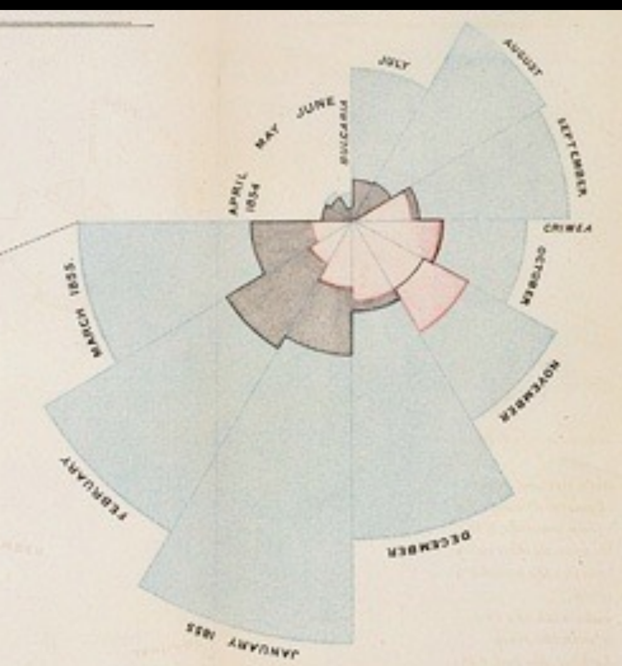
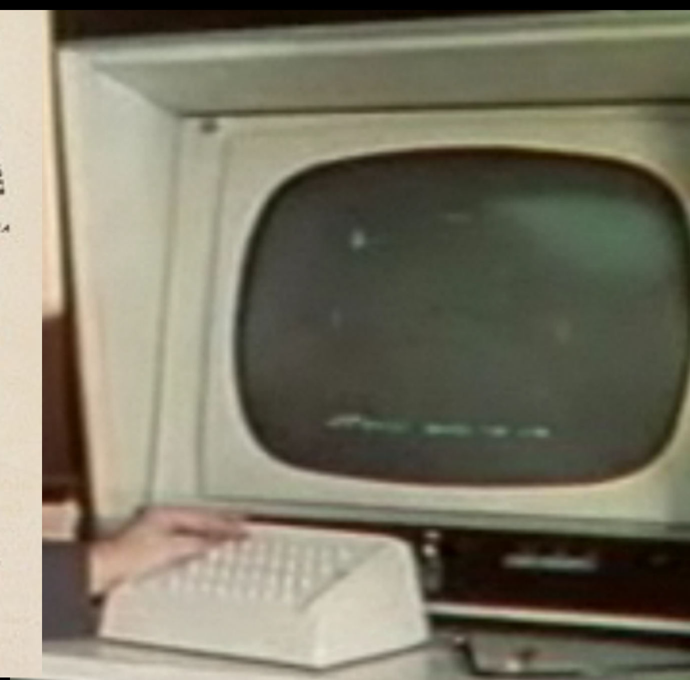
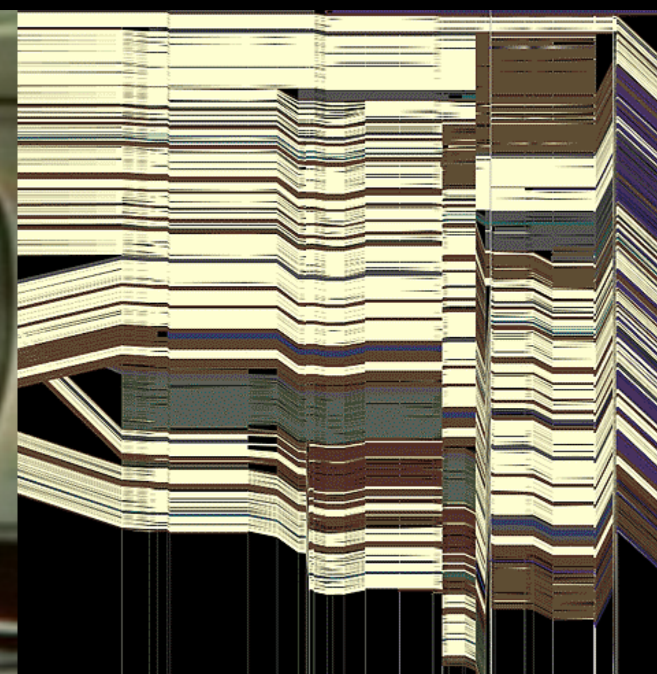
CSE 512 - Data Visualization

Networks







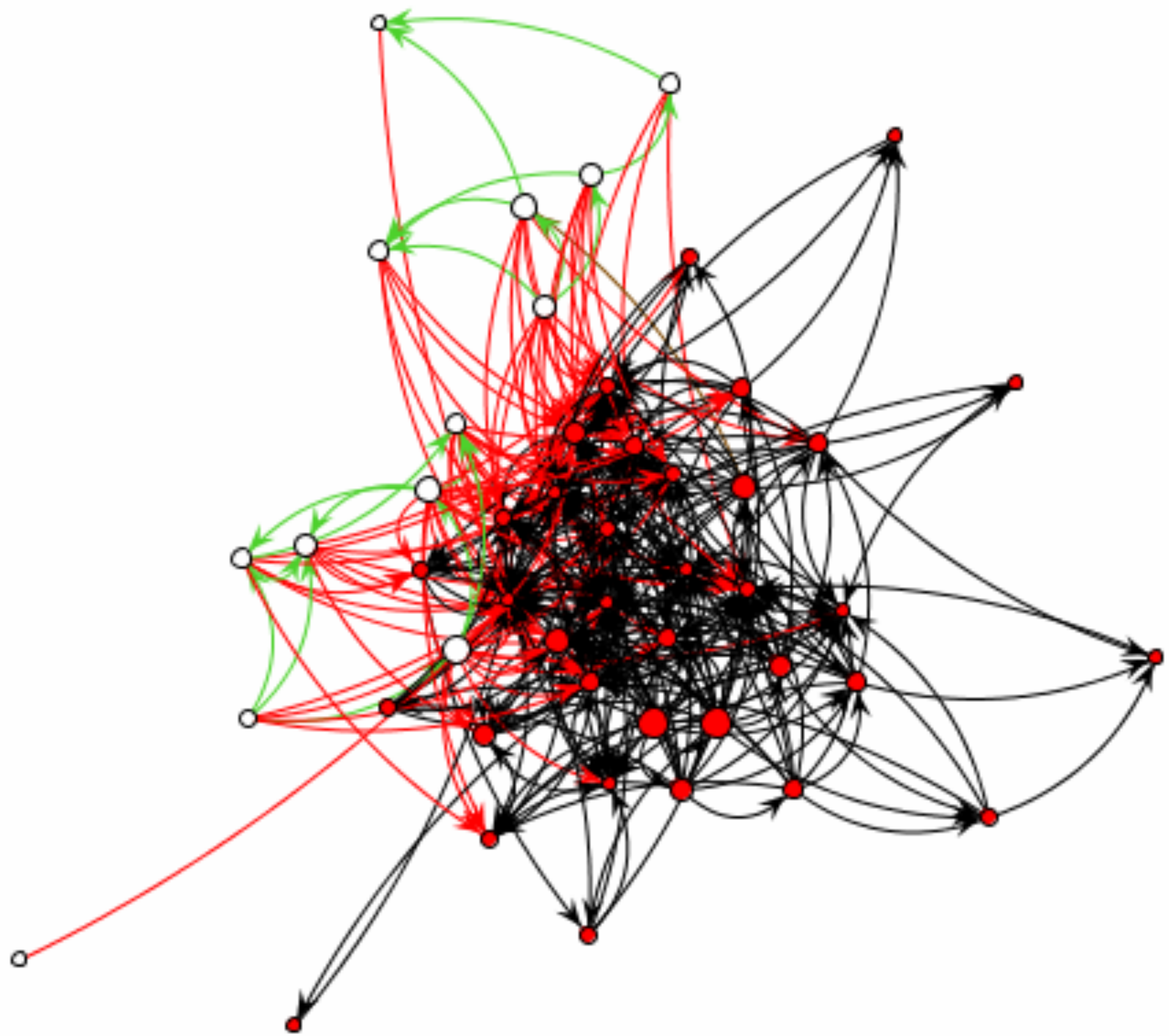
Jeffrey Heer University of Washington

Topics

Visualizing Trees
Visualizing Graphs

Goals

Overview of layout approaches
Assess strengths and weaknesses
Insight into implementation techniques

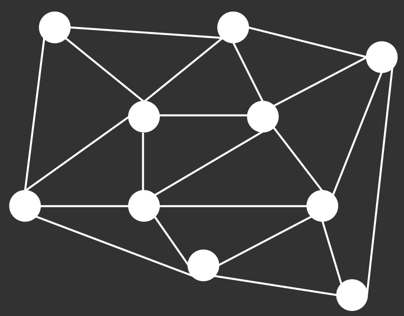


Graphs and Trees

Graphs

Model relations among data

Nodes and *edges*

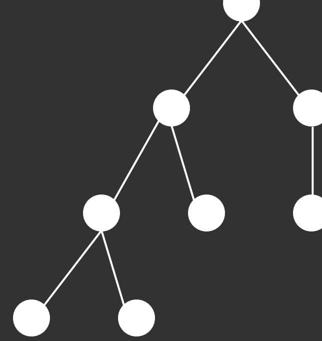


Trees

Graphs with hierarchical structure

- Connected graph with N-1 edges

Nodes as *parents* and *children*



Spatial Layout

A primary concern of 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
- Network distance
- Clustering
- 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

Tree Layout

Tree Visualization

Indentation

Linear list, indentation encodes depth

Node-Link diagrams

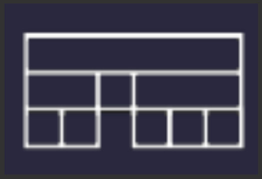
Nodes connected by lines/curves

Enclosure diagrams

Represent hierarchy by enclosure

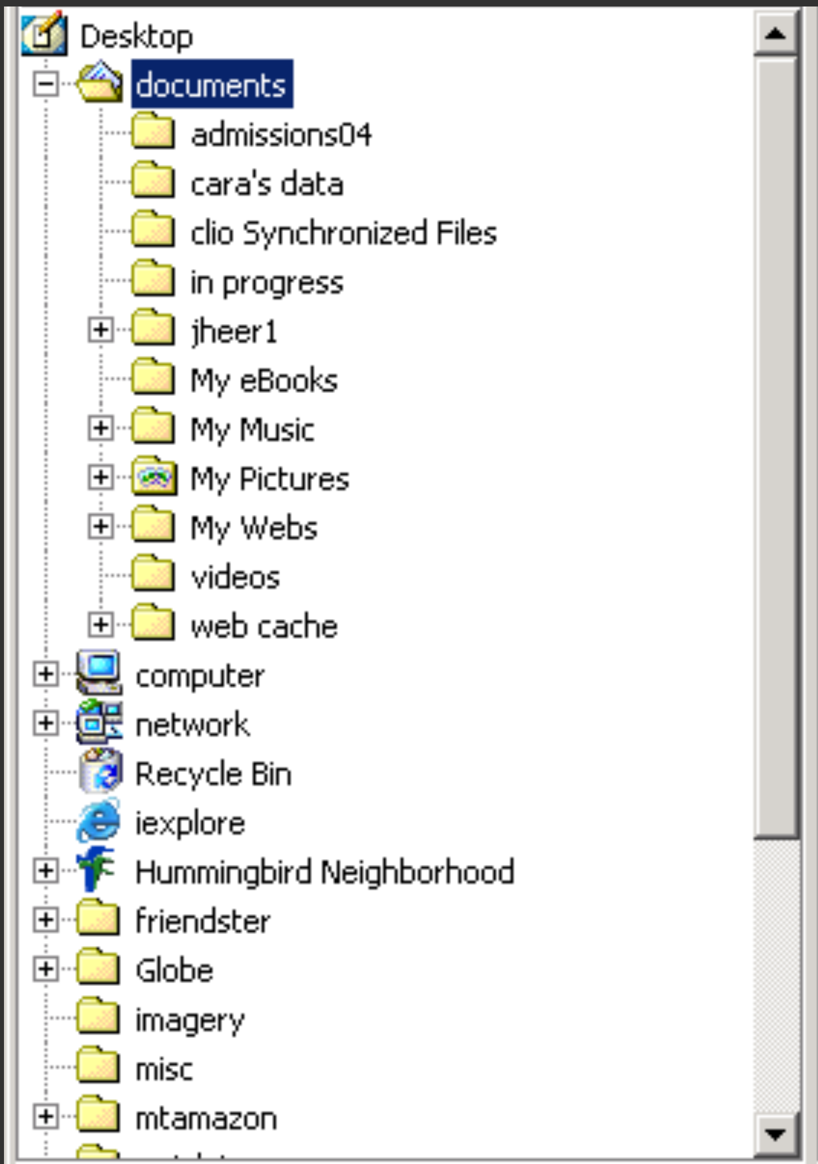
Layering

Relative position and alignment



Fast: O(n) or O(n log n), interactive layout

Indentation



Places all items along vertically spaced rows

Indentation used to show parent/child relationships

Commonly used as a component in an interface

Breadth and depth contend for space

Often requires a great deal of scrolling

Node-Link Diagram

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

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

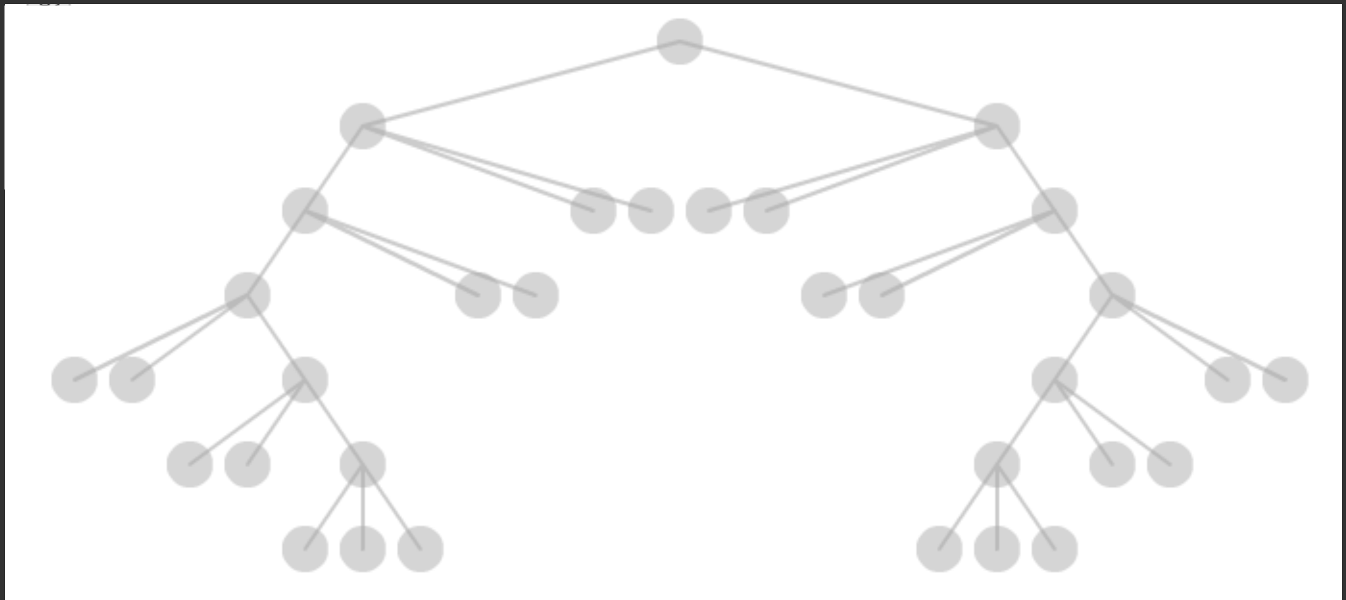
Often space is used to communicate hierarchical orientation (e.g., towards authority or generality)

