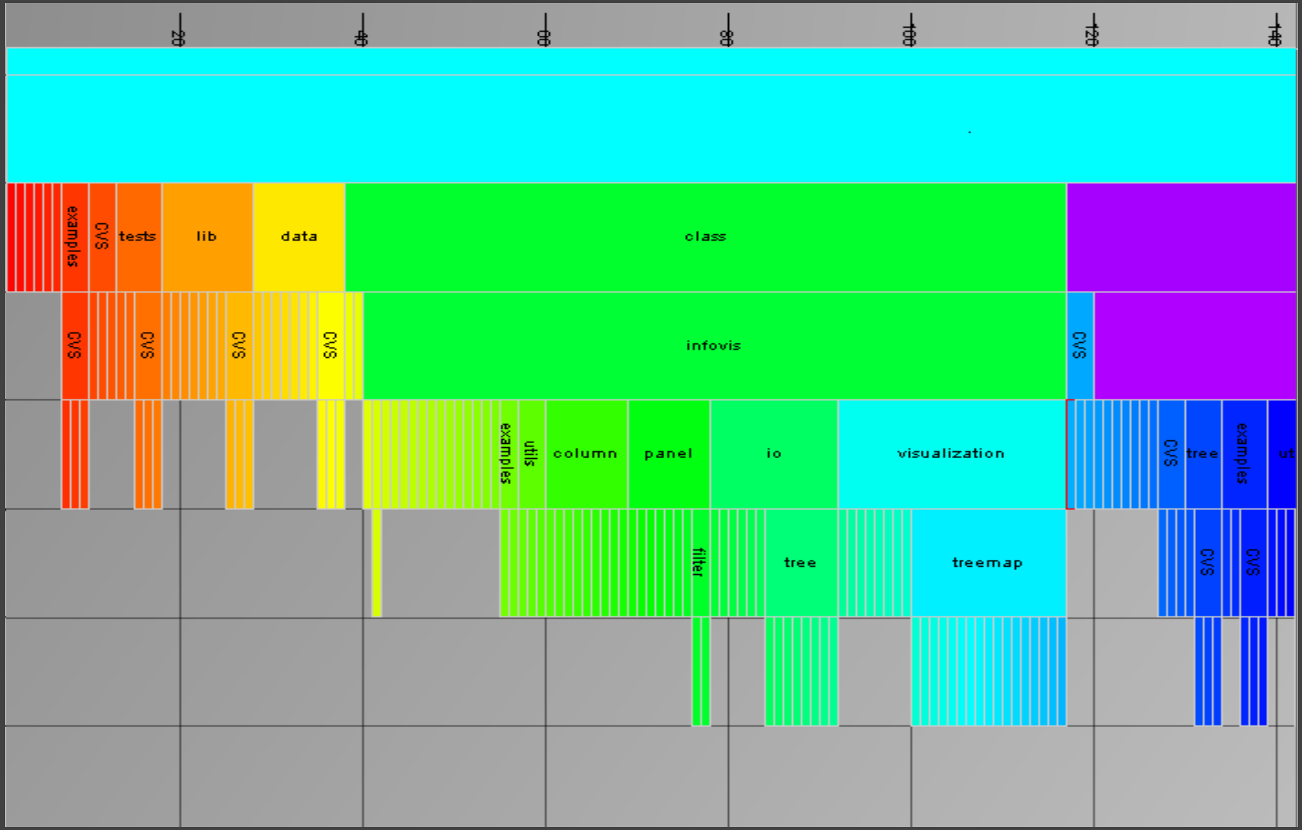


Signify tree structure using:
- Layering
- Adjacency
- Alignment

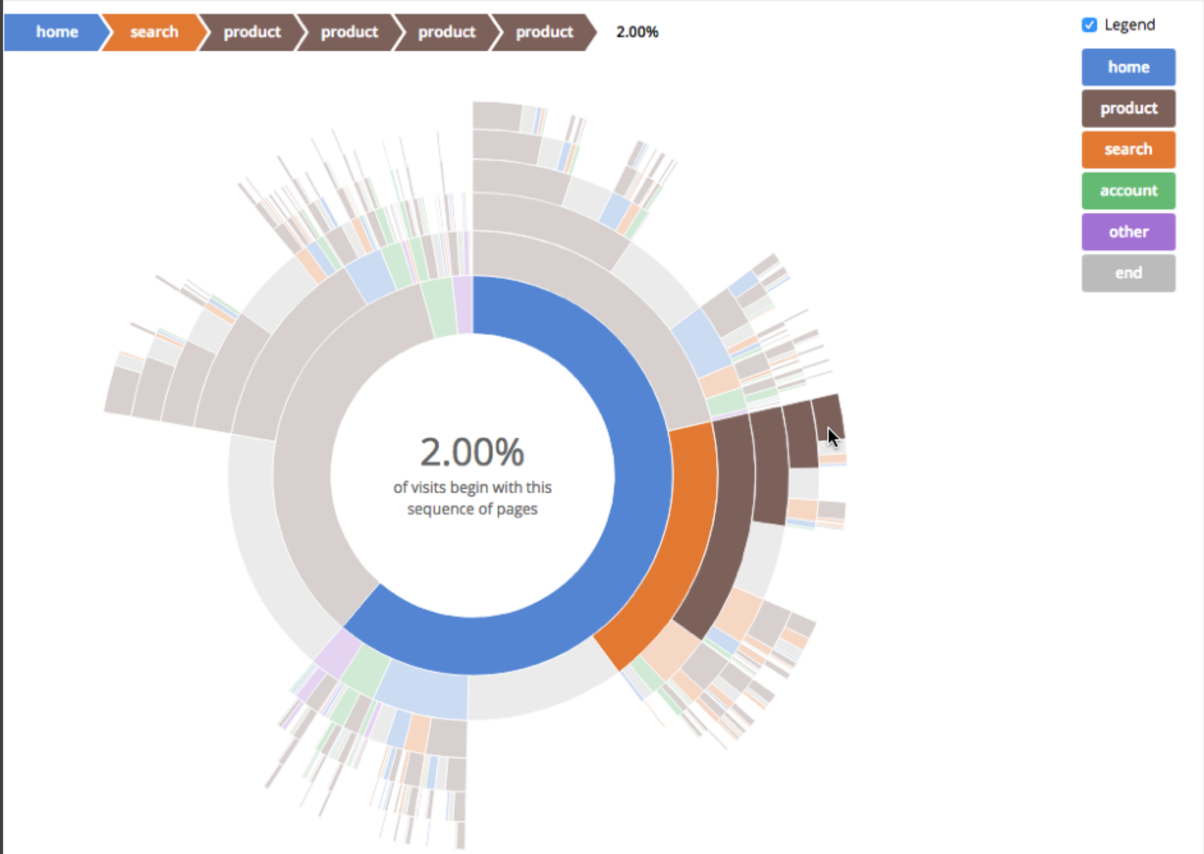
Involves recursive sub-division of space.

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

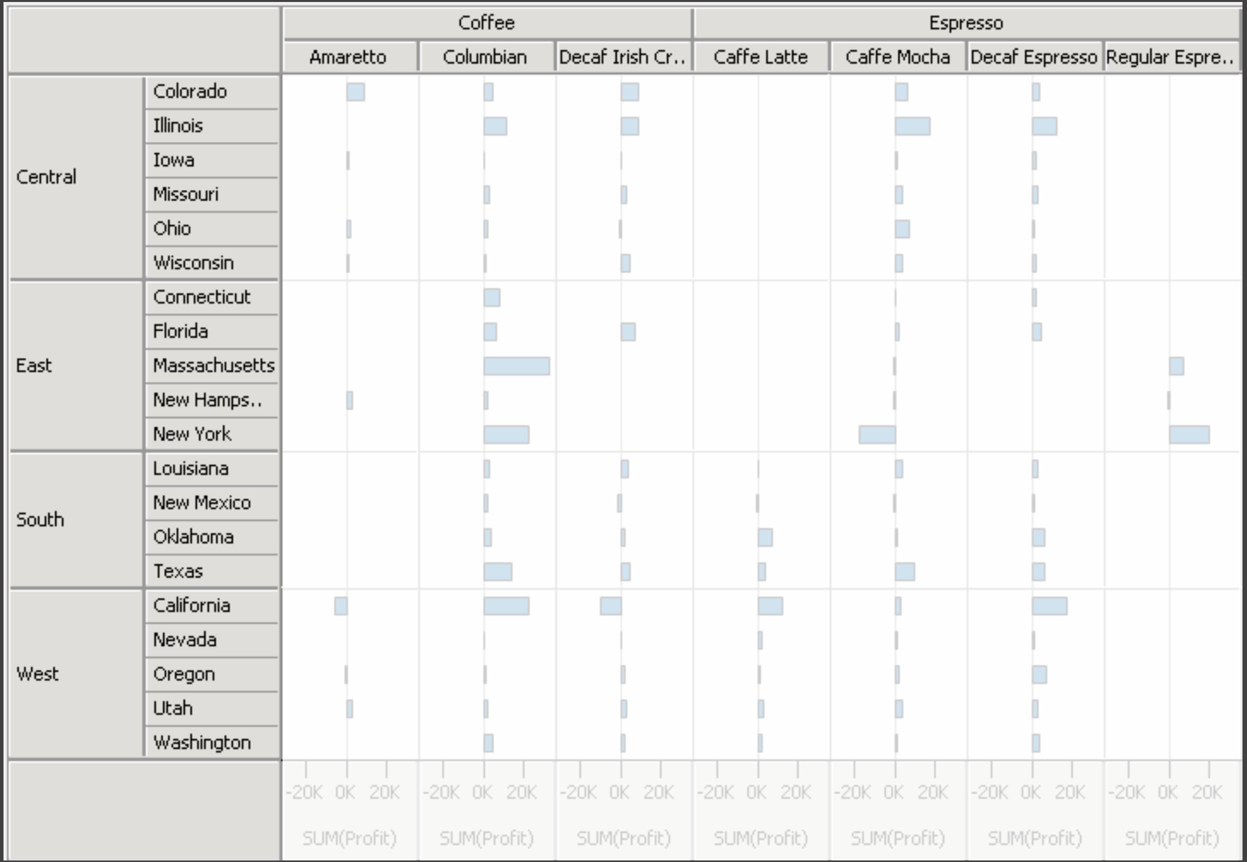
Icicle Trees: Cartesian Partition



"Sunburst" Trees: Polar Partition



Layered Trees Useful Elsewhere…



Node-Link Graph Layout

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout - arranged by depth

Force-Directed Layout - physical simulation

Attribute-Driven Layout - arranged by value

Constraint-Based Layout - optimization

Arc Diagrams - aligned layout

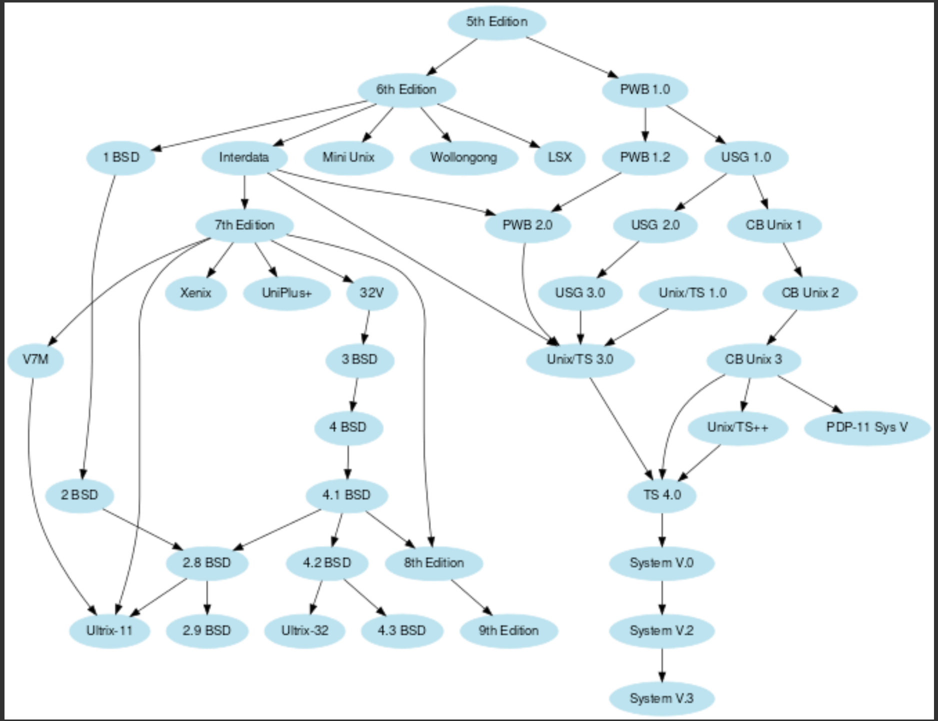
Sugiyama-Style Layout

Sugiyama-Style Layout

Evolution of the UNIX operating system

Hierarchical layering based on descent

GraphViz package!