Basic Recursive Approach

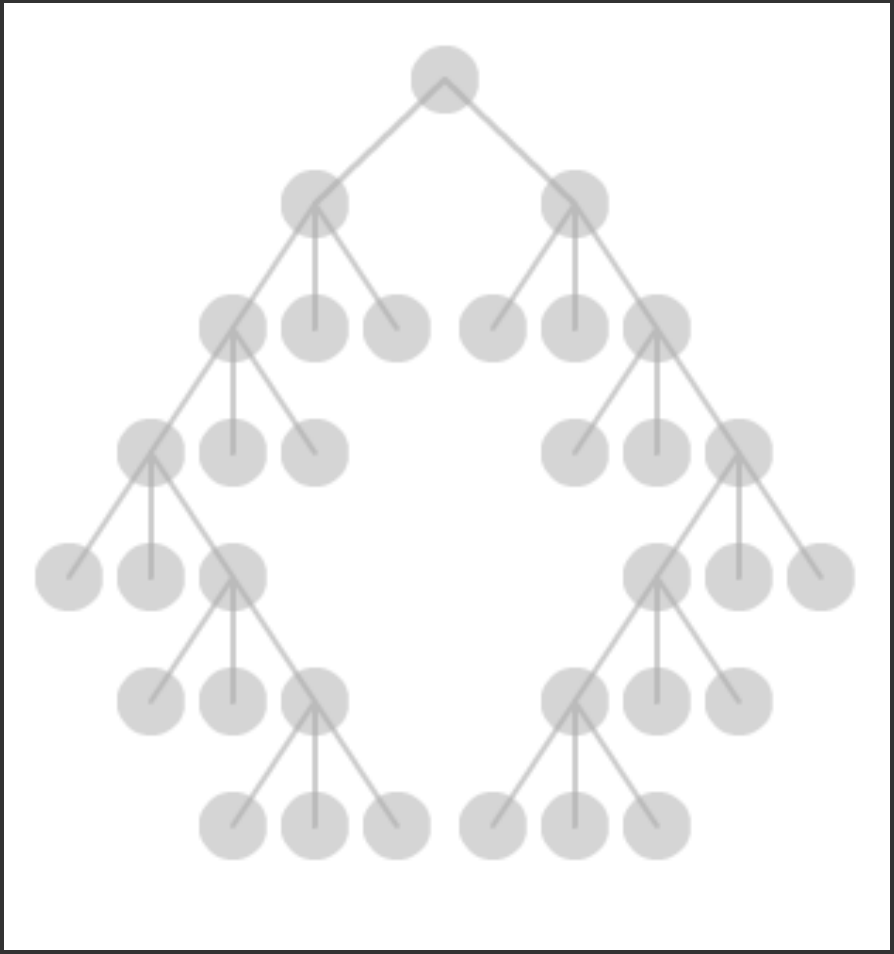
Repeatedly divide space for subtrees by leaf count

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

Problem: exponential growth of breadth



Reingold & Tilford's "Tidy" Layout



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

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

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

Reingold-Tilford Layout

Design considerations

Clearly encode depth level

No edge crossings

Isomorphic subtrees drawn identically

Ordering and symmetry preserved

Compact layout (don’t waste space)

Reingold-Tilford Layout

Linear algorithm – starts with bottom-up pass of the tree

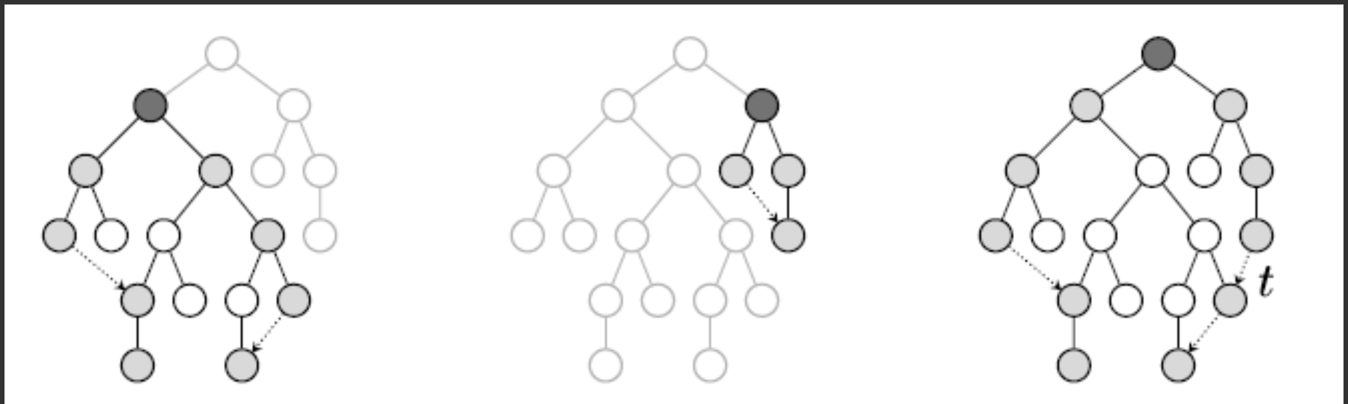
Y-coord by depth, arbitrary starting X-coord

Merge left and right subtrees

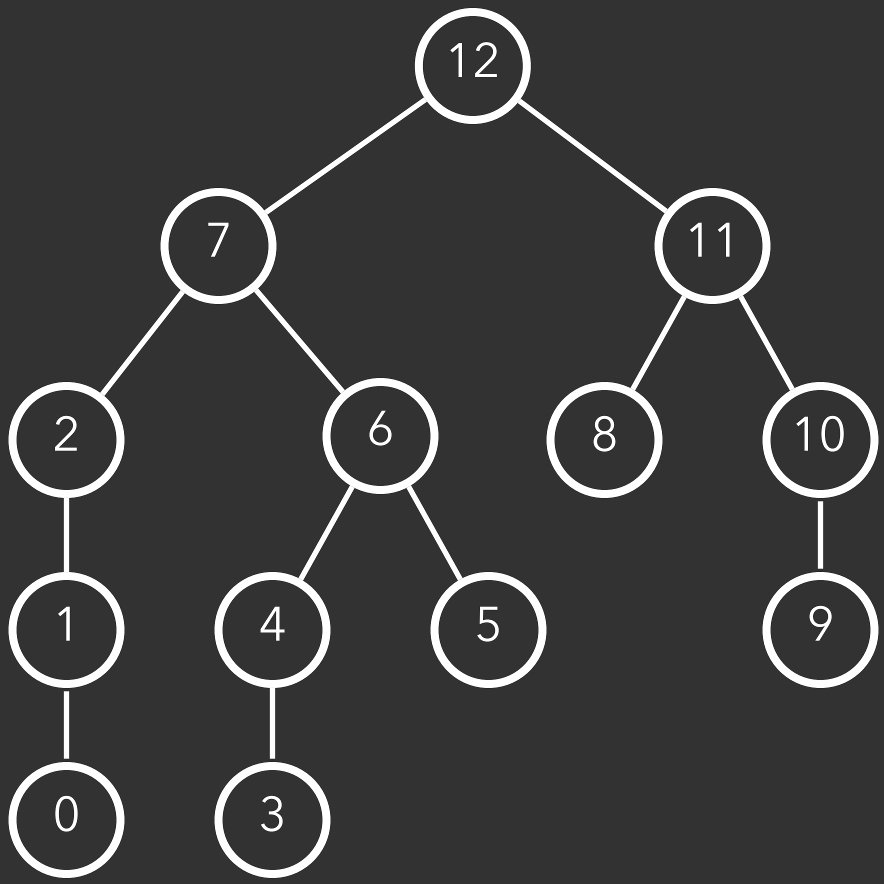
- Shift right as close as possible to left
  - Computed efficiently by maintaining subtree contours
- "Shifts" in position saved for each node as visited
- Parent nodes are centered above their children