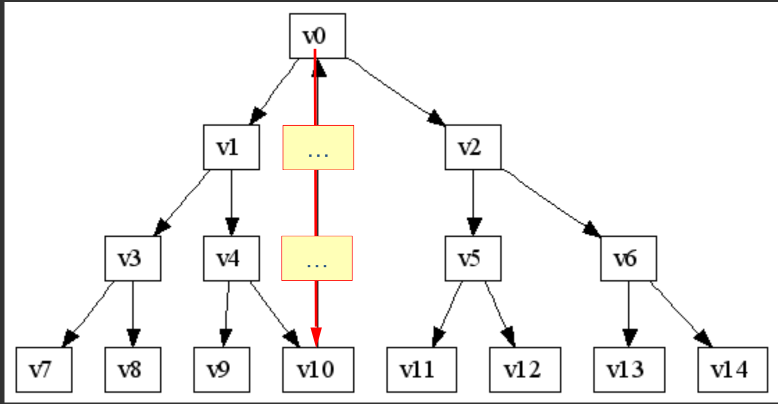
Sugiyama-Style Layout

Layer 1

Layer 2

Layer 3

Layer 4



Reverse edges to remove cycles

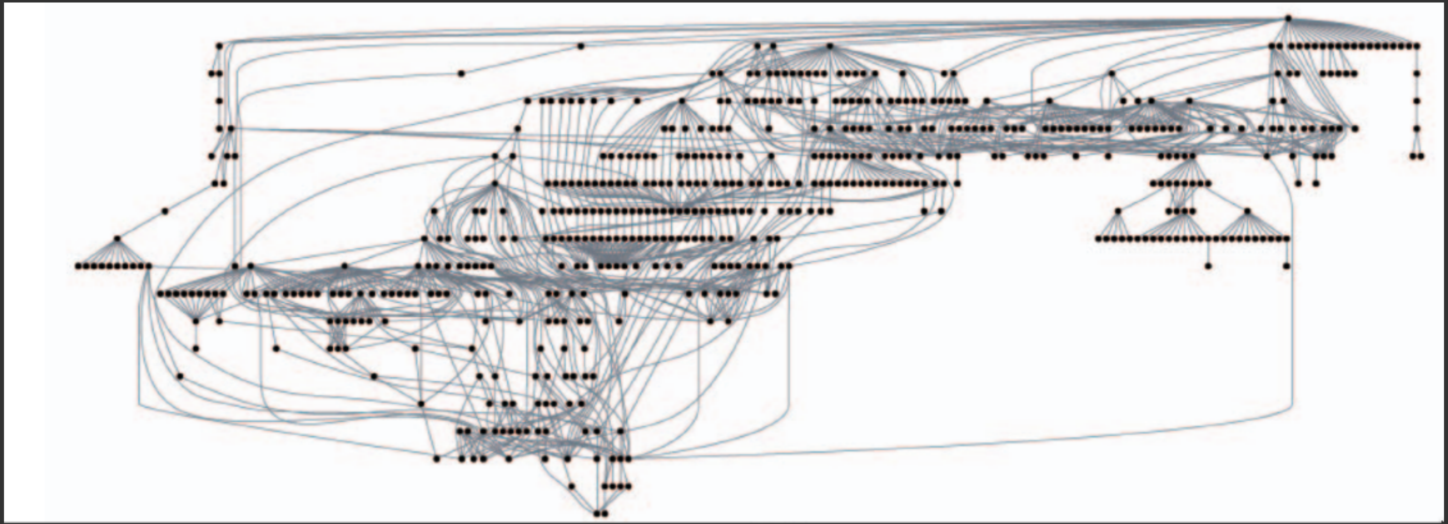
Assign nodes to hierarchy layers

Create dummy nodes to “fill in” missing layers

Arrange nodes within layer, minimize edge crossings

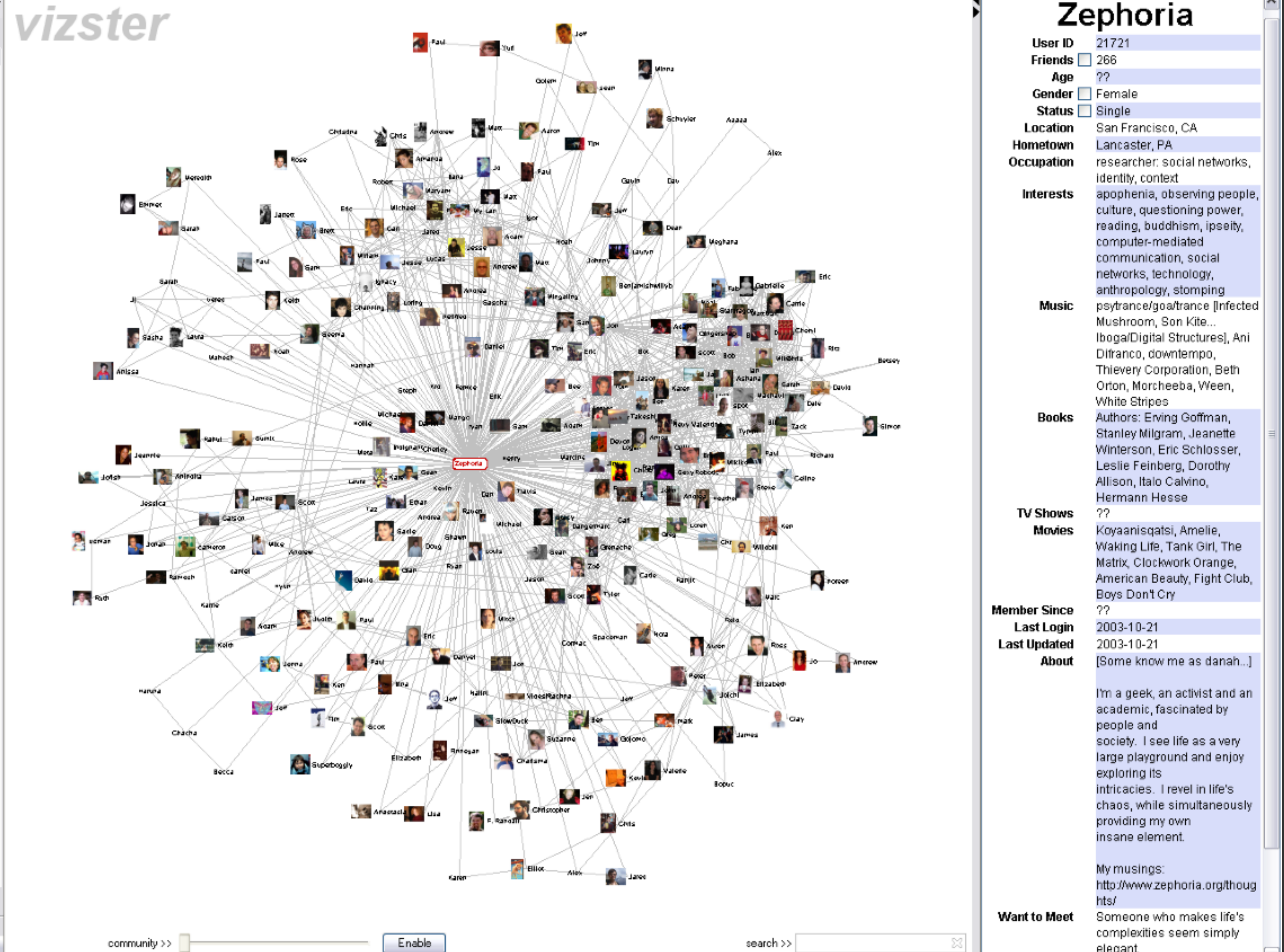
Route edges – layout splines if needed

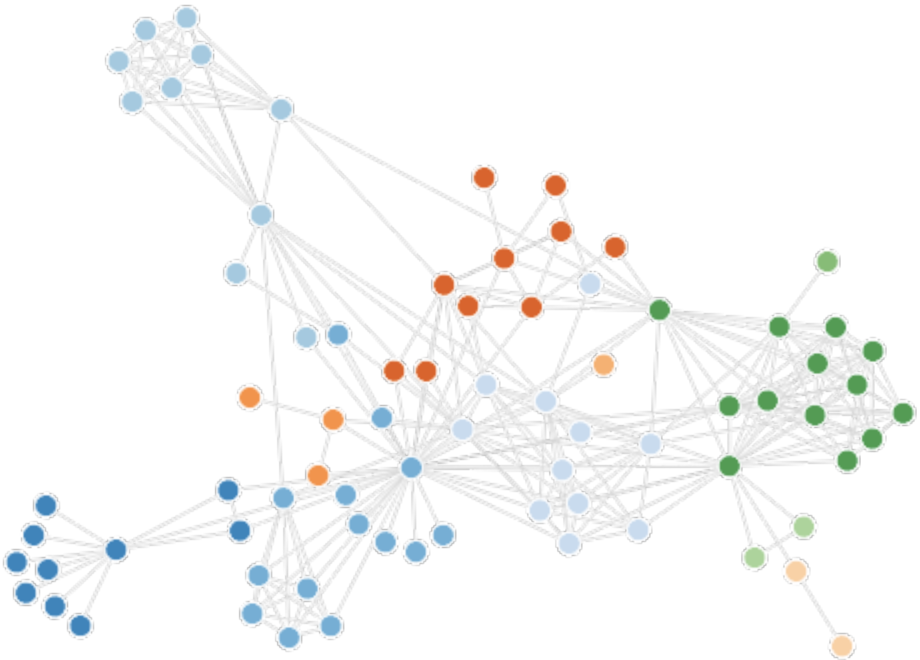
Produces Hierarchical Layouts



Sugiyama-style layout emphasizes hierarchy.
However, cycles in the graph may mislead.
Long edges can impede perception of proximity.

Force-Directed Layout


vizster
Zephoria
User ID 21721
Friends 266
Age ??
Gender Female
Status Single
Location San Francisco, CA
Hometown Lancaster, PA
Occupation researcher: social networks, identity, context
Interests apophenia, observing people, culture, questioning power, reading, buddhism, ipseity, computer-mediated communication, social networks, technology, anthropology, stomping
Music psytrance/goa/trance [Infected Mushroom, Son Kite... Iboga/Digital Structures], Ani Difranco, downtempo, Thievery Corporation, Beth Orton, Morcheeba, Ween, White Stripes
Books Authors: Erving Goffman, Stanley Milgram, Jeanette Winterson, Eric Schlosser, Leslie Feinberg, Dorothy Allison, Italo Calvino, Hermann Hesse
TV Shows ??
Movies Koyaanisqatsi, Amelie, Waking Life, Tank Girl, The Matrix, Clockwork Orange, American Beauty, Fight Club, Boys Don't Cry
Member Since ??
Last Login 2003-10-21
Last Updated 2003-10-21
About [Some know me as danah...]
I'm a geek, an activist and an academic, fascinated by people and society. I see life as a very large playground and enjoy exploring its intricacies. I revel in life's chaos, while simultaneously providing my own insane element.
My musings: http://www.zephoria.org/thoughts/
Want to Meet Someone who makes life's complexities seem simply elegant
community >>
Enable
search >>



Interactive Example: Configurable Force Layout

Use the Force!