Top-down pass for assignment of final positions

- Sum of initial layout and aggregated shifts

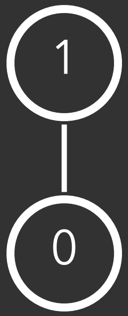


Reingold-Tilford Layout



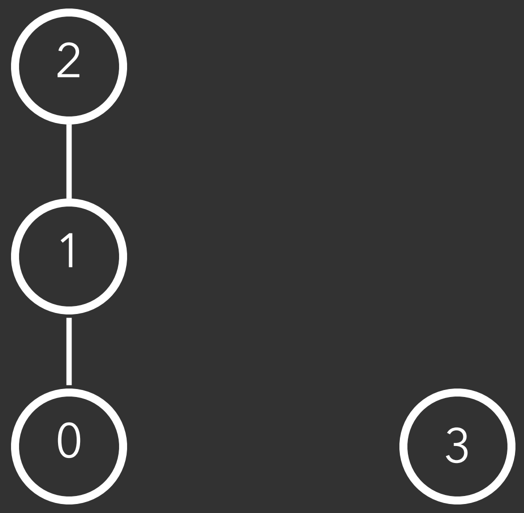
Reingold-Tilford Layout

Reingold-Tilford Layout

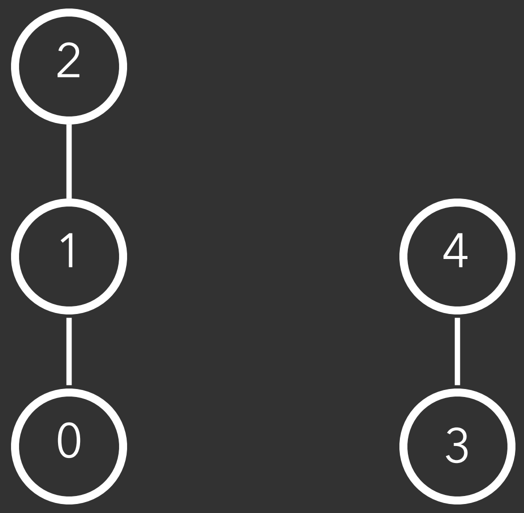


Reingold-Tilford Layout

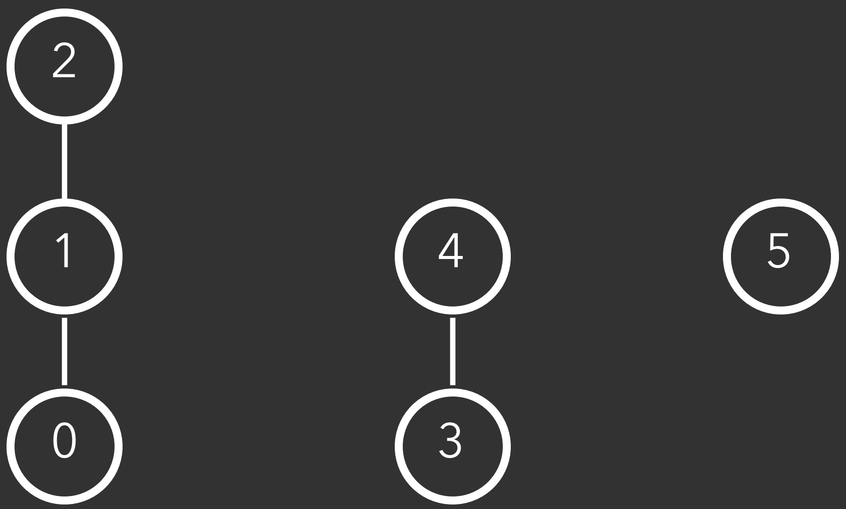
Reingold-Tilford Layout



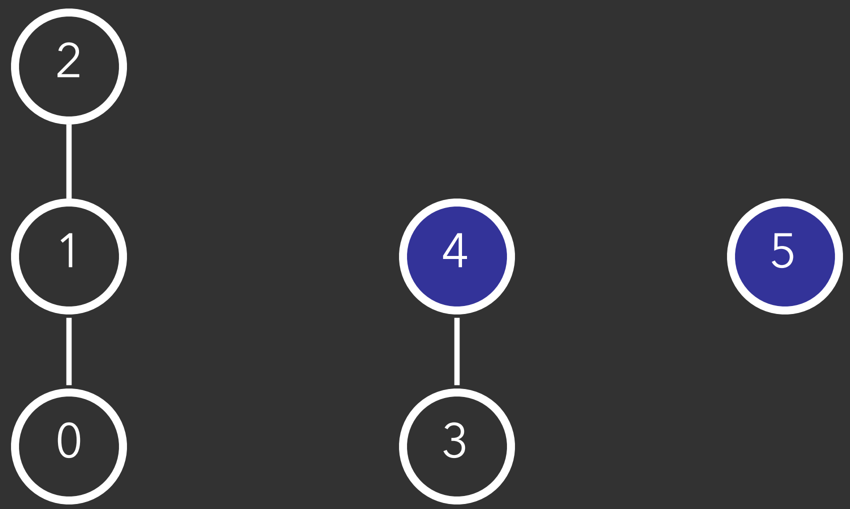
Reingold-Tilford Layout



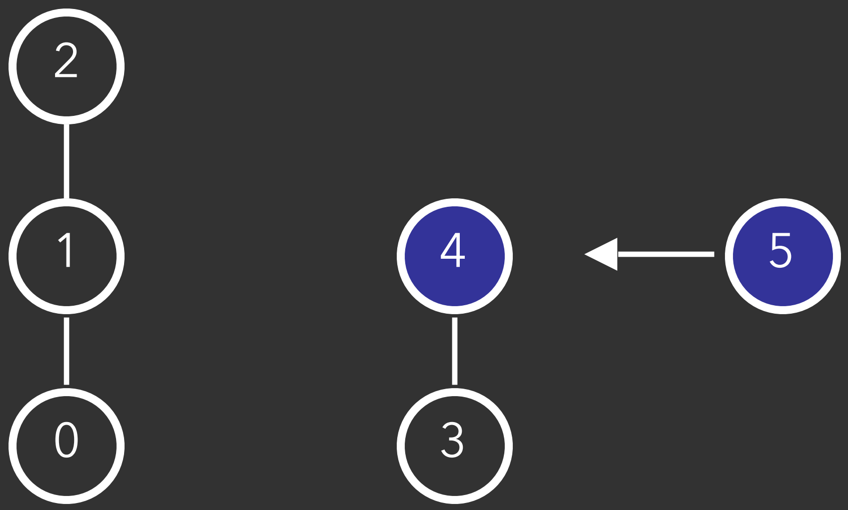
Reingold-Tilford Layout



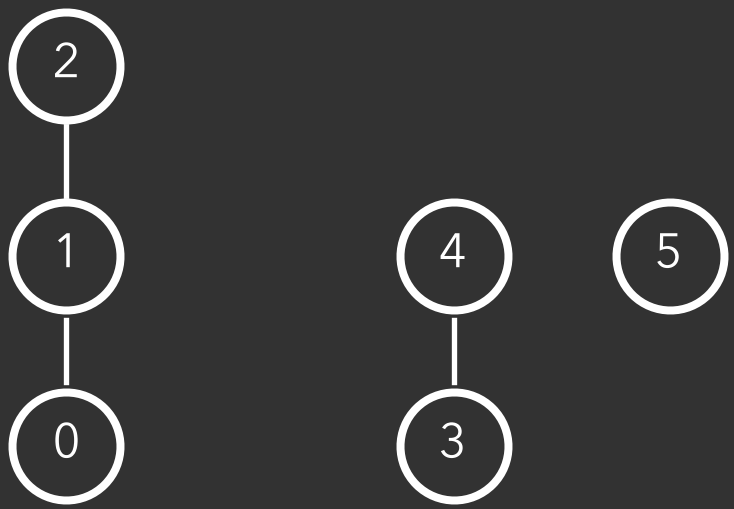
Reingold-Tilford Layout



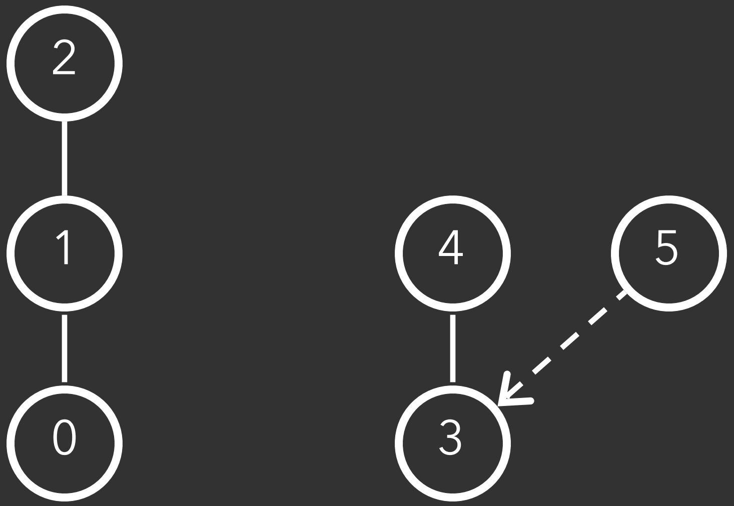
Reingold-Tilford Layout



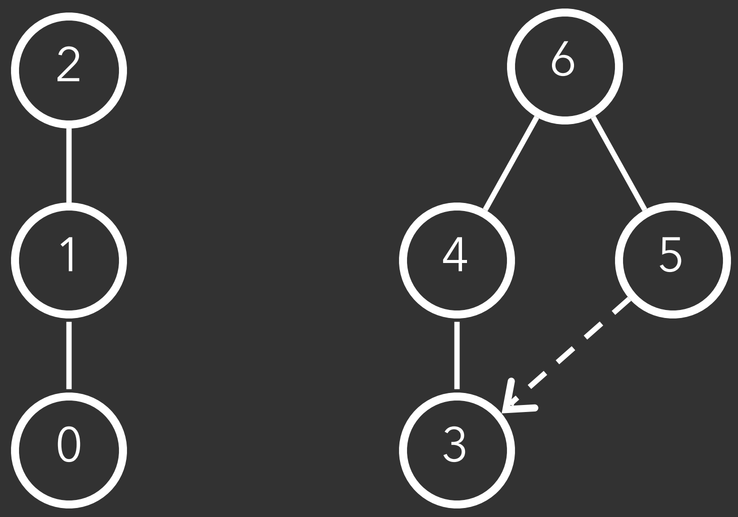
Reingold-Tilford Layout



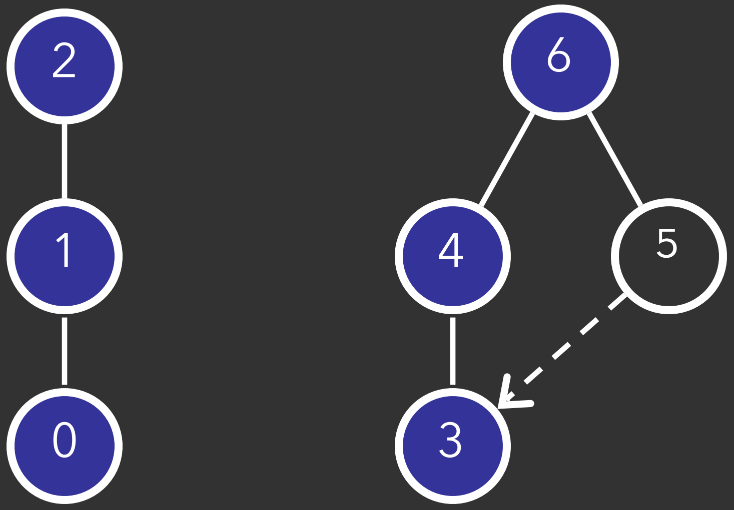
Reingold-Tilford Layout



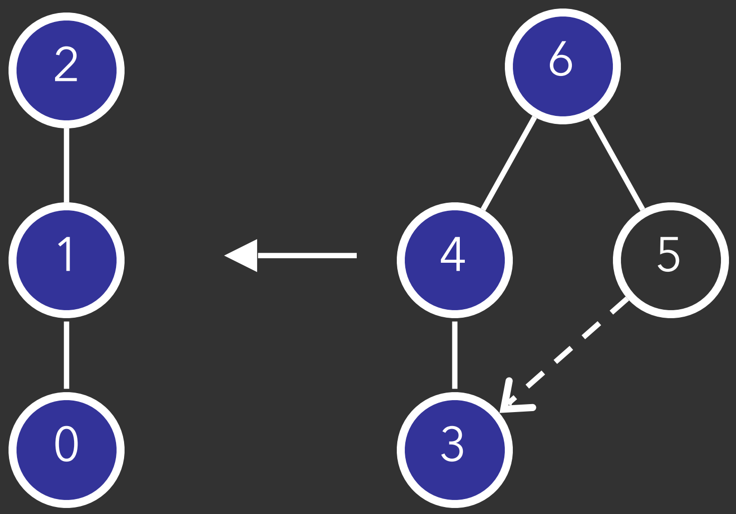
Reingold-Tilford Layout



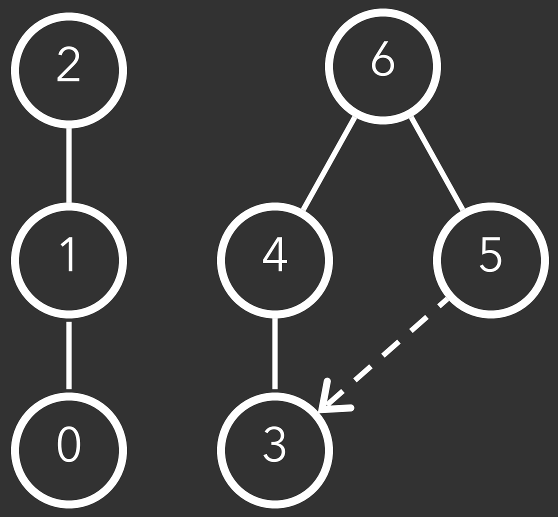
Reingold-Tilford Layout



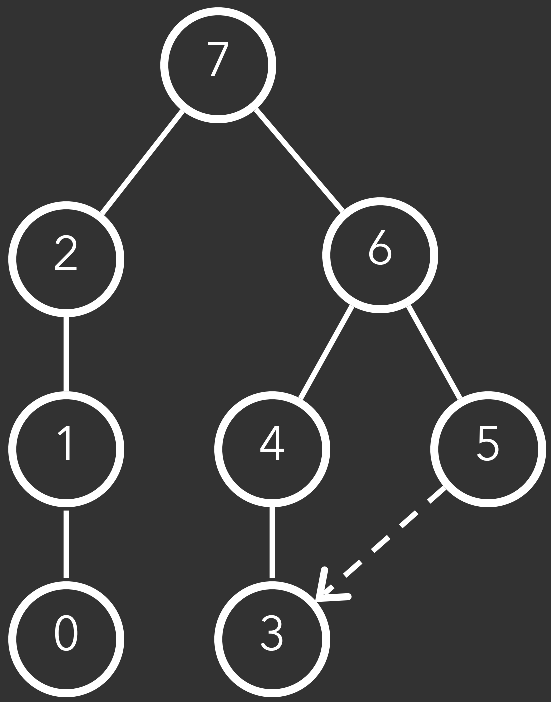
Reingold-Tilford Layout



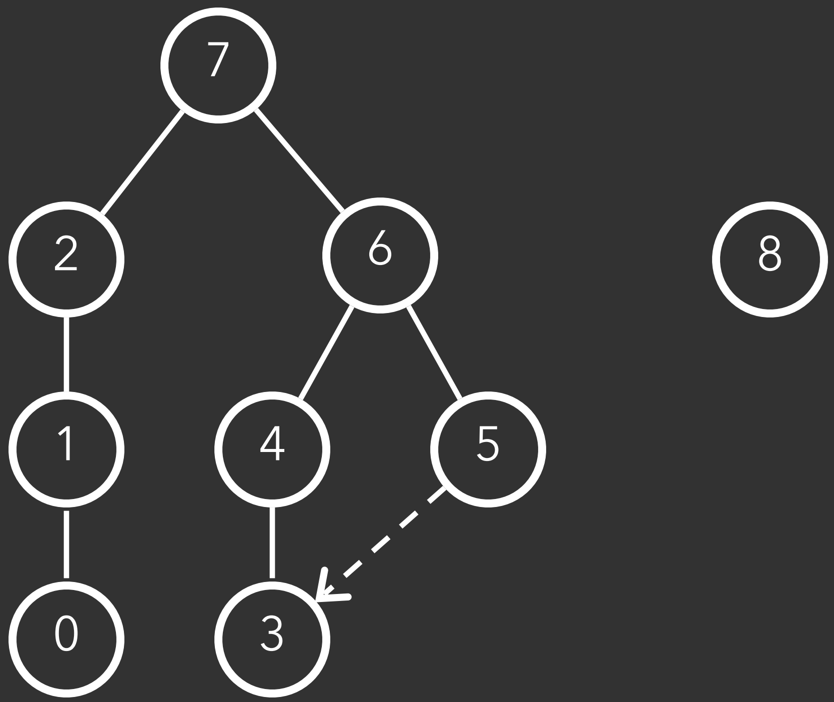
Reingold-Tilford Layout



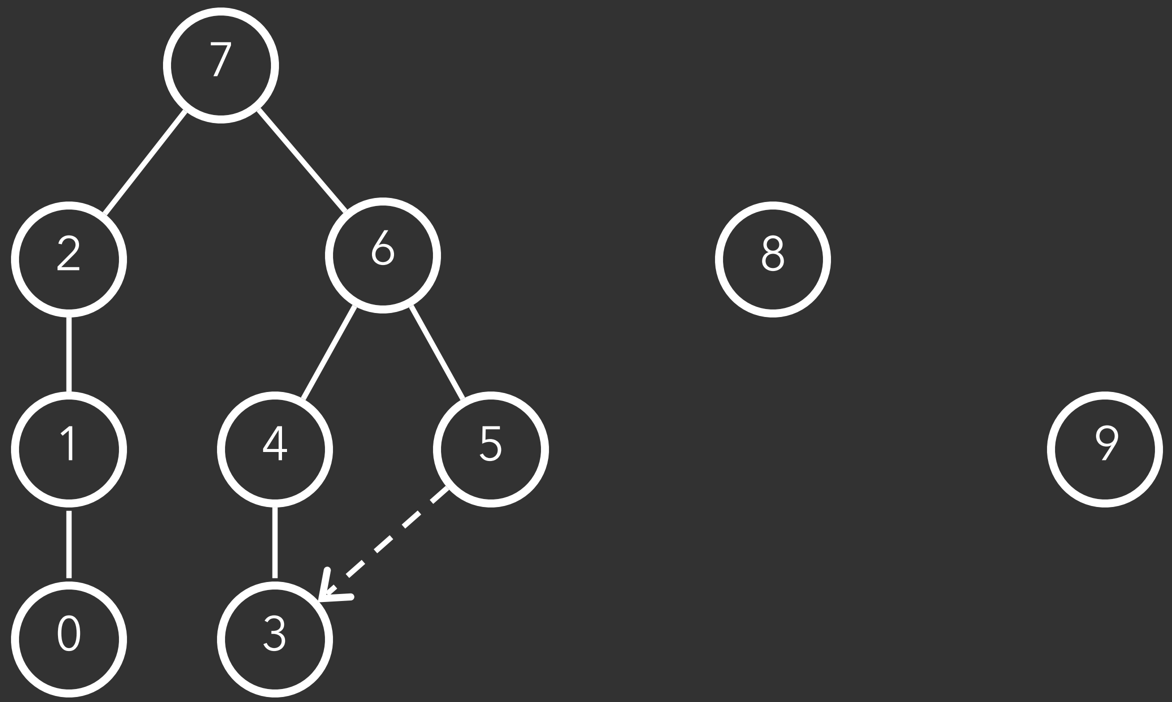
Reingold-Tilford Layout



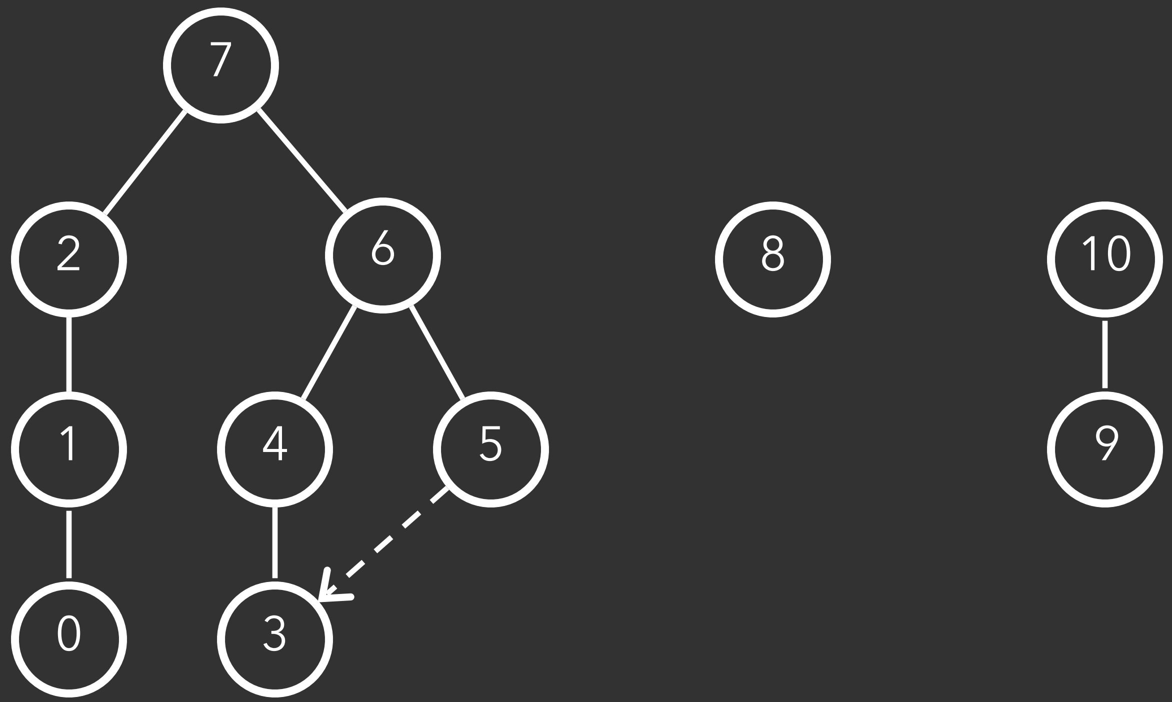
Reingold-Tilford Layout



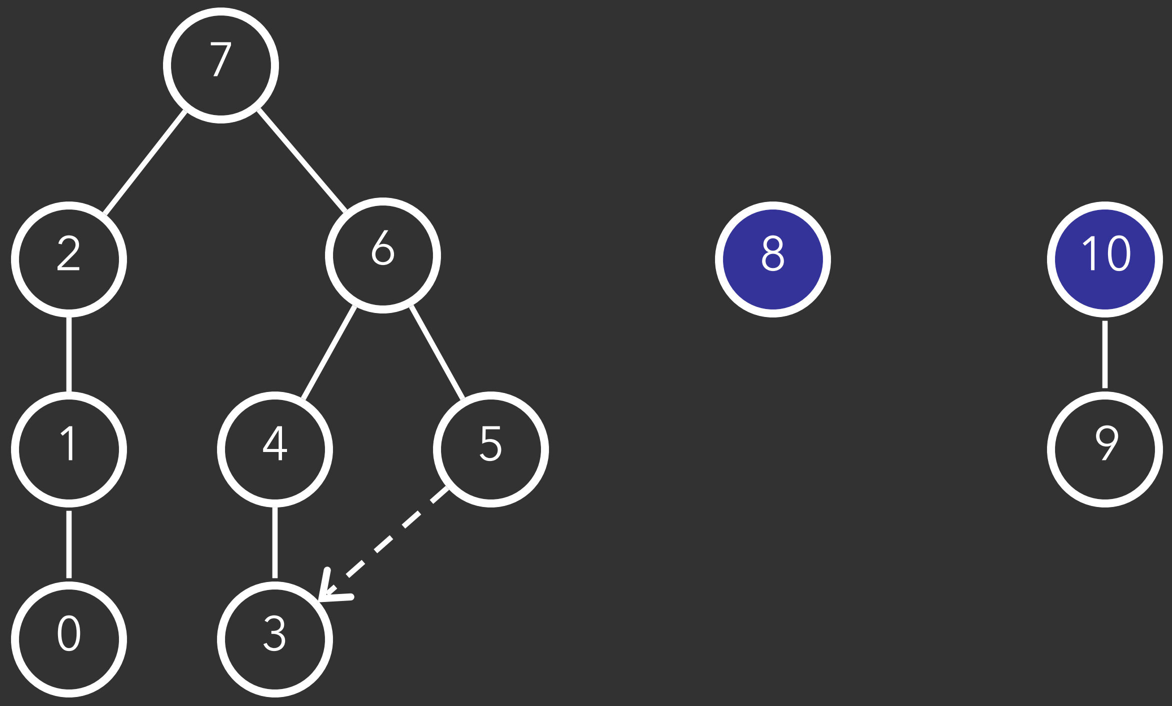
Reingold-Tilford Layout



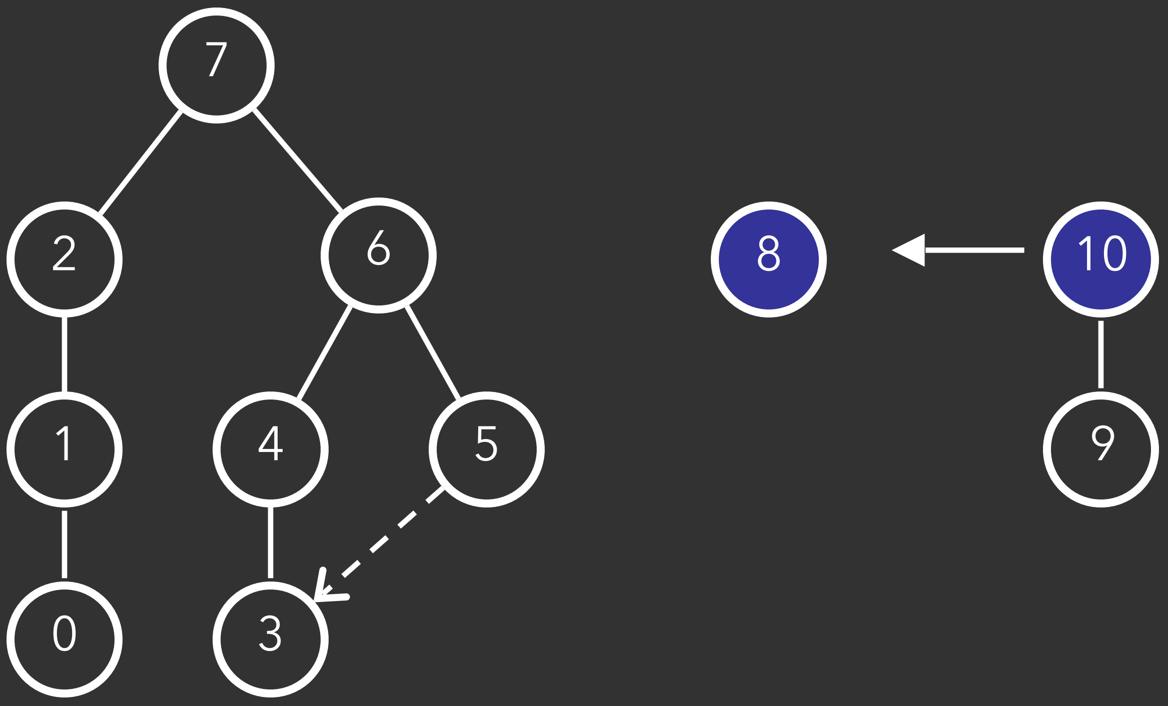
Reingold-Tilford Layout



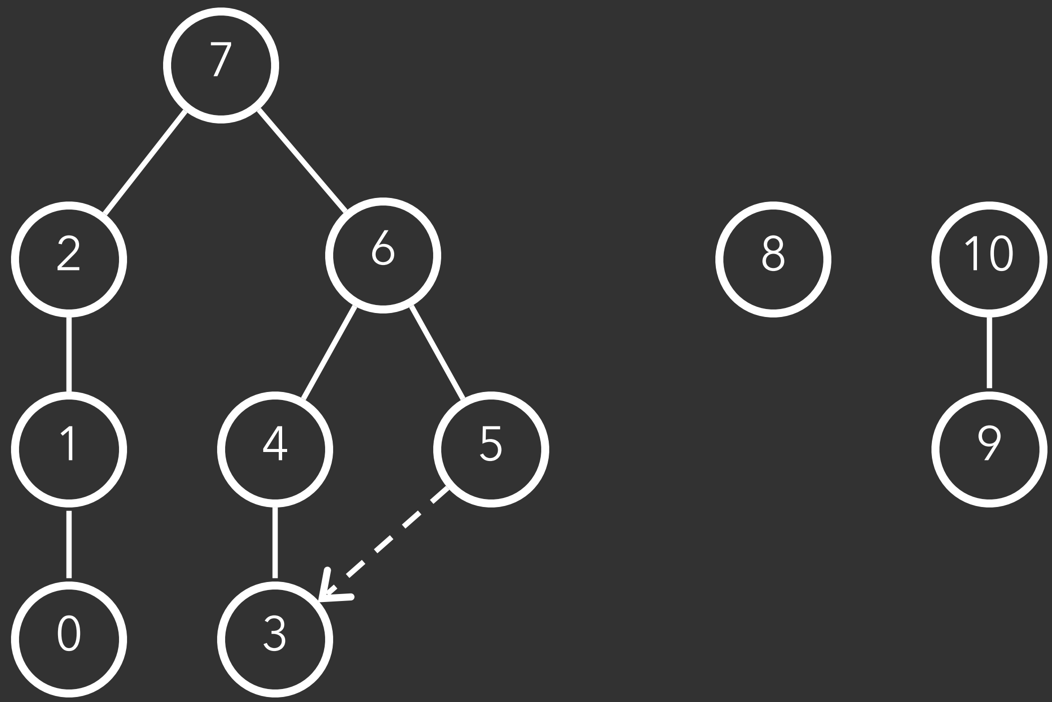
Reingold-Tilford Layout



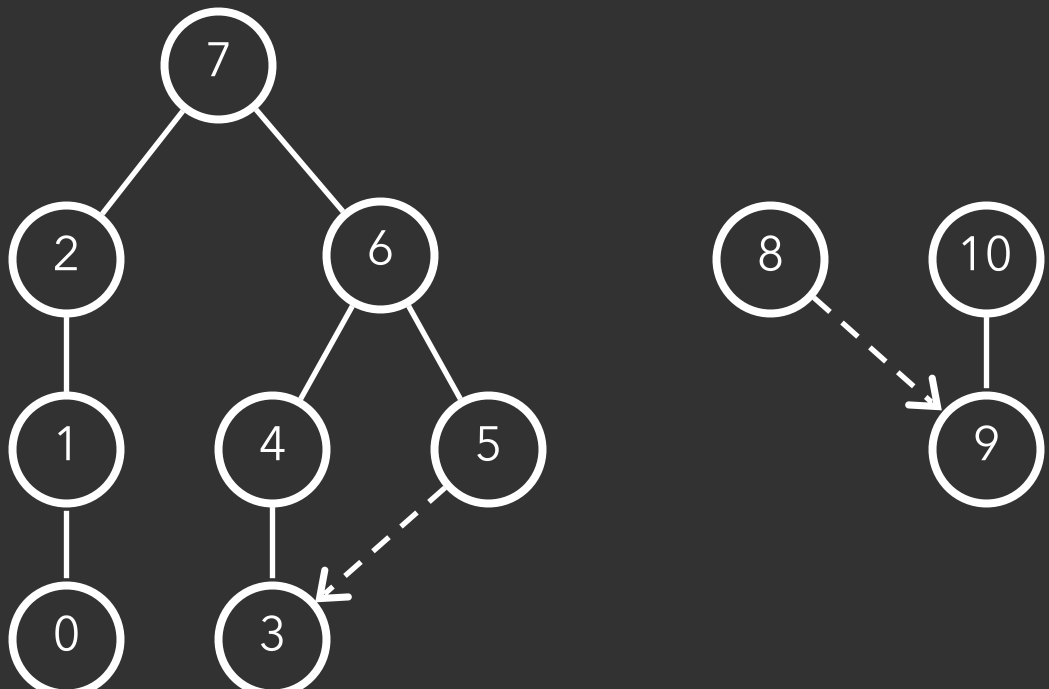
Reingold-Tilford Layout