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

Layout by Physics Simulation

Nodes = charged particles $F = q_i * q_j / d_{ij}^2$

with air resistance $F = -b * v_i$

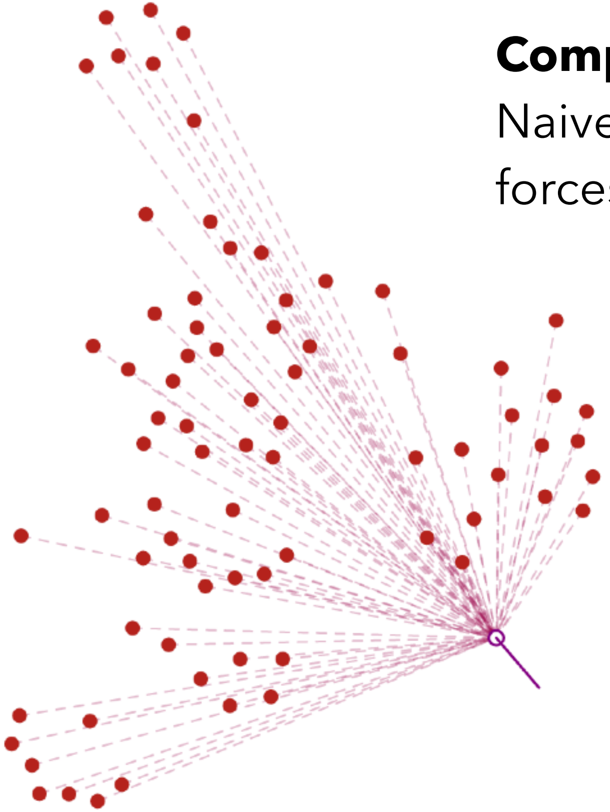
Edges = springs $F = k * (L - d_{ij})$

At each timestep, calculate forces acting on nodes.
Integrate for updated velocities and positions.

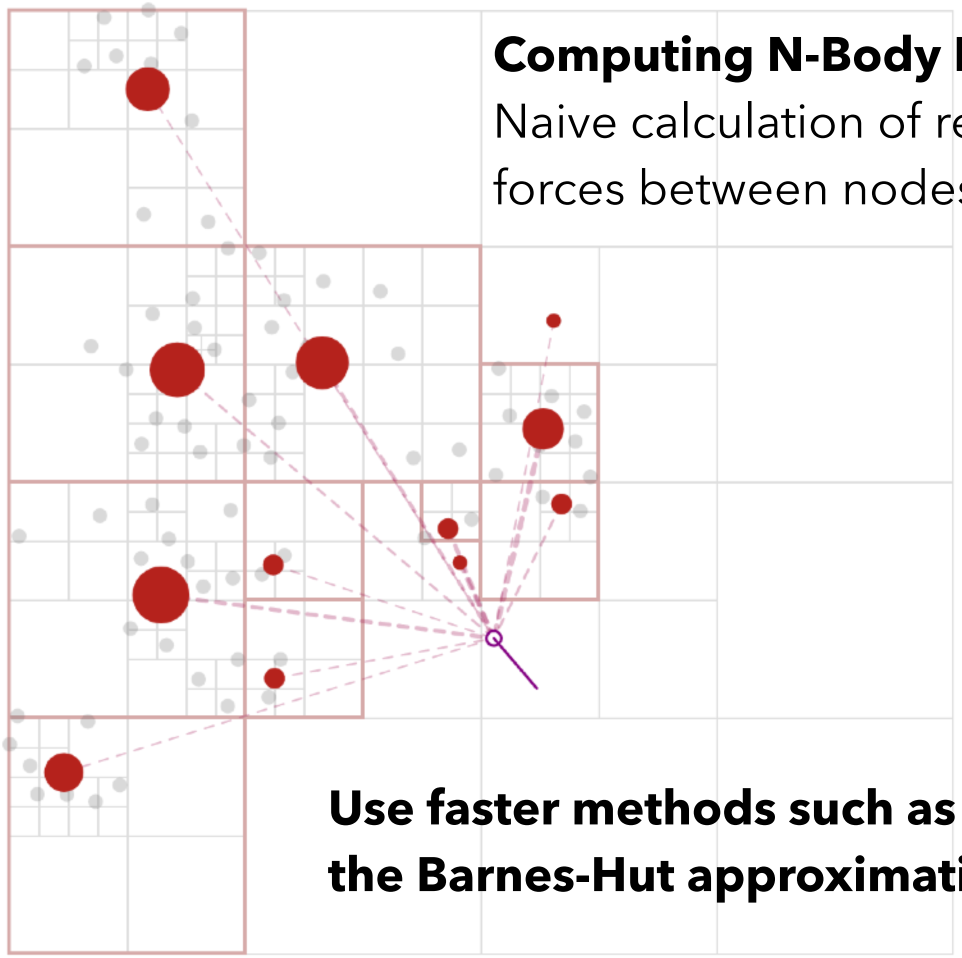
D3's force layout uses **velocity Verlet** integration.
Assume uniform mass ***m*** and timestep ***Δt***:
$F = ma \rightarrow F = a \rightarrow F = \Delta v / \Delta t \rightarrow F = \Delta v$
Forces simplify to velocity offsets!

Computing N-Body Forces

Naive calculation of repulsive forces between nodes is $O(n^2)$



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



Computing N-Body Forces

Naive calculation of repulsive forces between nodes is $O(n^2)$

Use faster methods such as the the Barnes-Hut approximation!

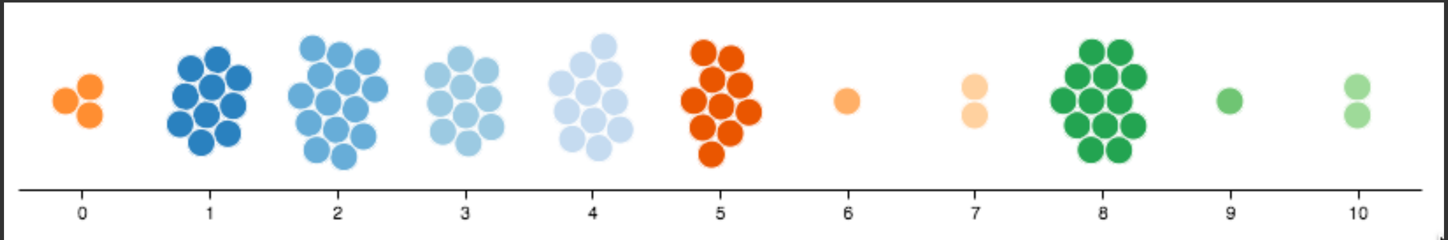
Customized Force Layouts

Different forces can be composed to create an expressive space of custom layouts.

A **beeswarm plot** can be made by combining:

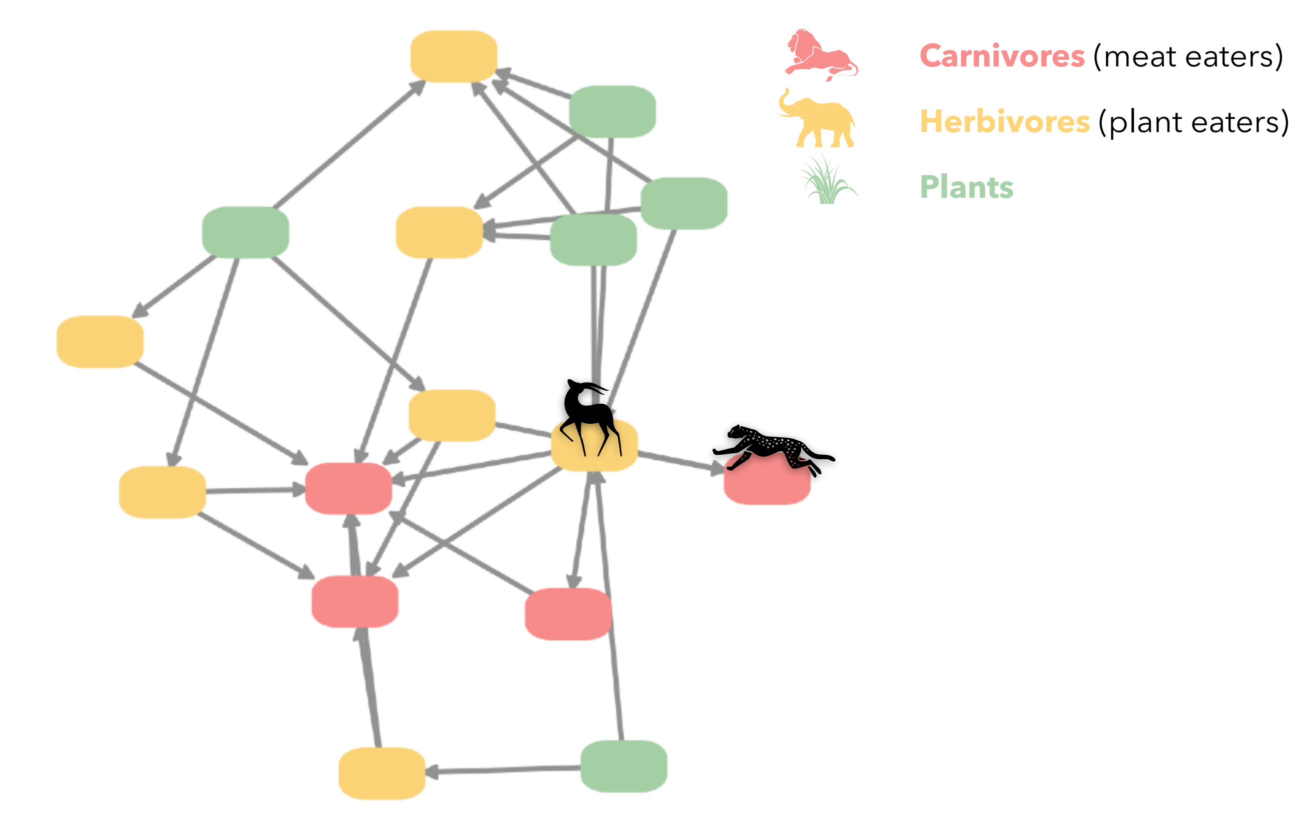
Attractive **X** and **Y** forces to draw nodes of a certain category to a desired point