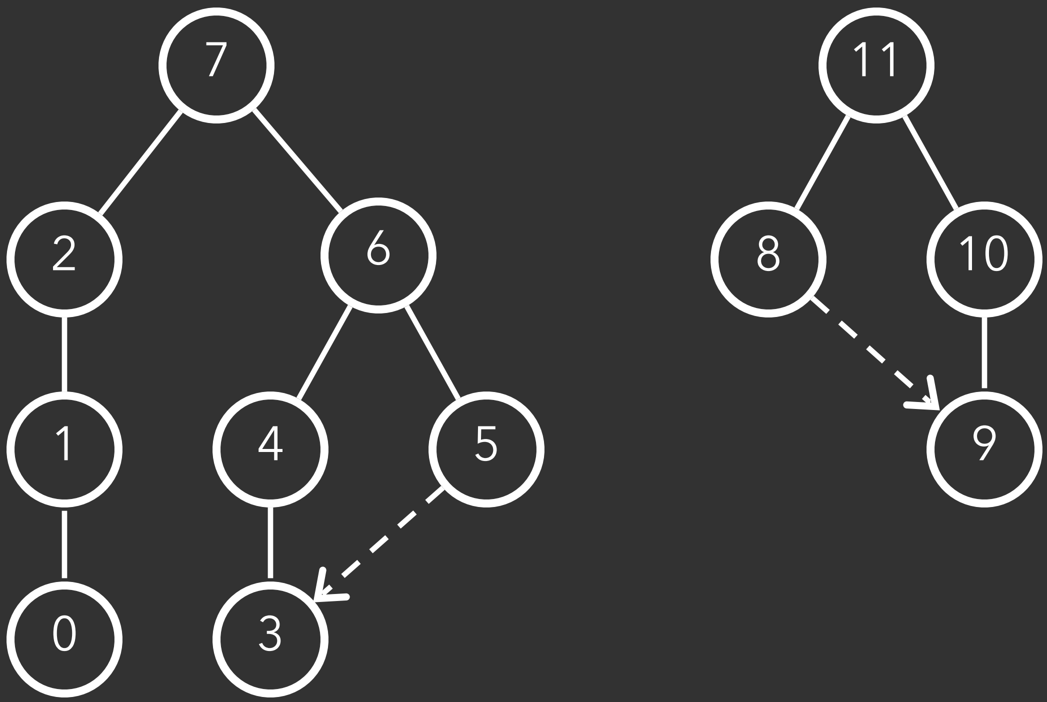
Reingold-Tilford Layout



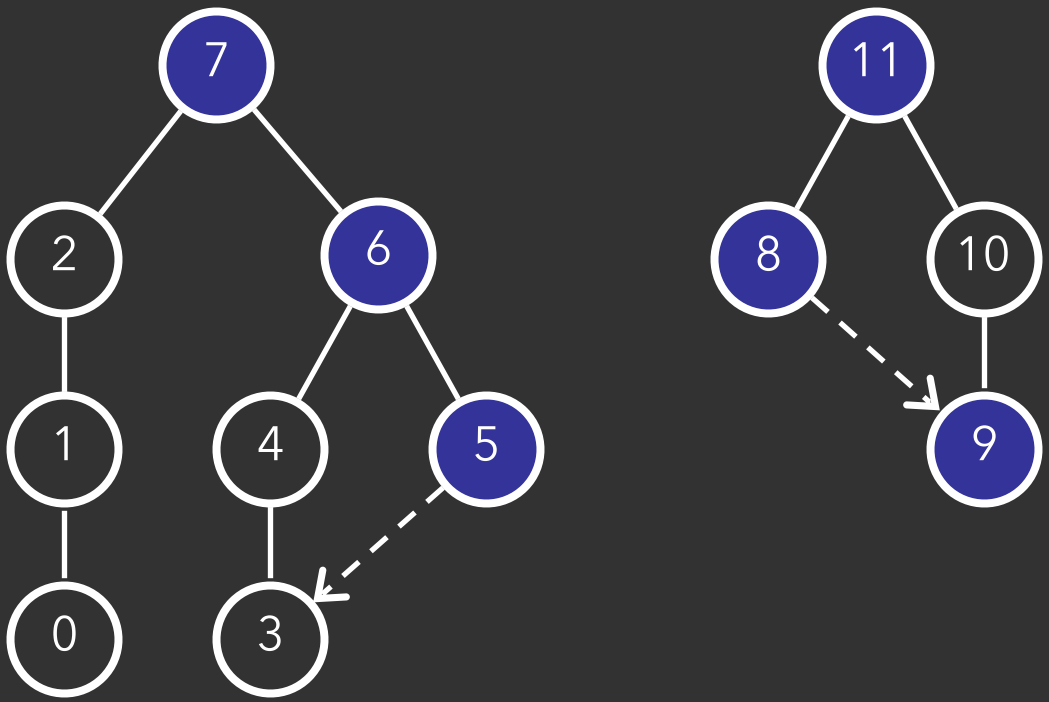
Reingold-Tilford Layout



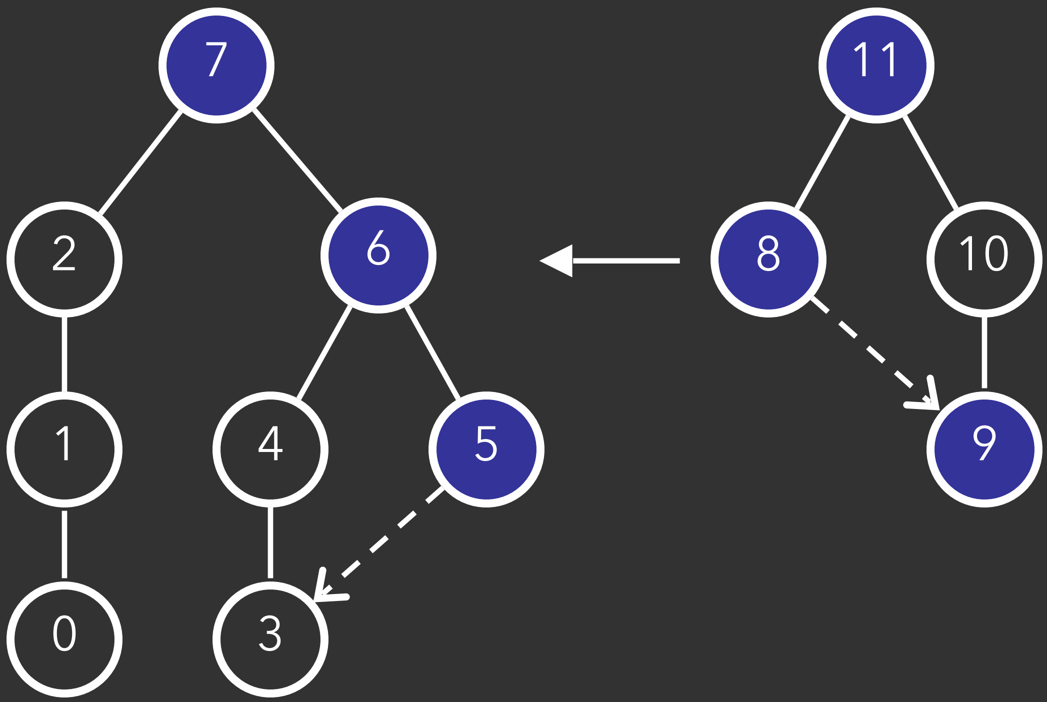
Reingold-Tilford Layout



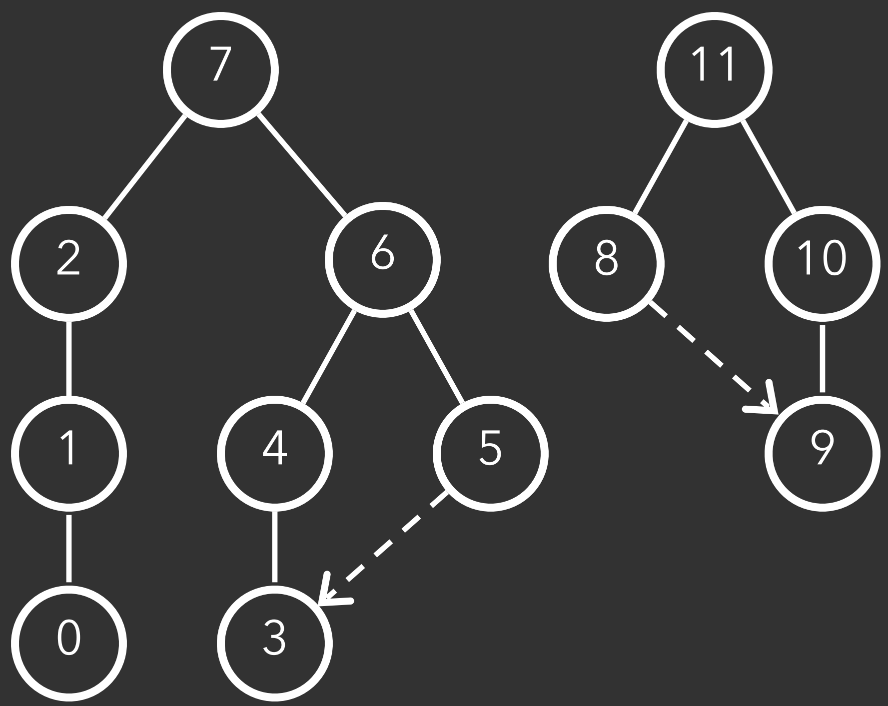
Reingold-Tilford Layout



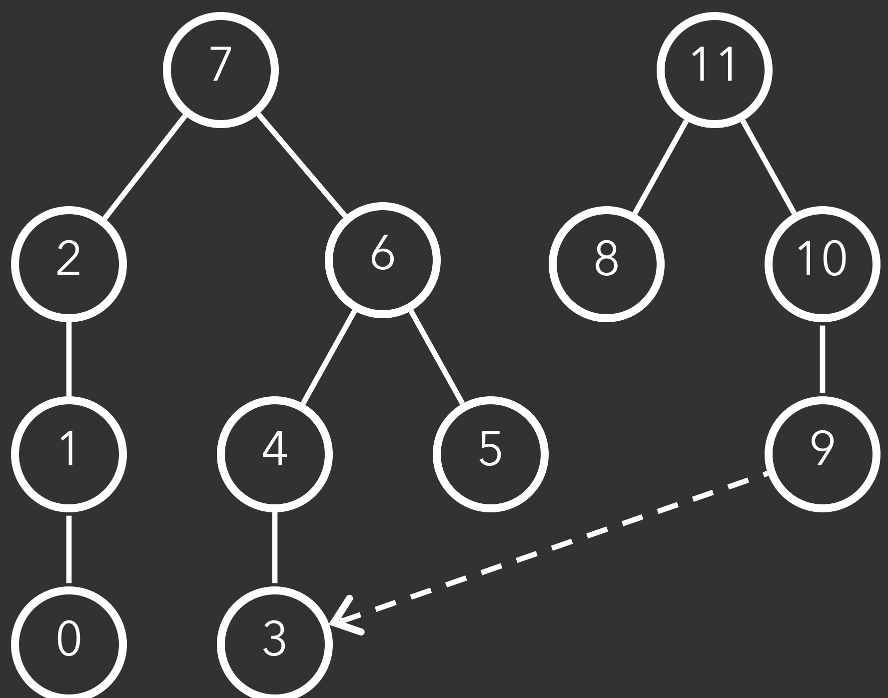
Reingold-Tilford Layout



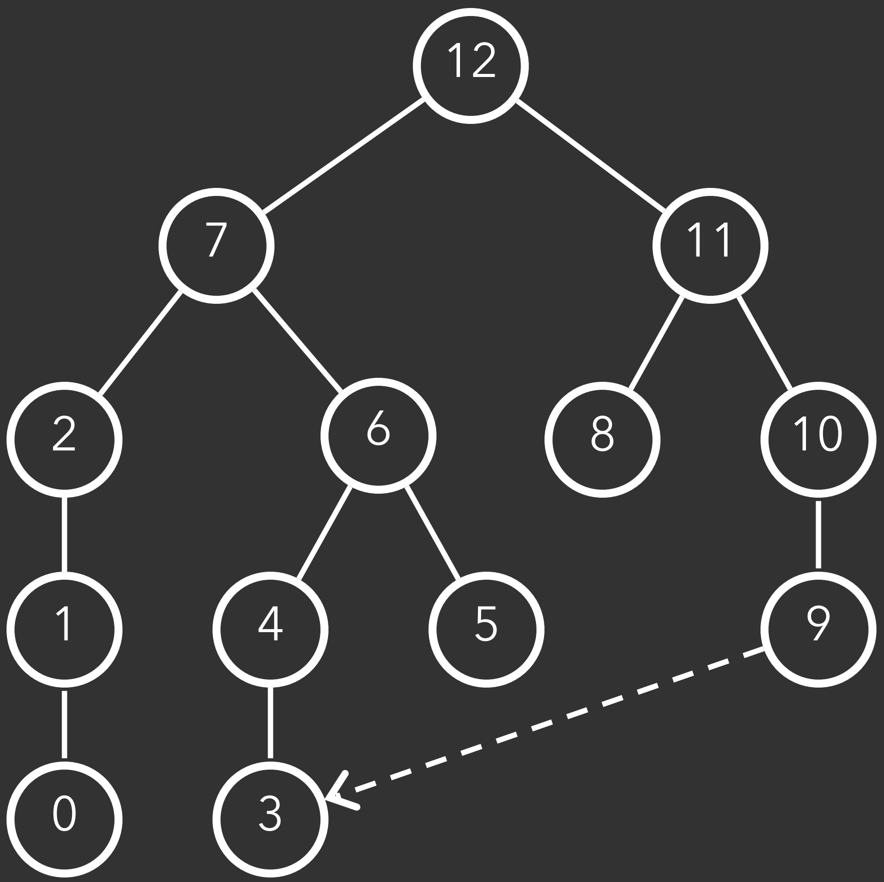
Reingold-Tilford Layout



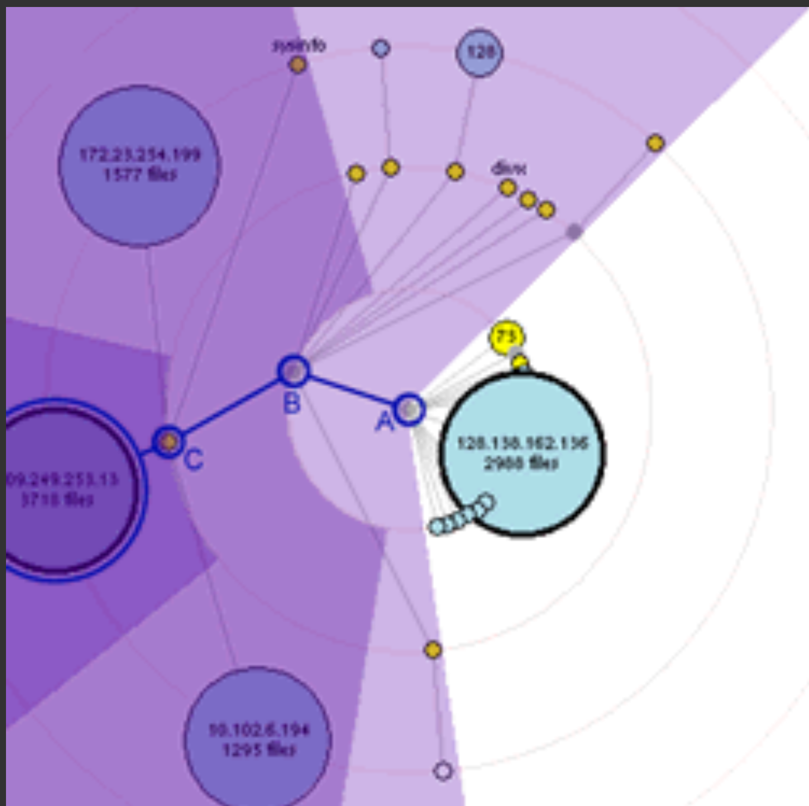
Reingold-Tilford Layout



Reingold-Tilford Layout



Radial Layout



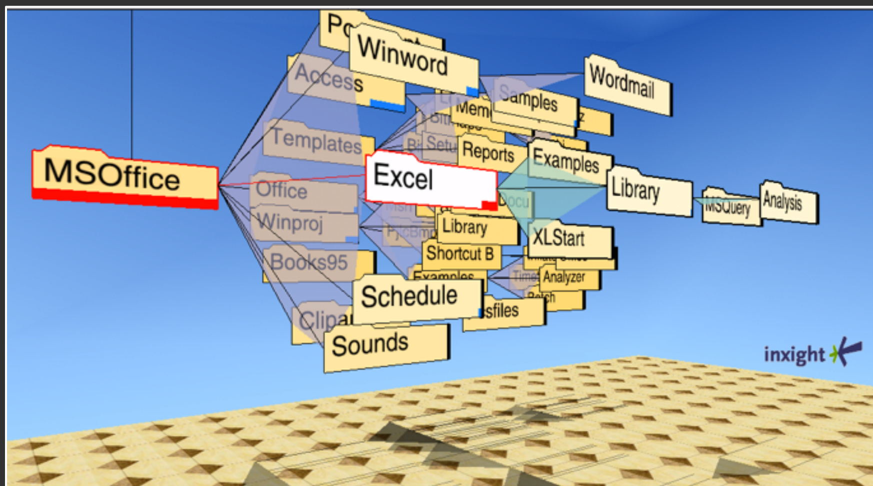
Node-link diagram in polar co-ordinates.

Radius encodes depth, with root in the center.

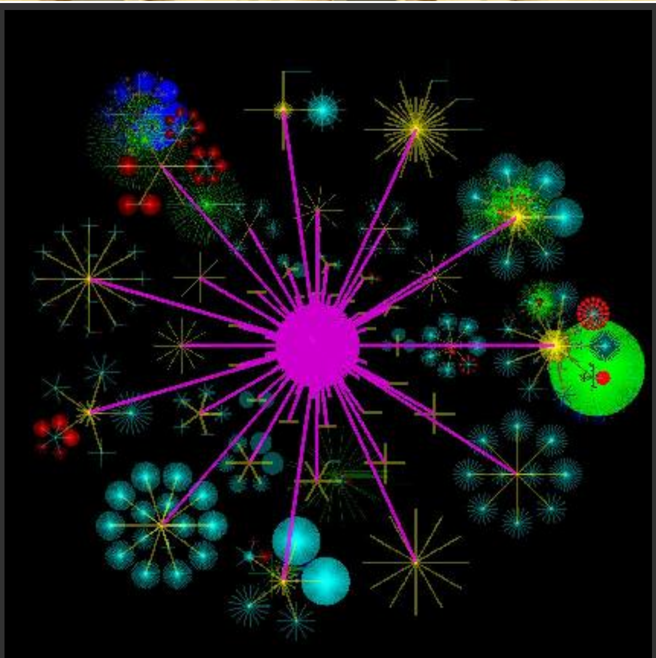
Angular sectors assigned to subtrees (typically uses recursive approach).

Reingold-Tilford method could be applied here.

Circular Tree Layouts



Layout in 3D to form Cone Trees.



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

Problems…

Scale

Tree breadth often grows exponentially

Even with tidy layout, quickly run out of space

Possible solutions

Filtering

Focus+Context

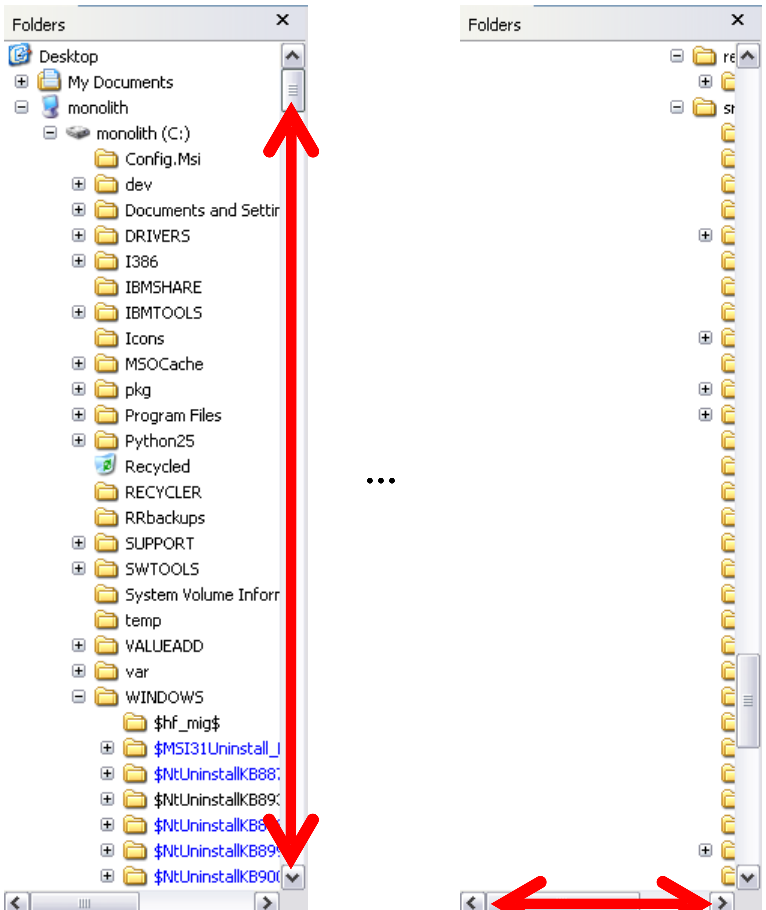
Scrolling or Panning

Zooming

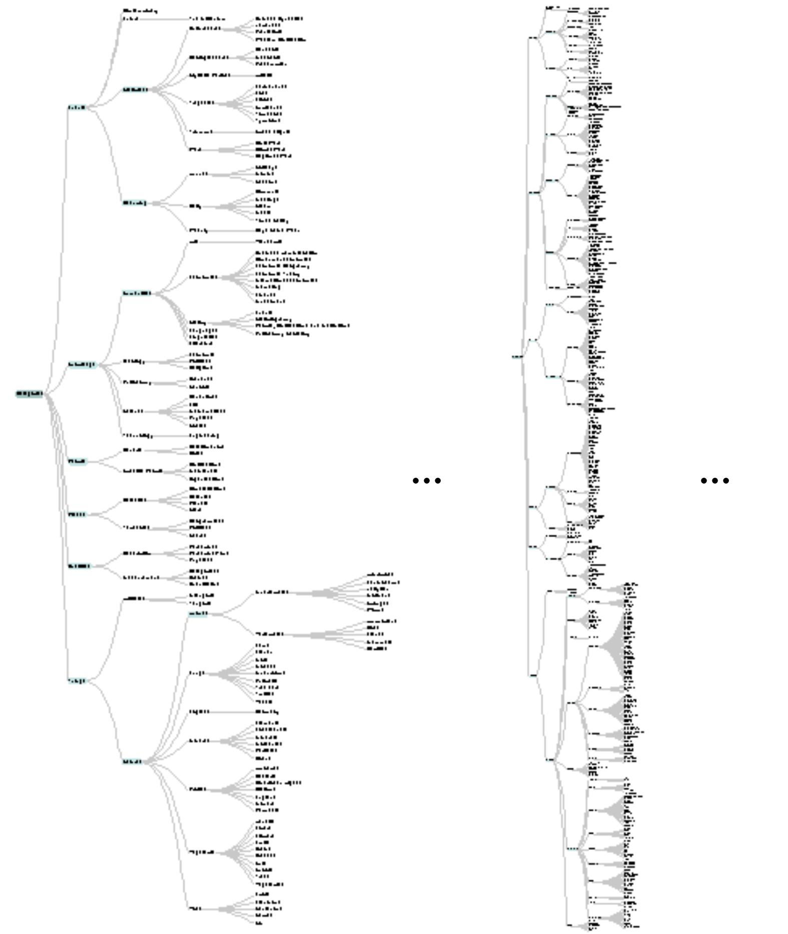
Aggregation

Focus + Context

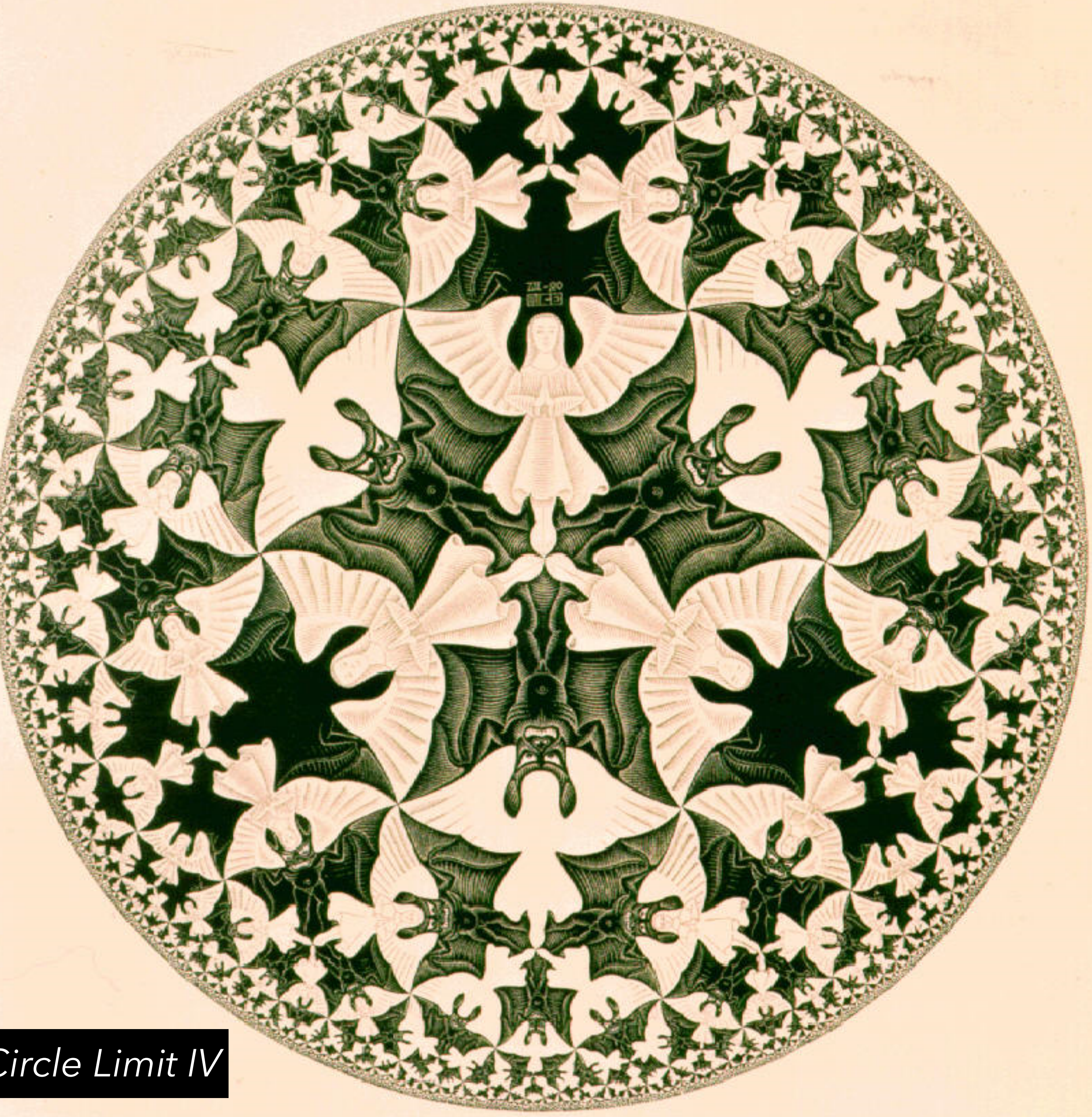
Visualizing Large Hierarchies



Indented Layout

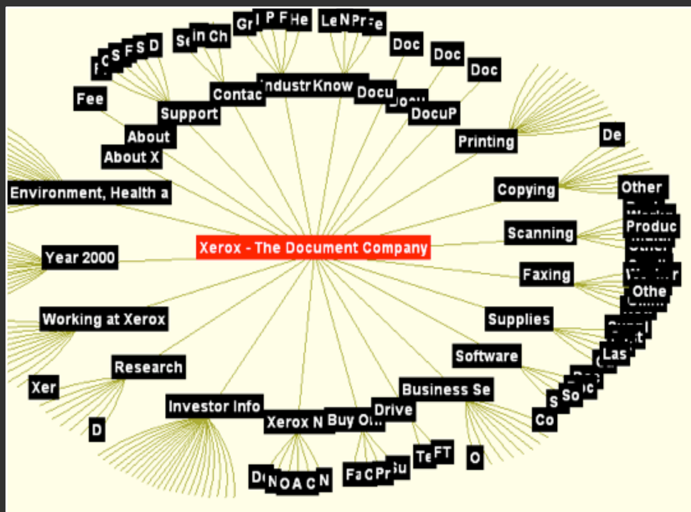


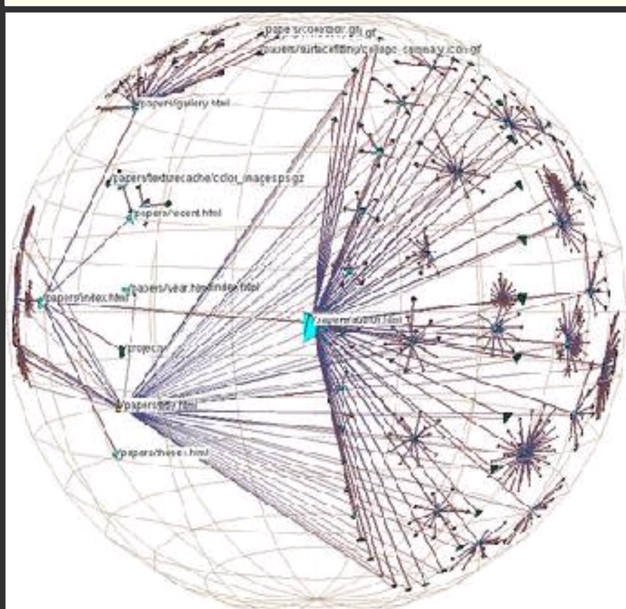
Reingold-Tilford Layout



MC Escher, *Circle Limit IV*

Hyperbolic Layout



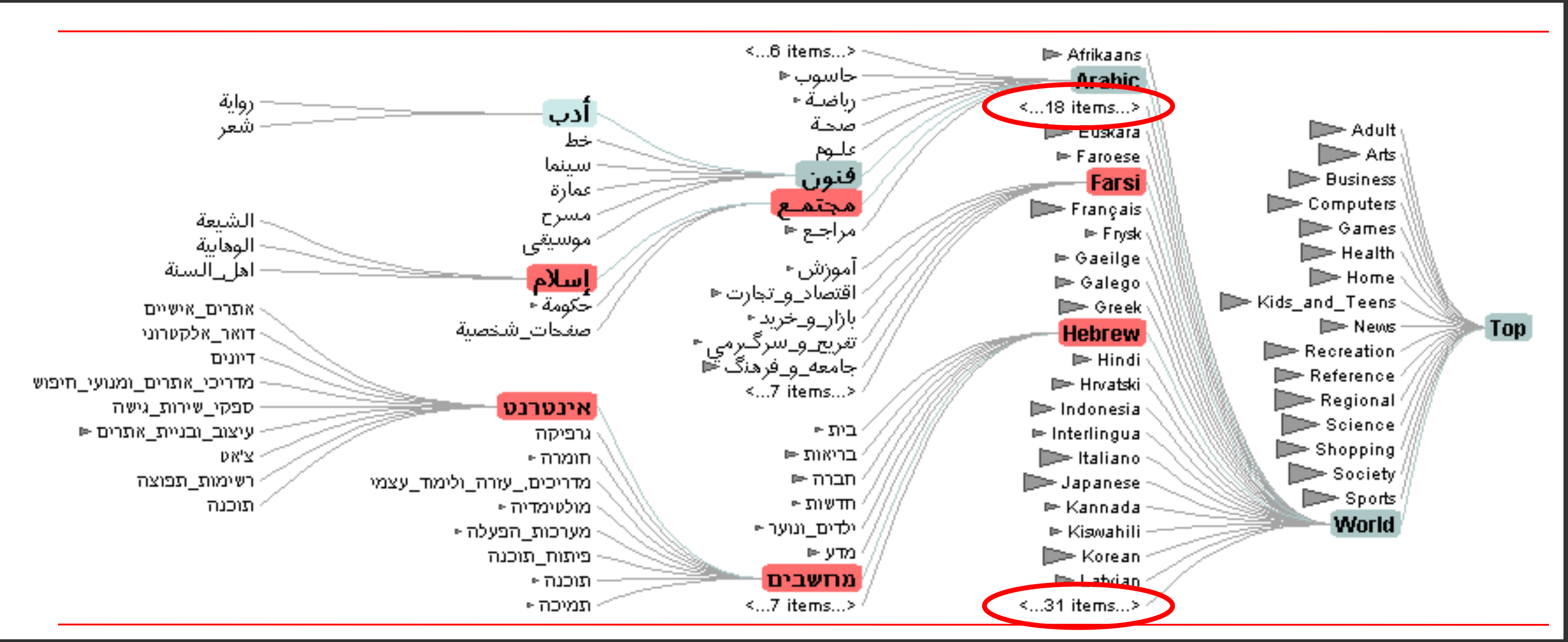


Perform tree layout in hyperbolic geometry, project the result on to the Euclidean plane.