Collide force to detect collision & remove overlap

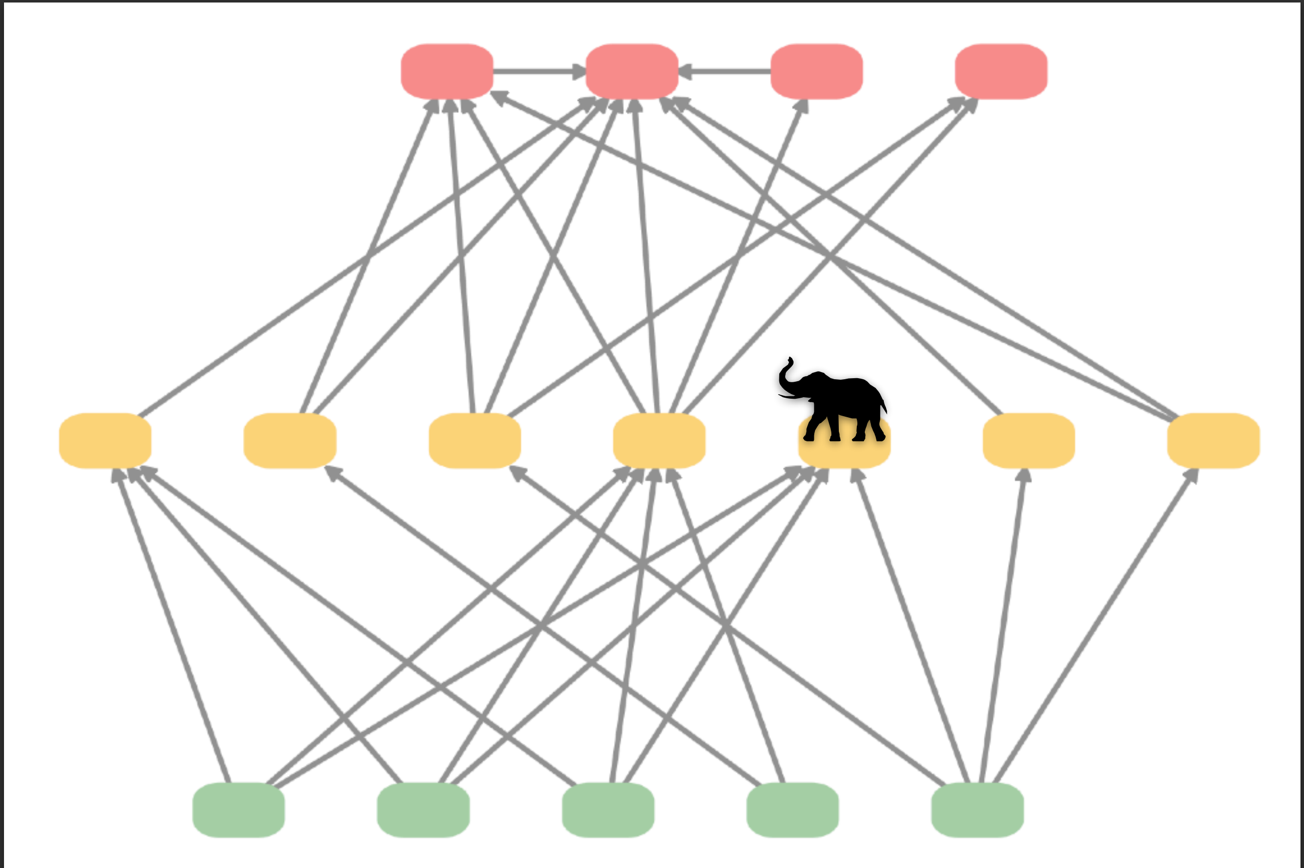


Attribute-Driven Layout

How many herbivores have no predators?



How many herbivores have no predators?



Attribute-Driven Layout

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

Idea: Use **data attributes** to perform layout
For example, scatter plot based on node values

Attributes may be associated with nodes or edges
or may be statistical properties of the graph.

Use dynamic queries / brushing to explore…

Attribute-Driven Layout

The "Skitter" Layout

Internet Connectivity

Radial Scatterplot

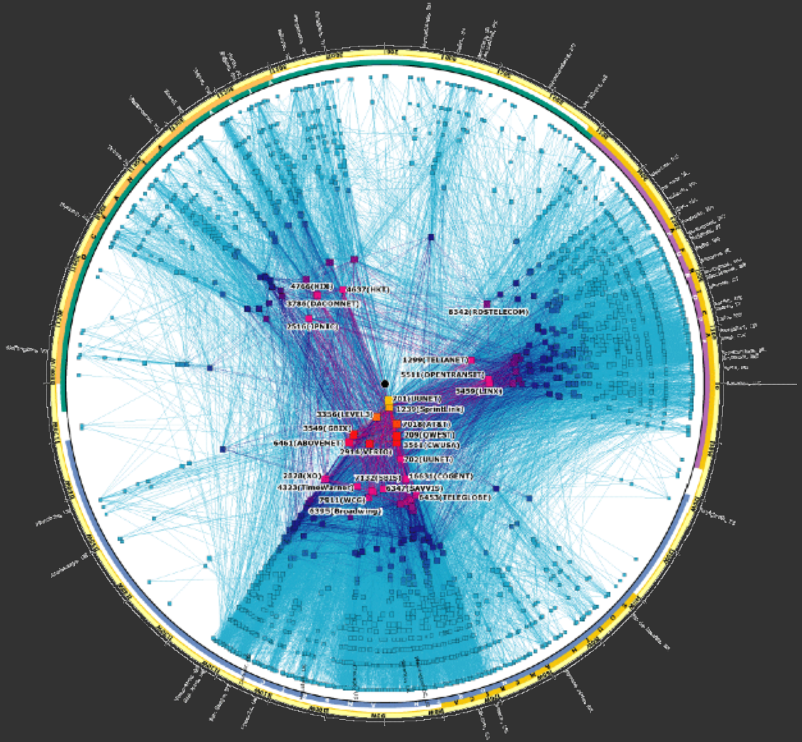
Angle = Longitude

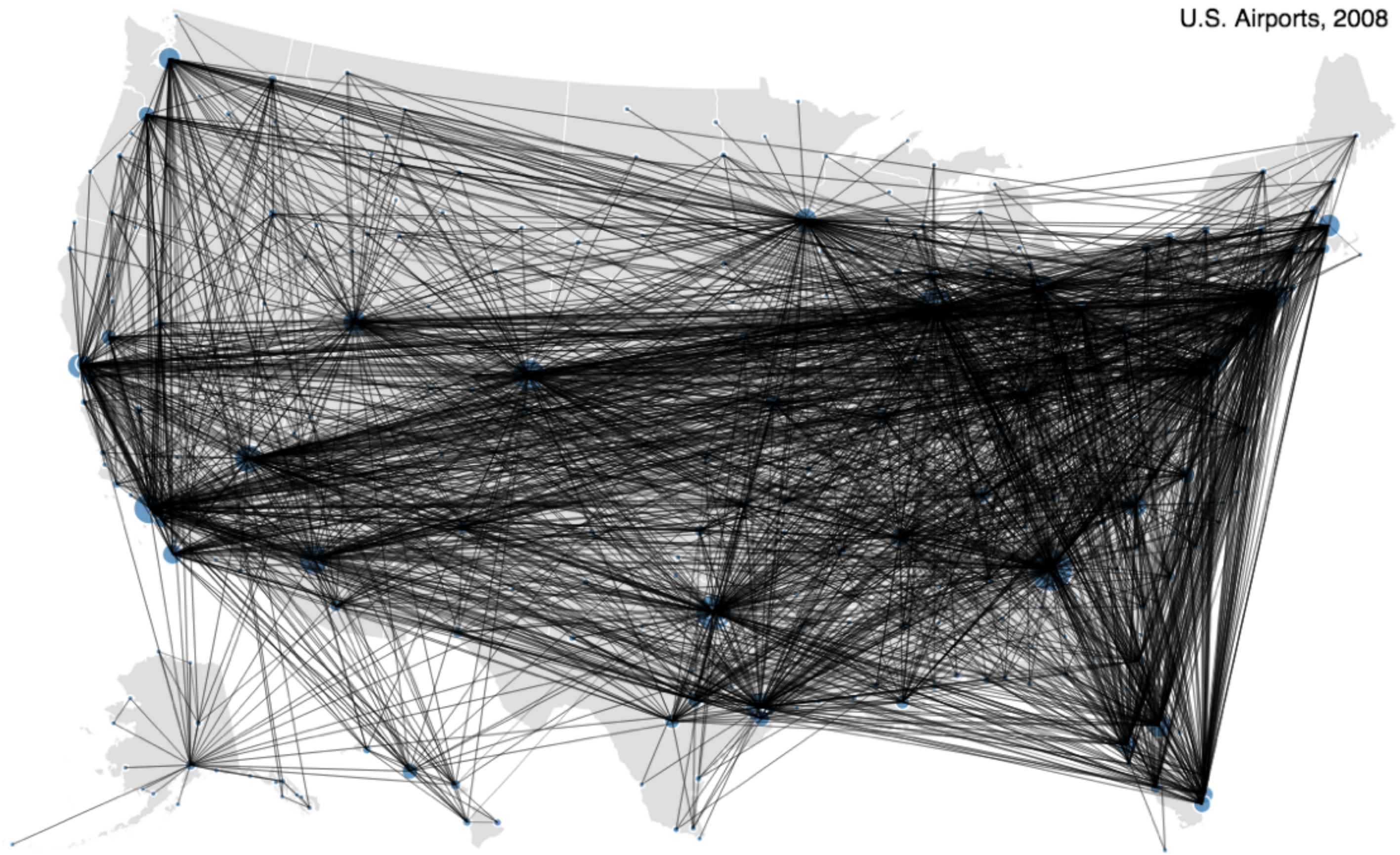
Geography

Radius = Degree

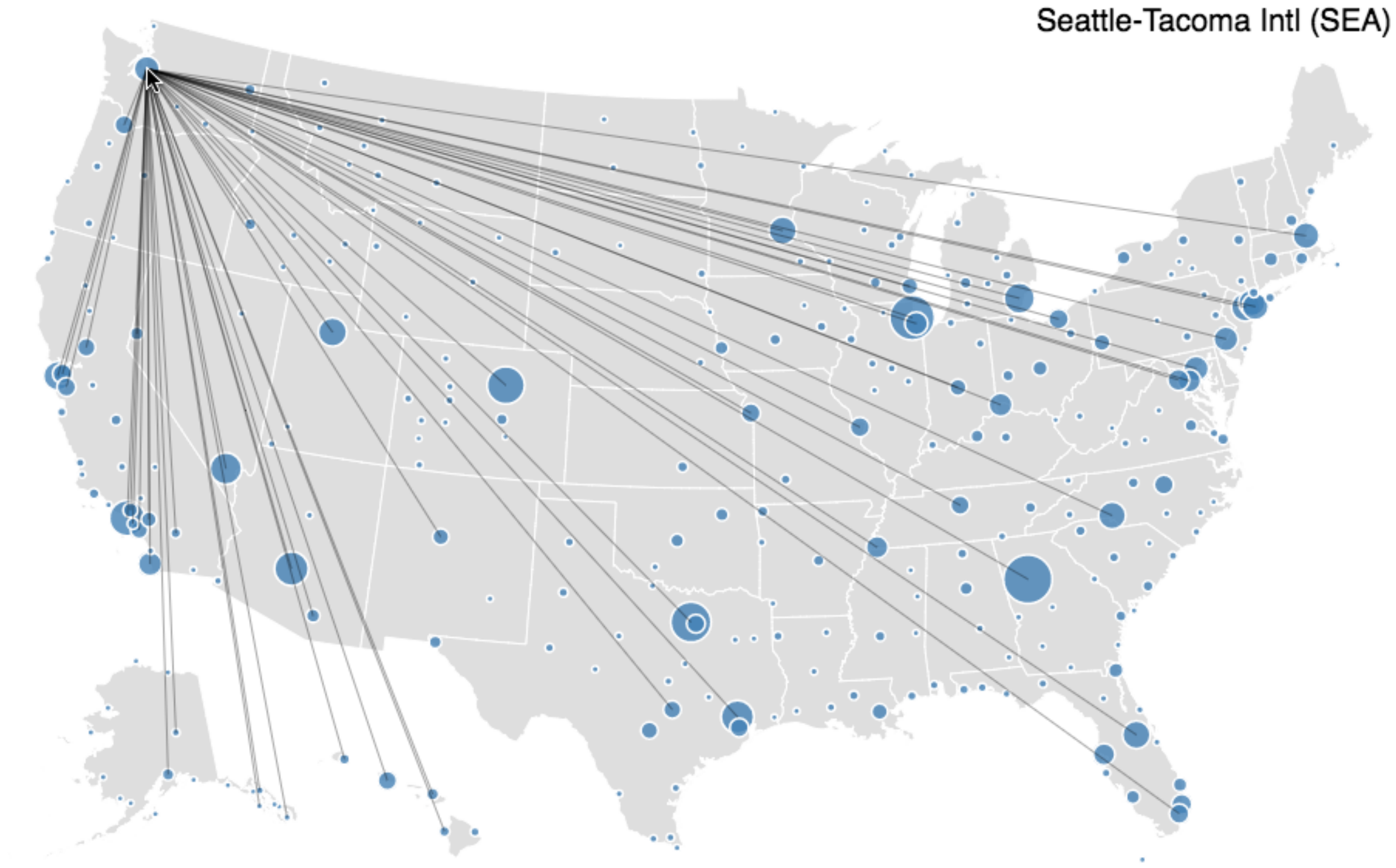
# of connections

(a statistic of the nodes)



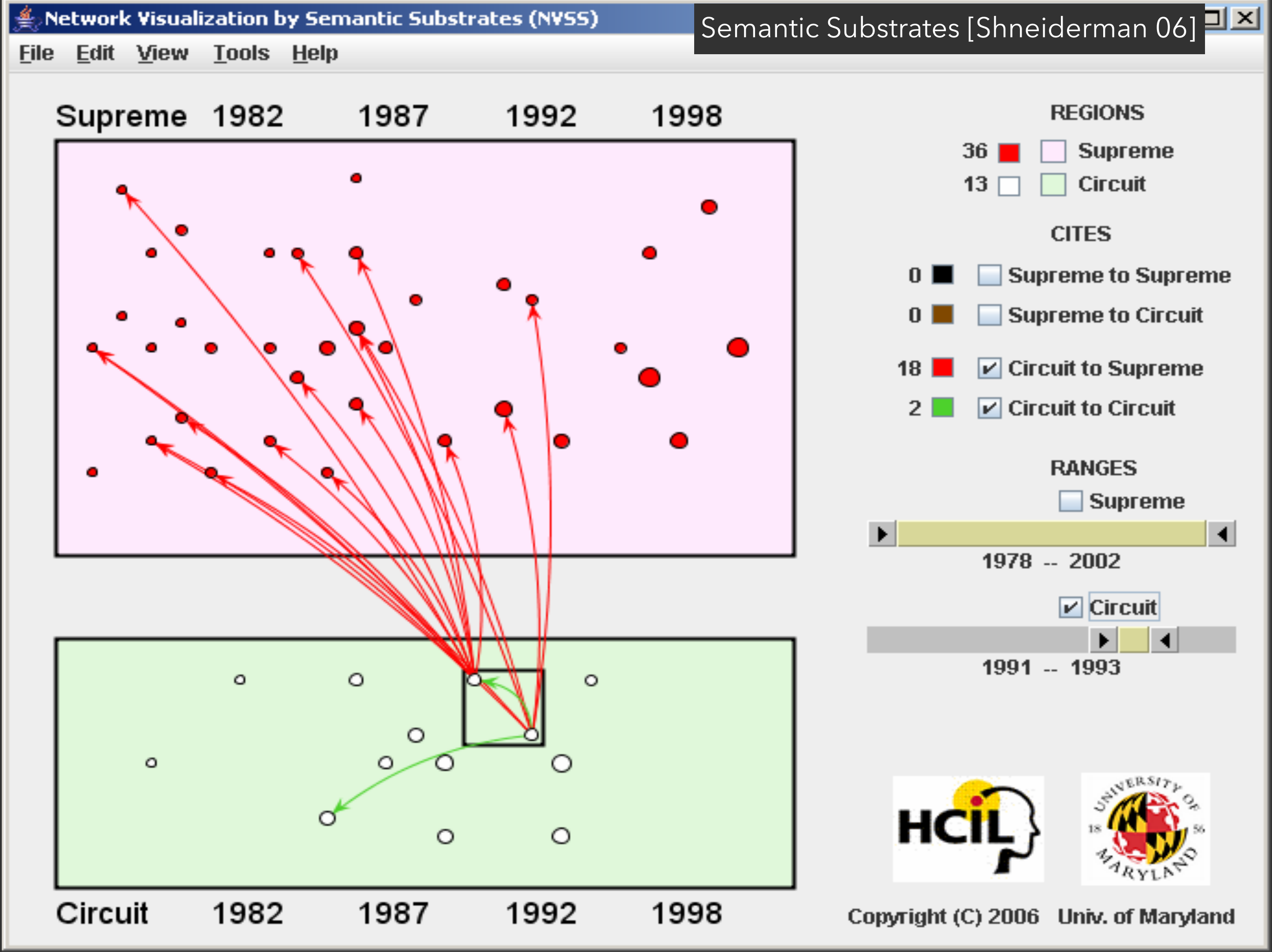


Drawing all edges is not particularly useful here…



Node layout determined by geographic location.
Adjacent edges shown on node selection.

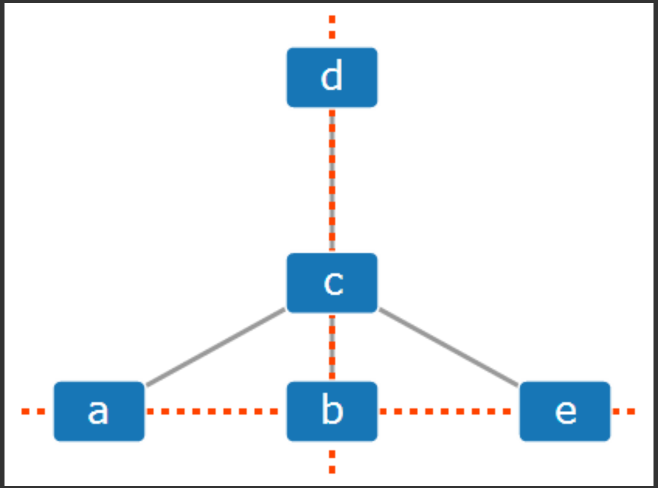
Semantic Substrates [Shneiderman 06]



Constraint-Based Layout

Constraint-Based Layout

Treat layout as an *optimization problem*
Define layout using an *energy model* along with *constraints*: equations the layout should obey.
Use optimization algorithms to solve



Position Constraints:

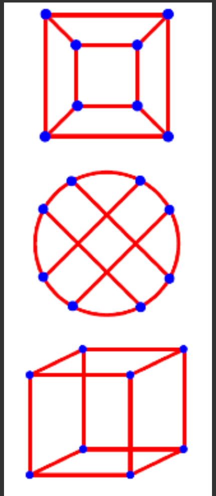
a must be to the left of b

d, c, and b must have the same x position

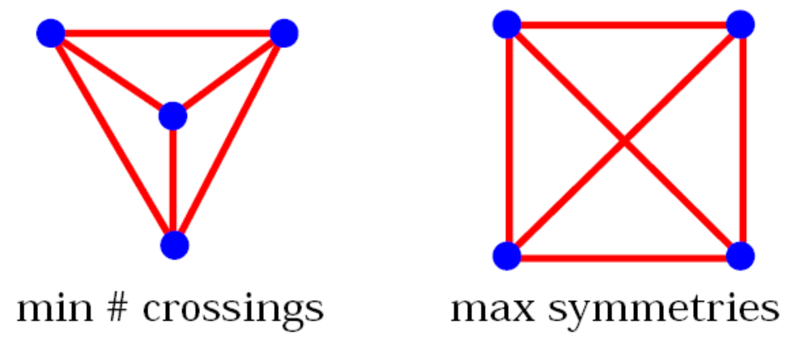
a, b, and e must have the same y position

Optimizing Aesthetic Constraints

Minimize edge crossings
Minimize area
Minimize line bends
Minimize line slopes
Maximize smallest angle between edges
Maximize symmetry

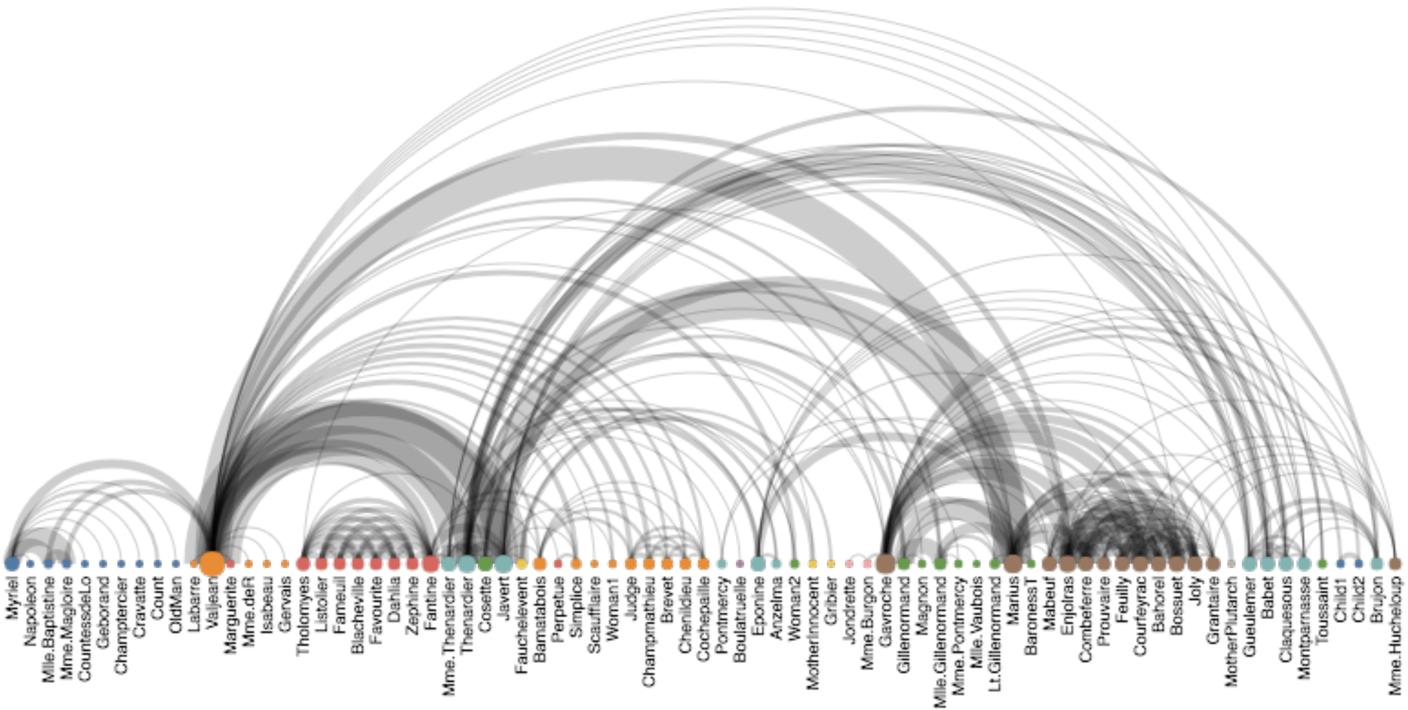


but, can't do it all.

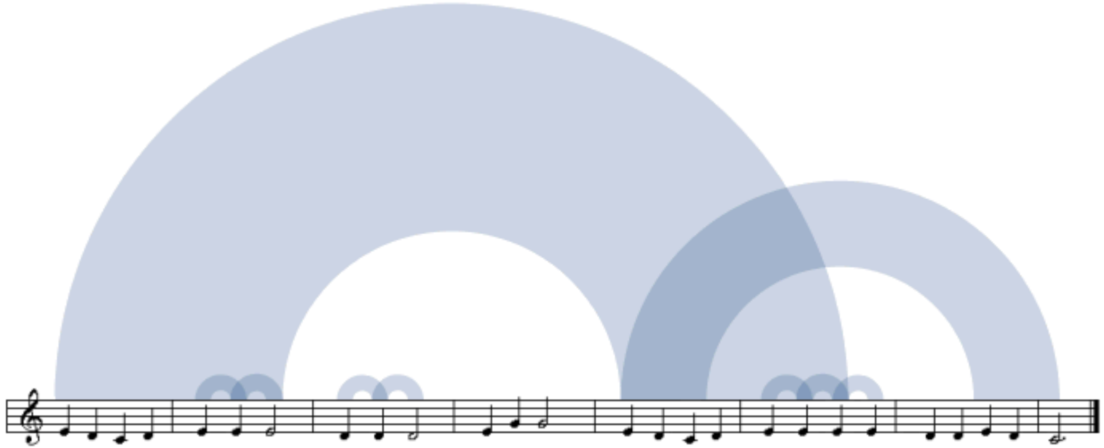


Optimizing these criteria is often NP-Hard, requiring approximations.