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

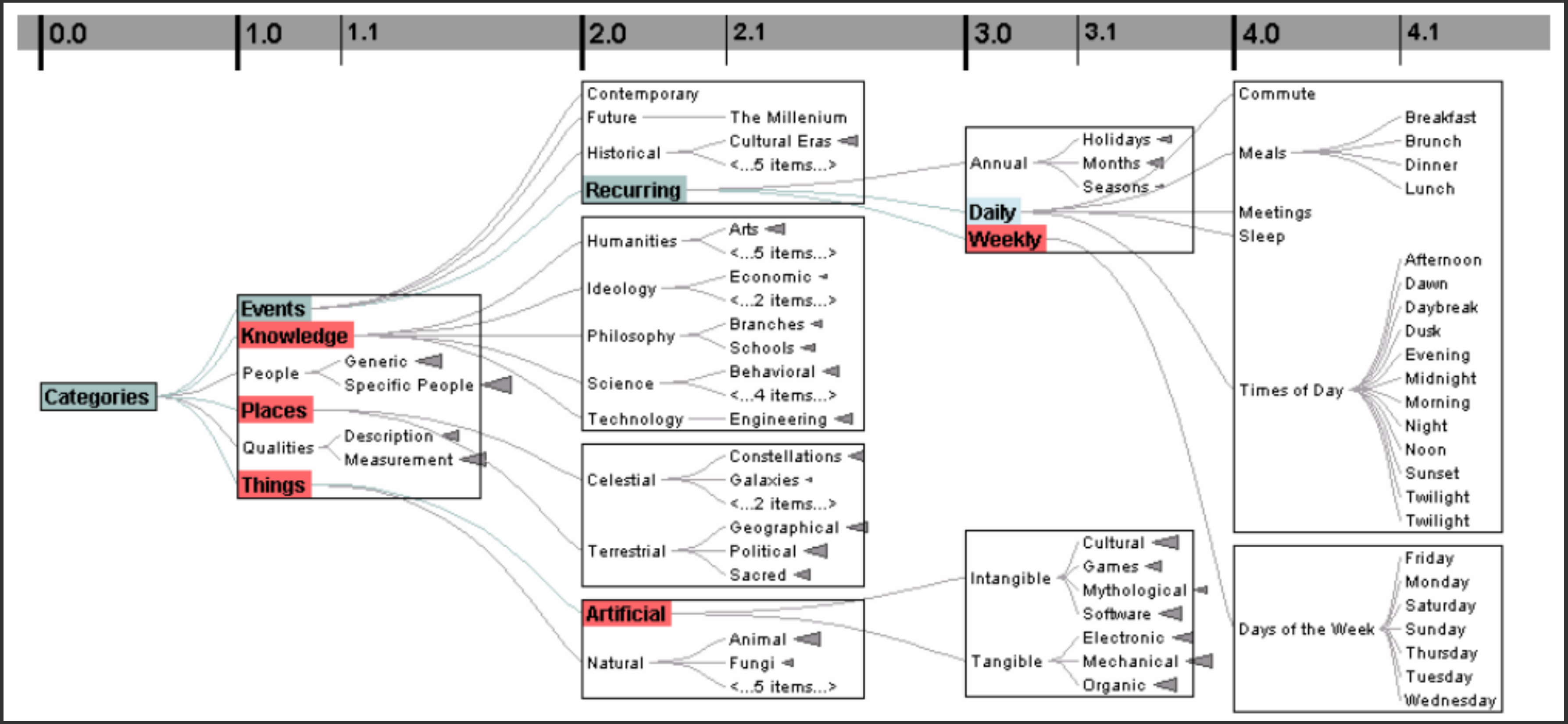
Also computable in 3D, projected into a sphere.

Degree-of-Interest Trees



Space-constrained, multi-focal tree layout

Degree-of-Interest Trees



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

Attempt to center child blocks beneath parents.

Enclosure / Layering

Enclosure Diagrams

Encode structure using **spatial enclosure**

Popularly known as **treemaps**

Benefits

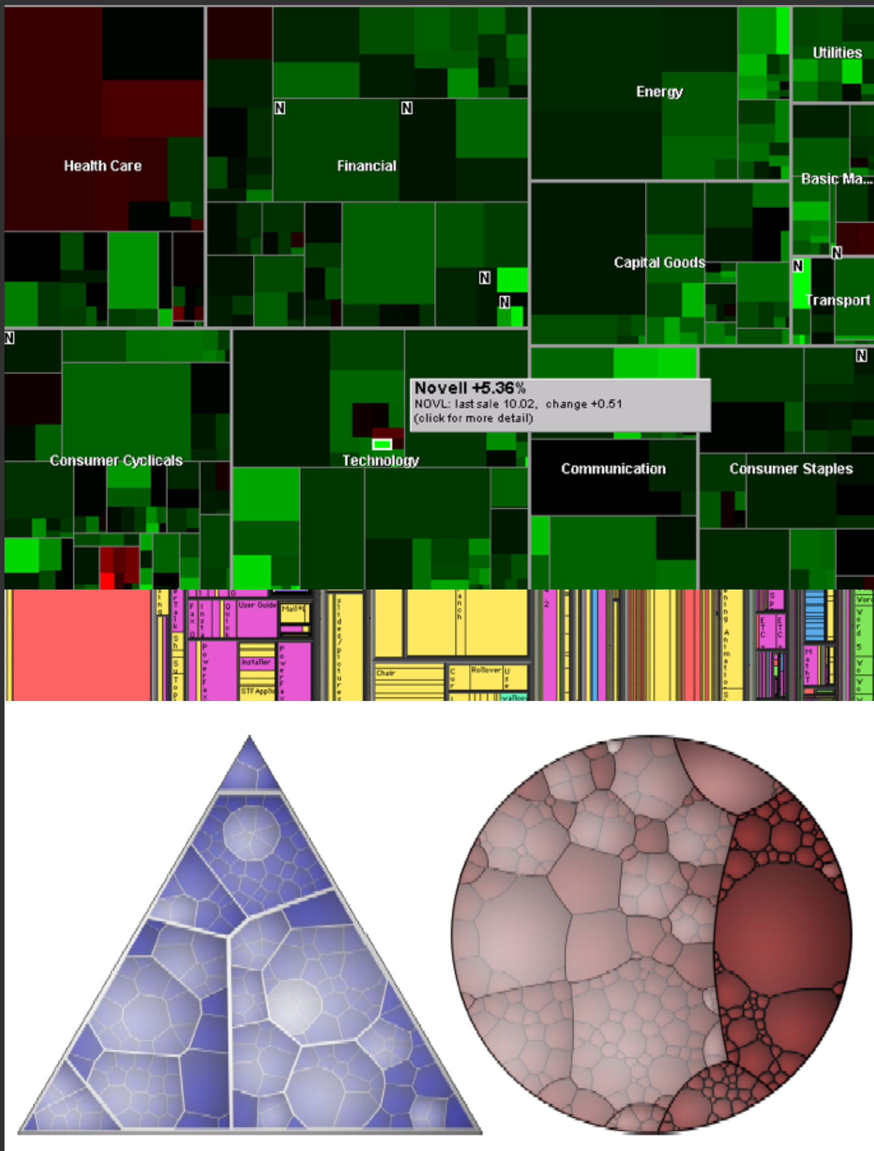
Provides a single view of an entire tree

Easier to spot large/small nodes

Problems

Difficult to accurately read structure / depth

Treemaps



Recursively fill space. Enclosure signifies hierarchy.

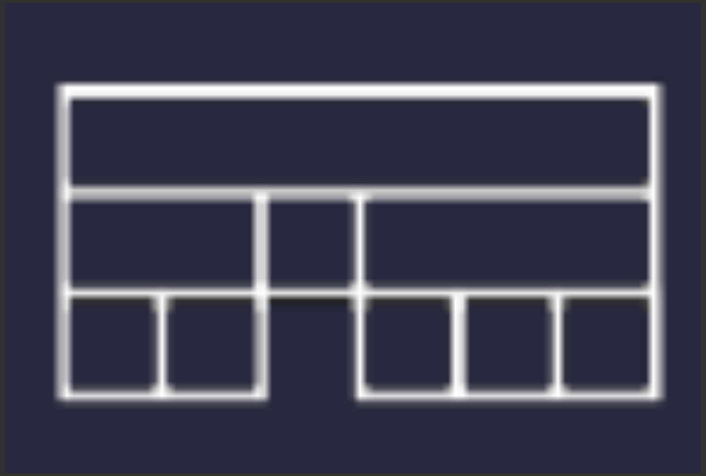
Additional measures can be taken to control aspect ratio of cells.

Often uses rectangles, but other shapes are possible, e.g., iterative Voronoi tesselation.

Layered Diagrams

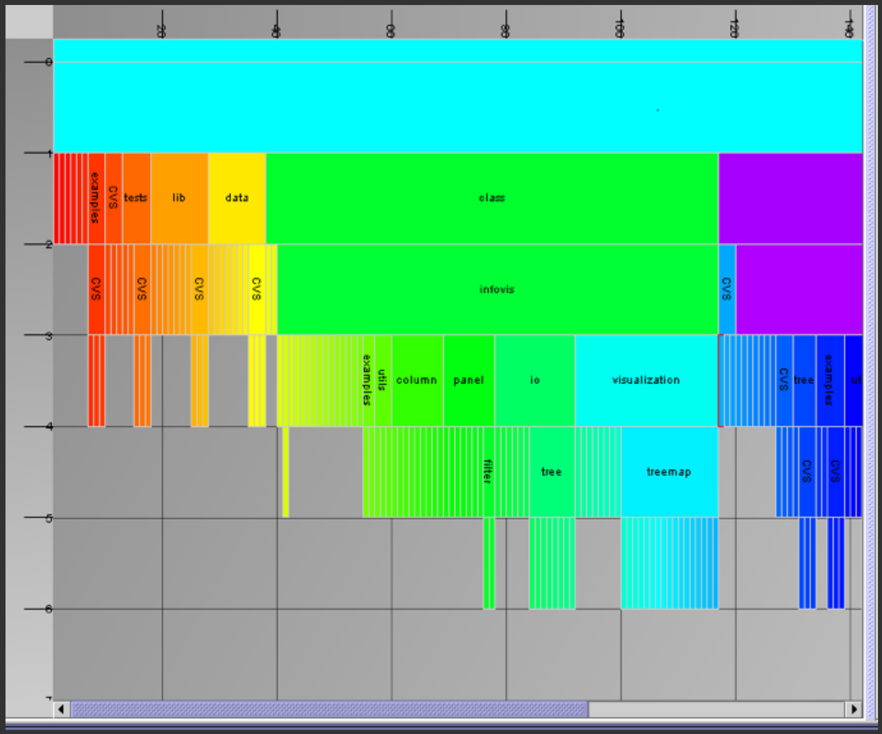
Signify tree structure using

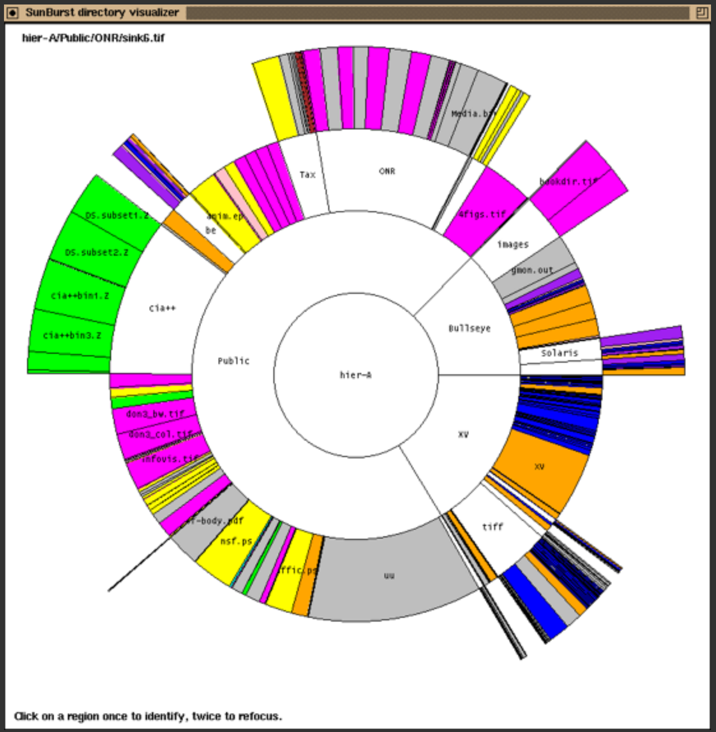
- Layering
- Adjacency
- Alignment



Involves recursive sub-division of space.