Arc Diagrams



Linear node layout, circular arcs show connections.
Layout quality sensitive to node ordering!



For example, the picture above was built from the first line of a very simple piece: *Mary Had a Little Lamb*. Each arch connects two identical passages. To clarify the connection between the visualization and the song, in this diagram the score is displayed beneath the arches.

The Shape of Song

[Wattenberg '01]

This diagram visualizes the refrain from the folk song *Clementine*. As you would expect, the refrain consists of multiple repetitions of the same passage--and that is exactly what the diagram shows. The score isn't shown in this diagram since the notes would be too small to read.

Task Analysis

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout - arranged by depth

Force-Directed Layout - physical simulation

Attribute-Driven Layout - arranged by value

Constraint-Based Layout - optimization

Arc Diagrams - aligned layout

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout

The Good: *Structured-based analysis of hierarchical relationships*
The Bad: *Browsing and path following due to long edges*

Force-Directed Layout

Attribute-Driven Layout

Constraint-Based Layout

Arc Diagrams

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout

Force-Directed Layout

Attribute-Driven Layout

Constraint-Based Layout

Arc Diagrams

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout

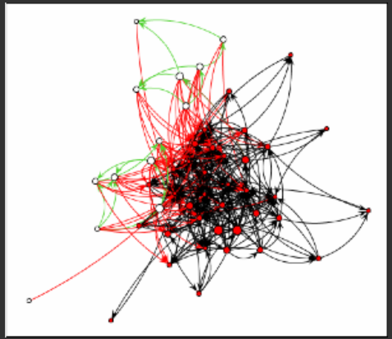
Force-Directed Layout

The Good: *Structured-based analysis of closely related elements*
The Bad: *Browsing and summarization of dense networks*

Attribute-Driven Layout

Constraint-Based Layout

Arc Diagrams



Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout

Force-Directed Layout

Attribute-Driven Layout

Constraint-Based Layout

Arc Diagrams

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout

Force-Directed Layout

Attribute-Driven Layout

The Good: *Attribute-based analysis tasks*
The Bad (Difficult): *Designing layouts appropriately*

Constraint-Based Layout

Arc Diagrams

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout

Force-Directed Layout

Attribute-Driven Layout

Constraint-Based Layout

Arc Diagrams

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout

Force-Directed Layout

Attribute-Driven Layout

Constraint-Based Layout

The Good: *Graph layout based on structural/aesthetic properties*
The Bad (Difficult): *Selecting constraints appropriately*

Arc Diagrams

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout

Force-Directed Layout

Attribute-Driven Layout

Constraint-Based Layout

Arc Diagrams

Node-Link Graph Visualization

Nodes connected by lines/curves

Sugiyama-Style Layout

Force-Directed Layout

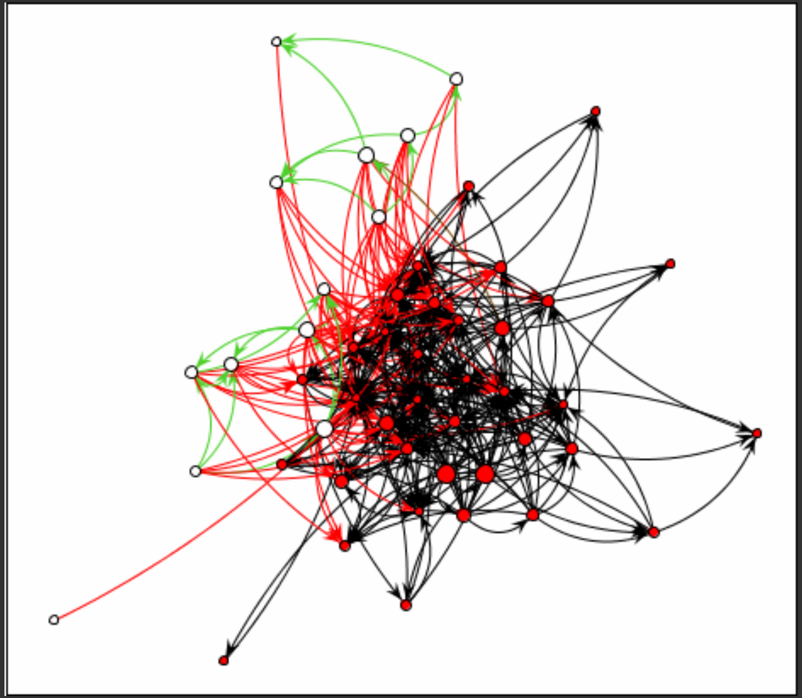
Attribute-Driven Layout

Constraint-Based Layout

Arc Diagrams

The Good: *Summarization and comparison of overall structure*
The Bad: *Order matters for node layout; Structure-based and path following*

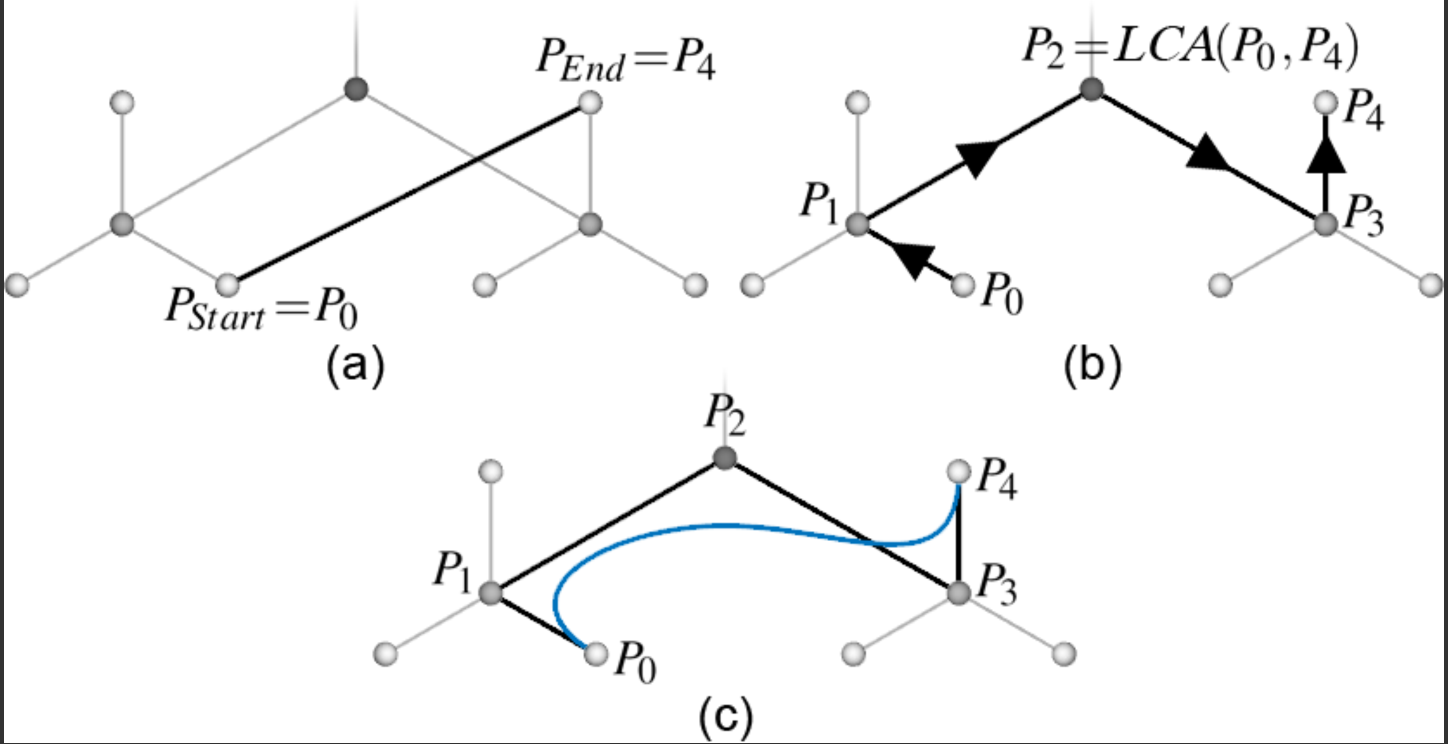
Limitations of Node-Link Layouts



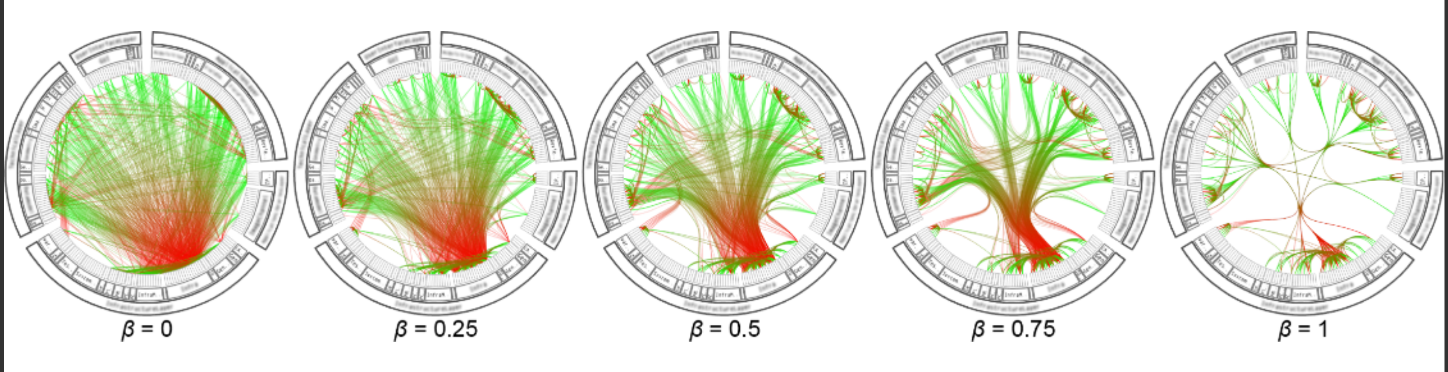
Edge-crossings and occlusion! Poor scalability….

Hierarchical Edge Bundling

Bundle Edges Along Tree Paths



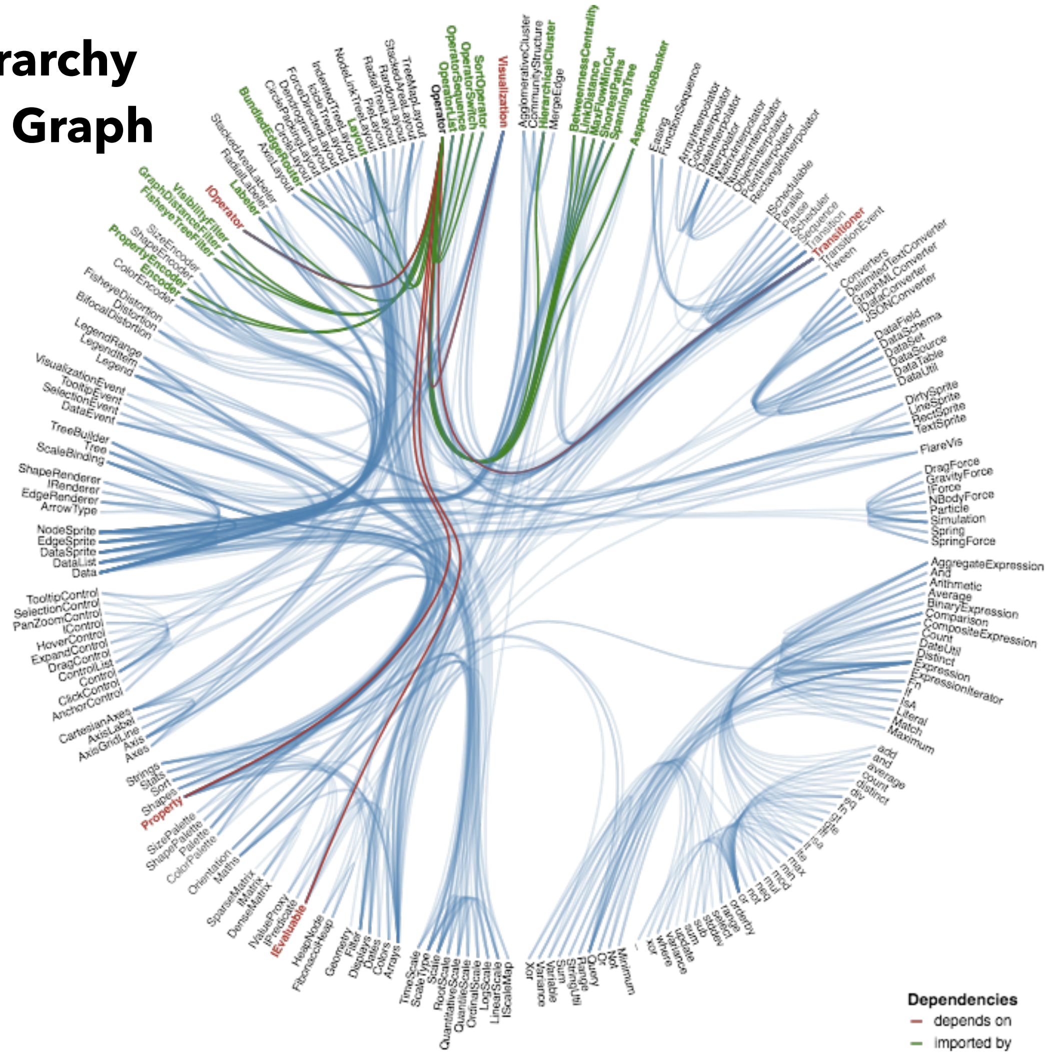
Hierarchical Edge Bundling



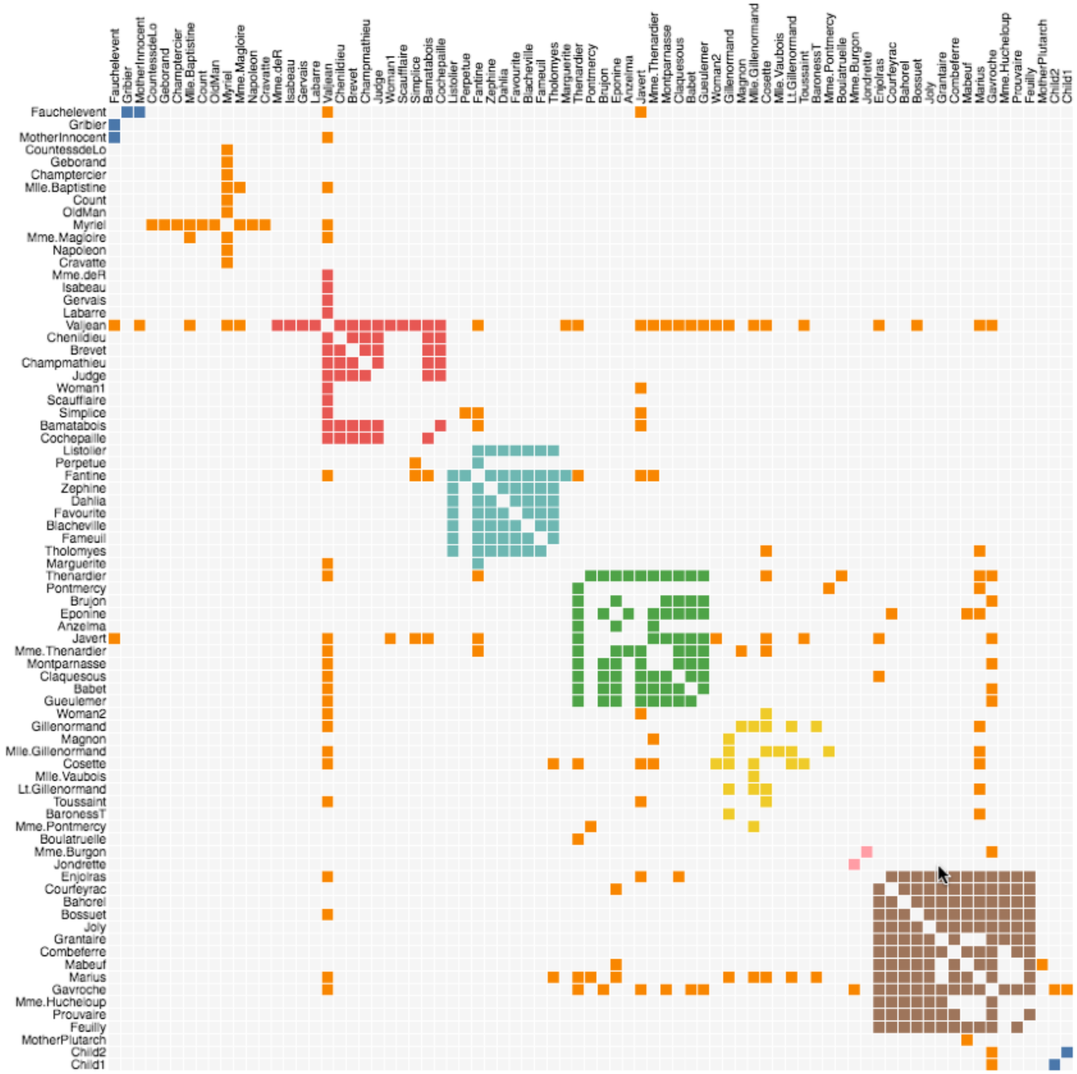
Bundle edges with varying amounts of tension

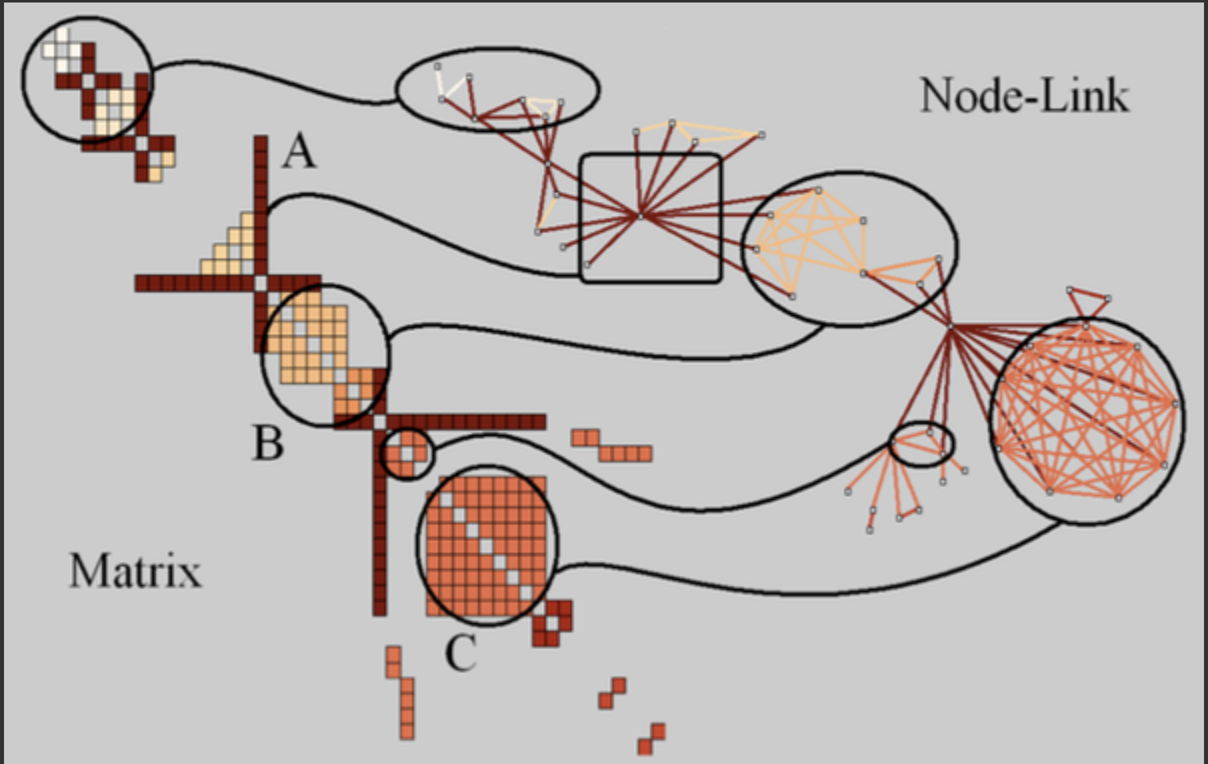
Low-level vs. high-level information

Flare Class Hierarchy & Dependency Graph

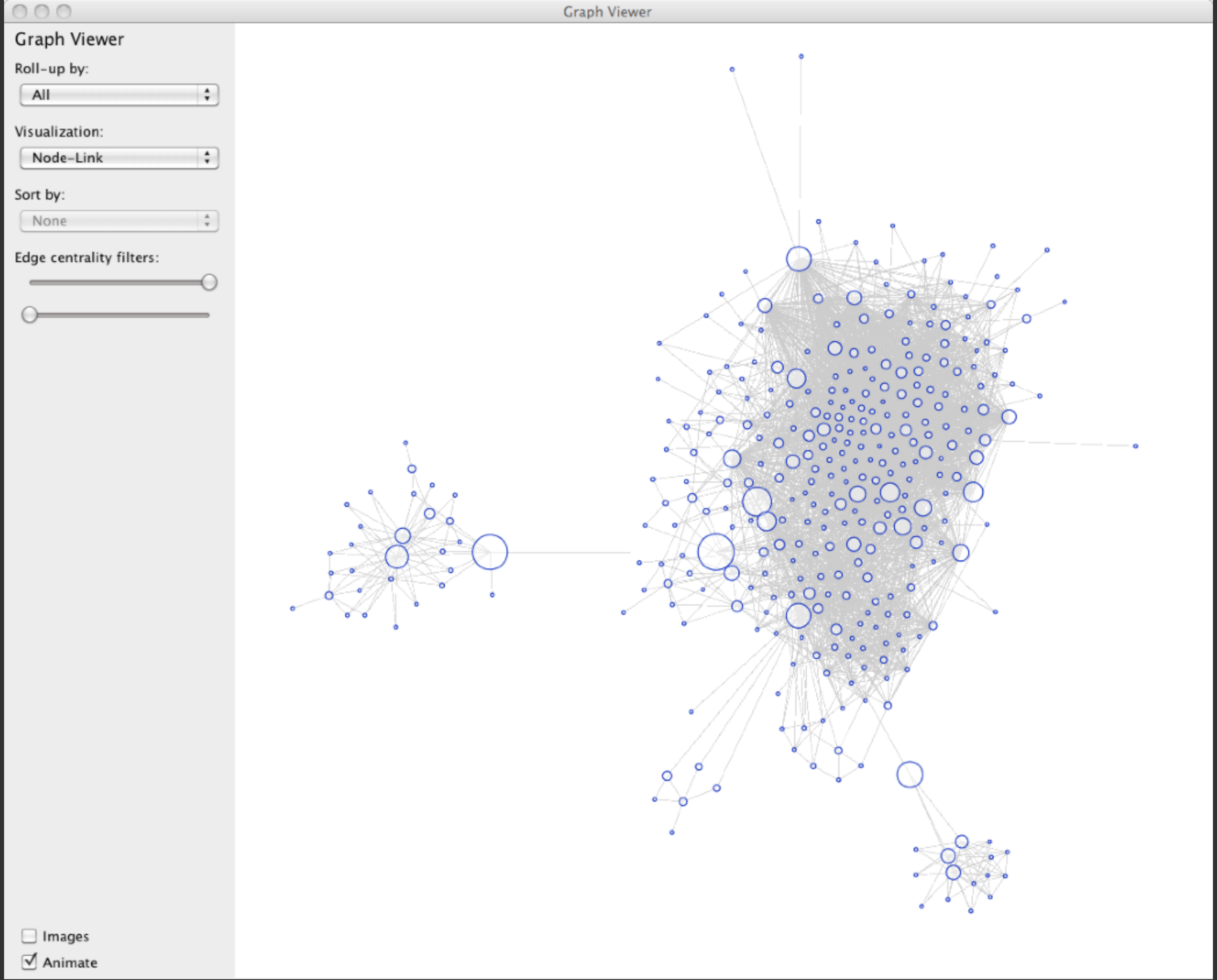


Matrix Diagrams


Fauchelevent
Gribier
MotherInnocent
CountessdeLo
Geborand
Champtercier
Mlle.Baptistine
Count
OldMan
Myriel
Mme.Magloire
Napoleon
Cravatte
Mme.deR
Isabeau
Gervais
Labarre
Valjean
Chenildieu
Brevet
Champmathieu
Judge
Woman1
Scaufflaire
Simplice
Bamatabois
Cochepaille
Listolier
Perpetue
Fantine
Zephine
Dahlia
Favourite
Blacheville
Fameuil
Tholomyes
Marguerite
Thenardier
Pontmercy
Brujon
Eponine
Anzelma
Javert
Mme.Thenardier
Montparnasse
Claquesous
Babet
Gueulemer
Woman2
Gillenormand
Magnon
Mlle.Gillenormand
Cosette
Mlle.Vaubois
Lt.Gillenormand
Toussaint
BaronessT
Mme.Pontmercy
Boulatruelle
Mme.Burgon
Jondrette
Enjolras
Courfeyrac
Bahorel
Bossuet
Joly
Grantaire
Combeferre
Mabeuf
Marius
Gavroche
Mme.Hucheloup
Prouvaire
Feuilly
MotherPlutarch
Child2
Child1
Fauchelevent
Gribier
MotherInnocent
CountessdeLo
Geborand
Champtercier
Mlle.Baptistine
Count
OldMan
Myriel
Mme.Magloire
Napoleon
Cravatte
Mme.deR
Isabeau
Gervais
Labarre
Valjean
Chenildieu
Brevet
Champmathieu
Judge
Woman1
Scaufflaire
Simplice
Bamatabois
Cochepaille
Listolier
Perpetue
Fantine
Zephine
Dahlia
Favourite
Blacheville
Fameuil
Tholomyes
Marguerite
Thenardier
Pontmercy
Brujon
Eponine
Anzelma
Javert
Mme.Thenardier
Montparnasse
Claquesous
Babet
Gueulemer
Woman2
Gillenormand
Magnon
Mlle.Gillenormand
Cosette
Mlle.Vaubois
Lt.Gillenormand
Toussaint
BaronessT
Mme.Pontmercy
Boulatruelle
Mme.Burgon
Jondrette
Enjolras
Courfeyrac
Bahorel
Bossuet
Joly
Grantaire
Combeferre
Mabeuf
Marius
Gavroche
Mme.Hucheloup
Prouvaire
Feuilly
MotherPlutarch
Child2
Child1



Adjacency Matrices


Graph Viewer
Graph Viewer
Roll-up by:
All
Visualization:
Node-Link
Sort by:
None
Edge centrality filters:
Images
Animate

Graph Viewer

Graph Viewer

Roll-up by:

All

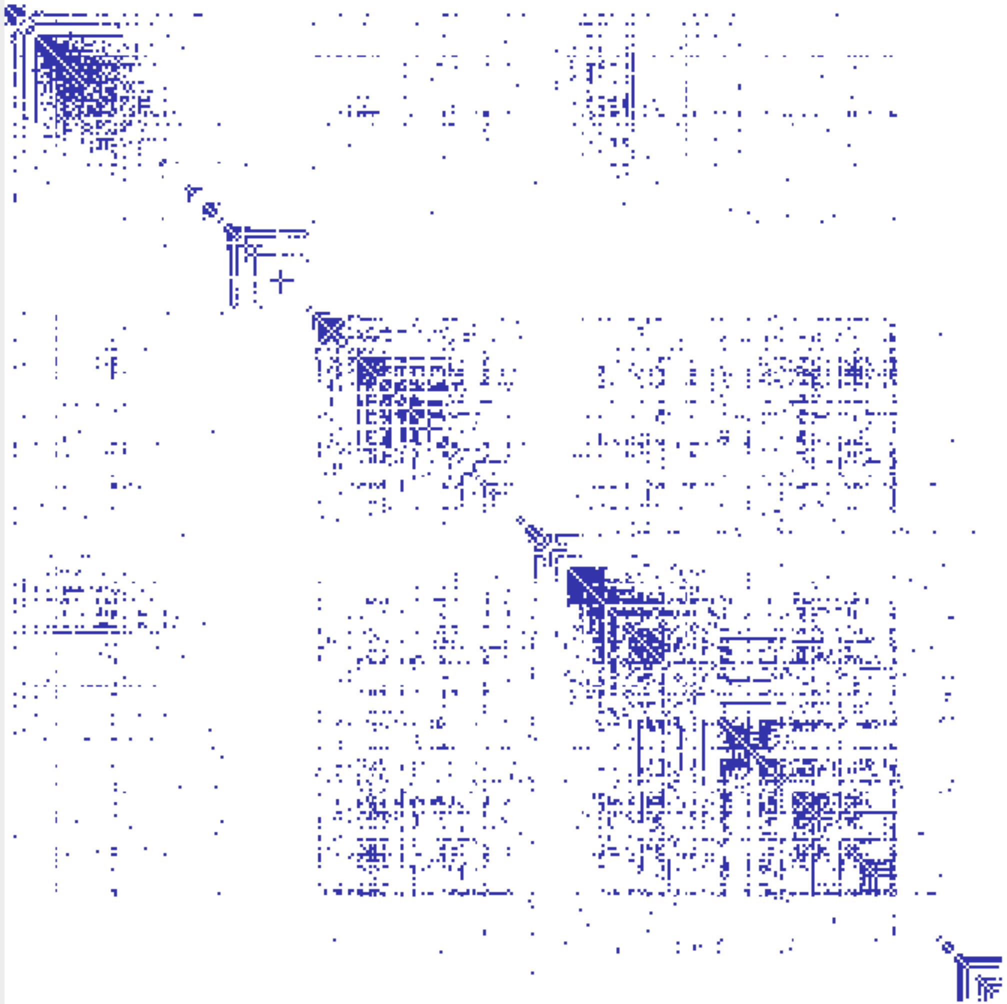
Visualization:

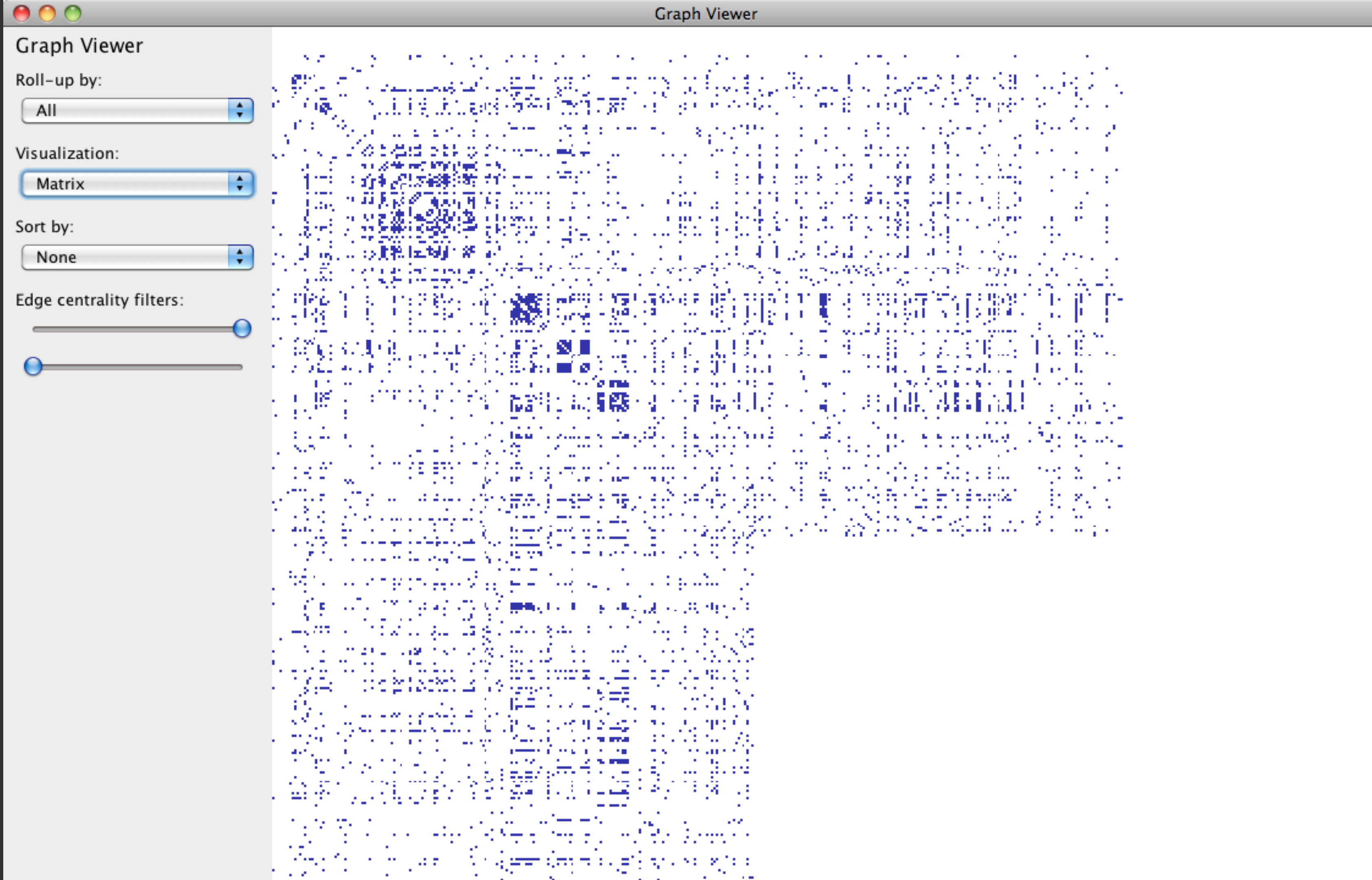
Matrix

Sort by:

Linkage

Edge centrality filters:




Graph Viewer
Graph Viewer
Roll-up by:
All
Visualization:
Matrix
Sort by:
None
Edge centrality filters:

Summary: Hierarchies & Networks

Tree Layout

Indented / Node-Link / Enclosure / Layers

Focus+Context techniques for scale

Graph Layout

“Sugiyama” Layout

Force-Directed Layout

Attribute-Driven Layout

Constraint Layout

Arc Diagrams

Matrix Diagrams