Icicle & Sunburst Trees

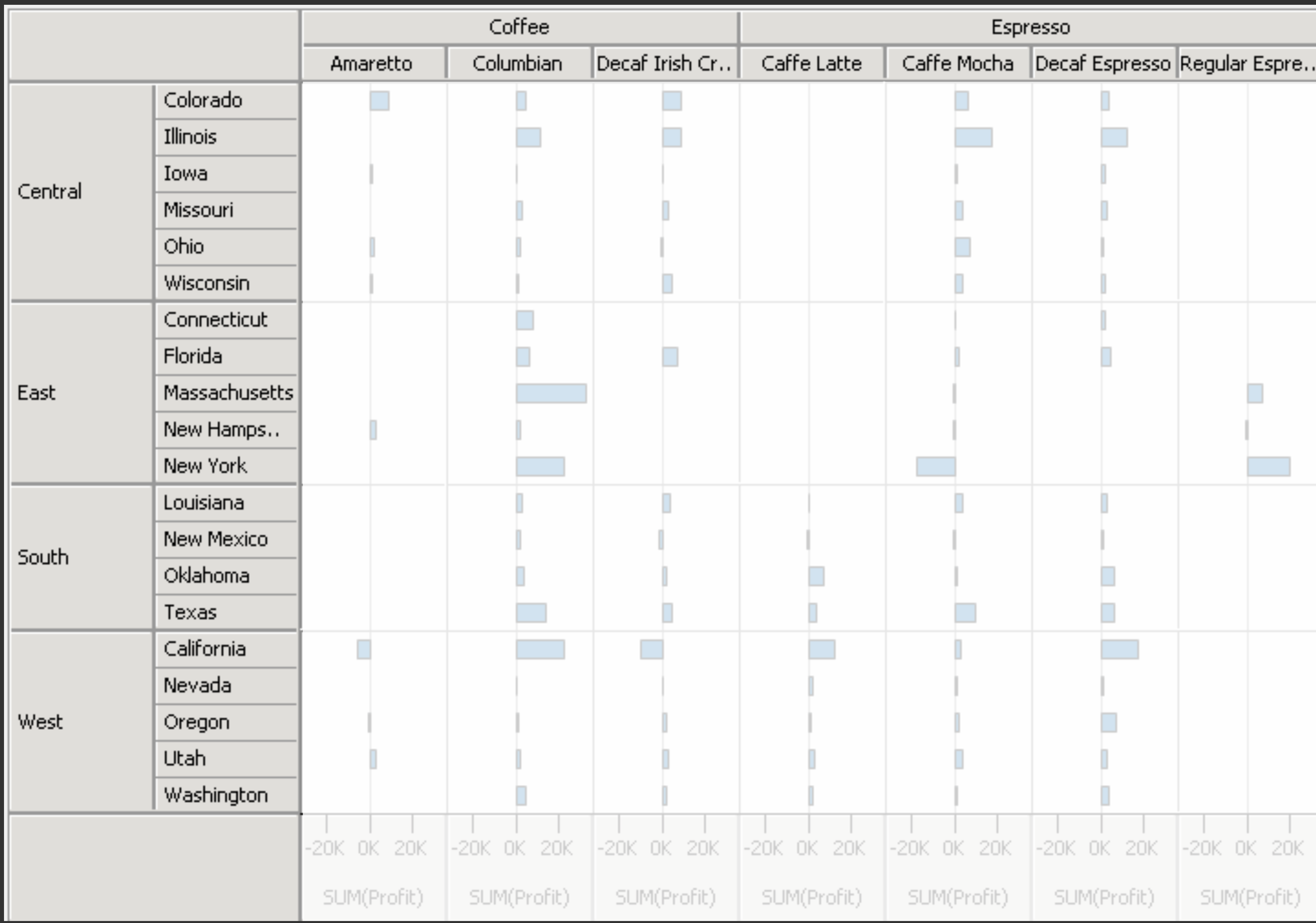




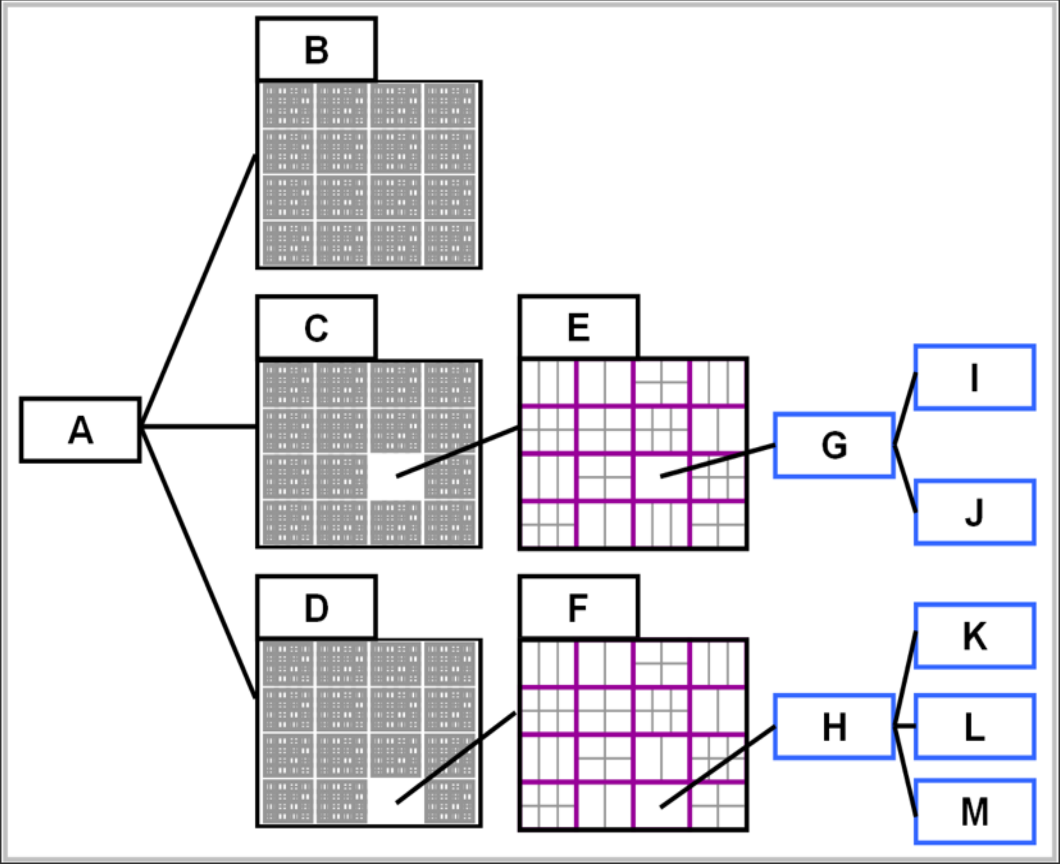
Higher-level nodes get a larger layer area, whether that is horizontal or angular extent.

Child levels are layered, constrained to parent's extent

Layered Tree Drawing



Hybrids are also possible…



“Elastic Hierarchies”

Node-link diagram with treemap nodes.

Administrivia

Final Project Schedule

Proposal	**Tues, May 12 (5pm)**
Presentation	Thur, May 21 (slides: 5/20, 5pm)
Poster & Demo	Mon, Jun 8 (5-8pm)
Final Paper	Thur, Jun 11 (8am)

Logistics

Groups of up to 4 people

Clearly report responsibilities of each member

Graph Layout

Approaches to Graph Drawing

Direct Calculation using Graph Structure

Tree layout on spanning tree

Hierarchical layout

Adjacency matrix layout

Optimization-based Layout

Constraint satisfaction

Force-directed layout

Attribute-Driven Layout

Layout using data attributes, not linkage

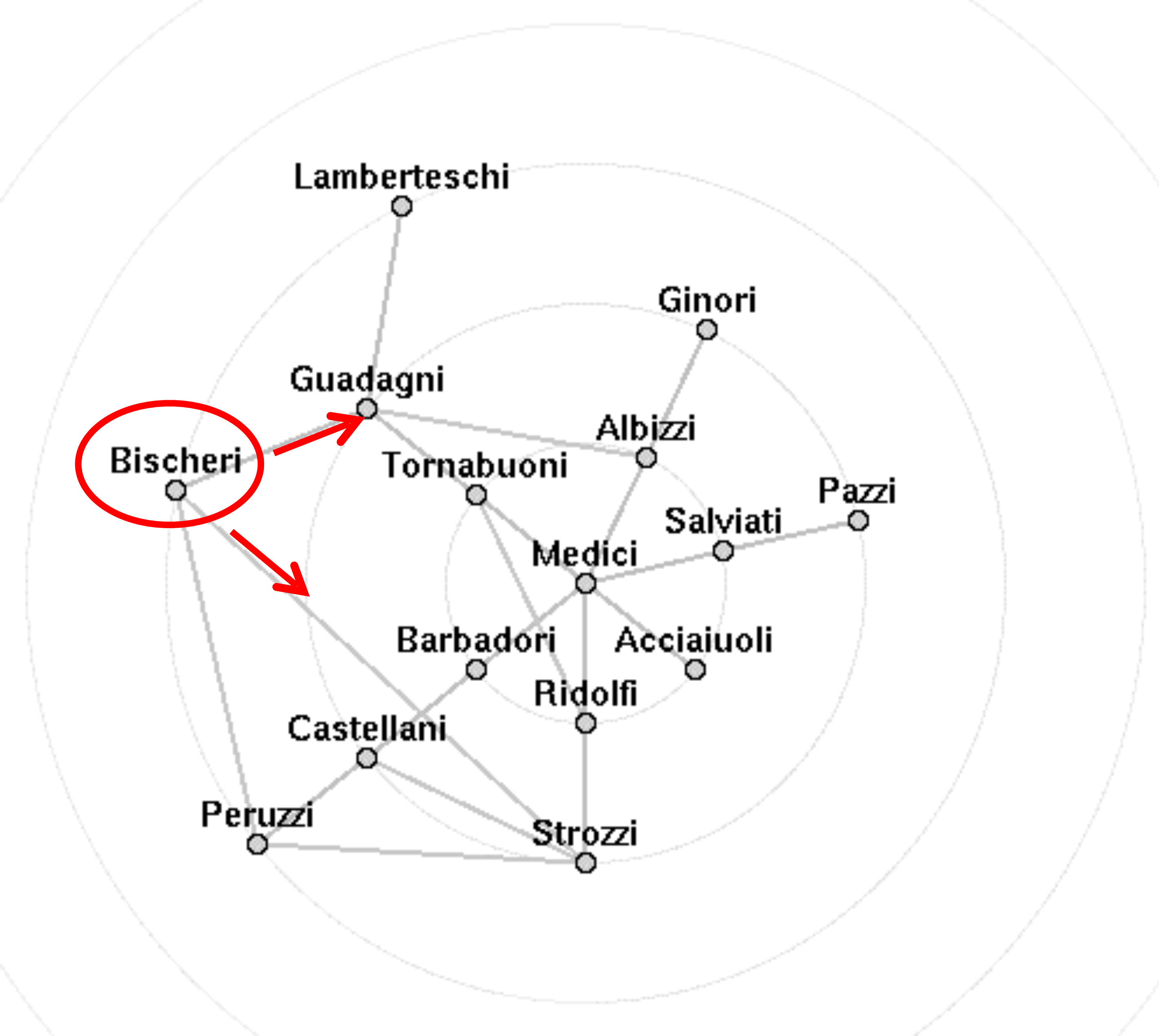
Spanning Tree Layout

Spanning Tree Layout

Many graphs 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



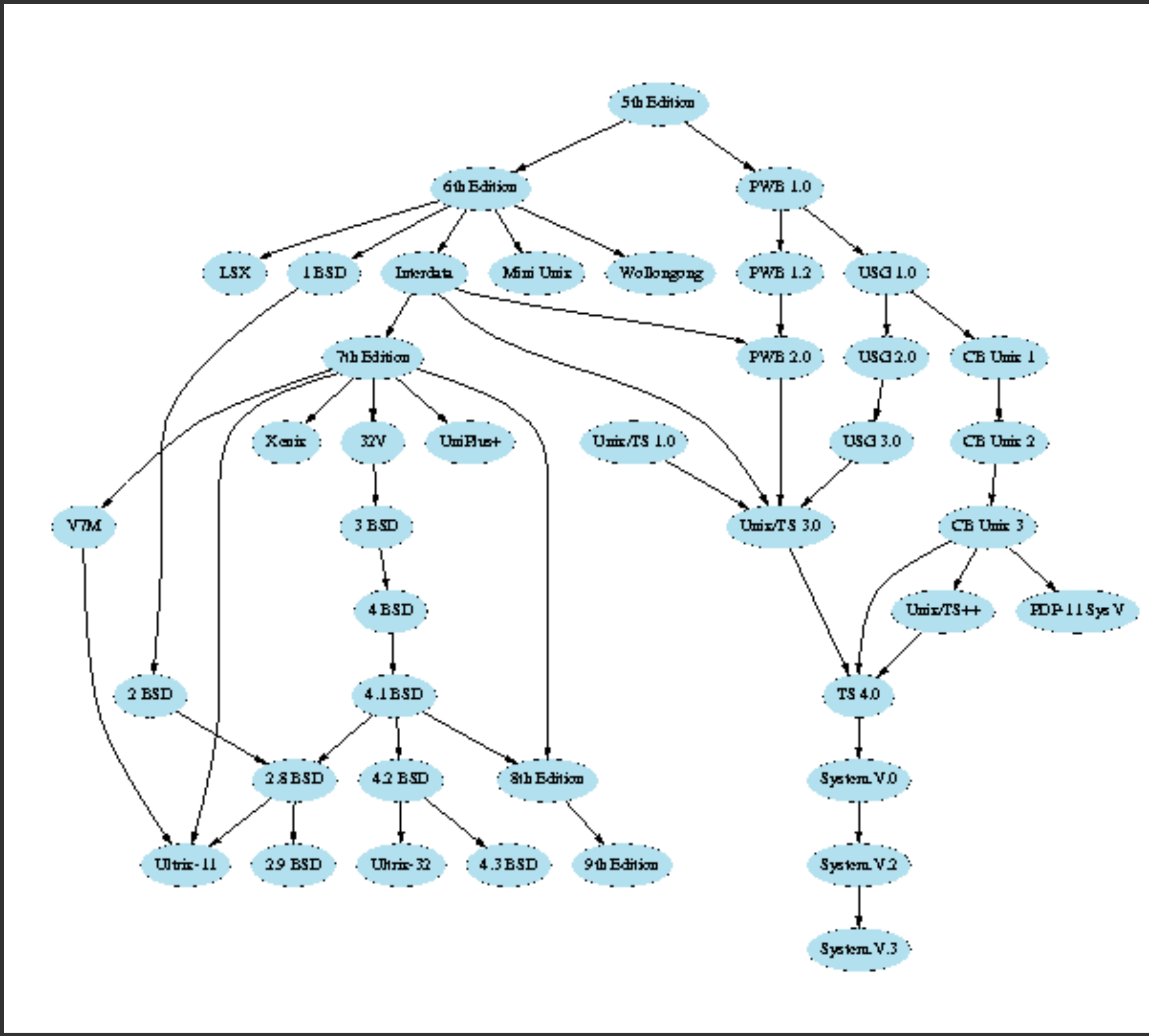
Spanning tree layout may result in arbitrary parent node

Sugiyama-Style Layout

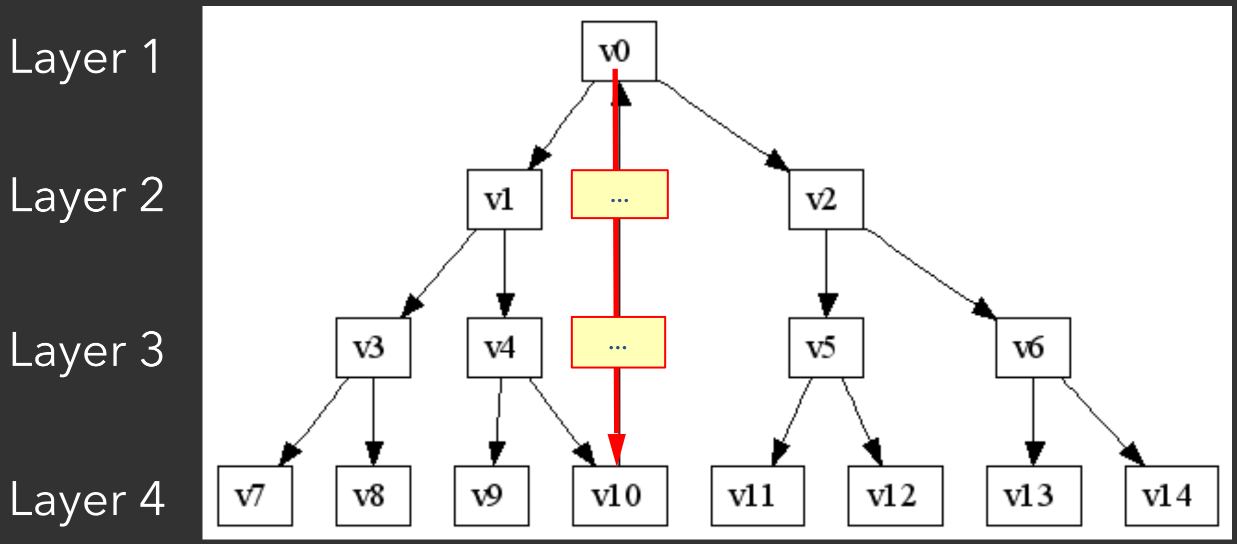
Sugiyama-style Layout

Evolution of the UNIX operating system

Hierarchical layering based on descent



Sugiyama-style Layout



Reverse edges to remove cycles

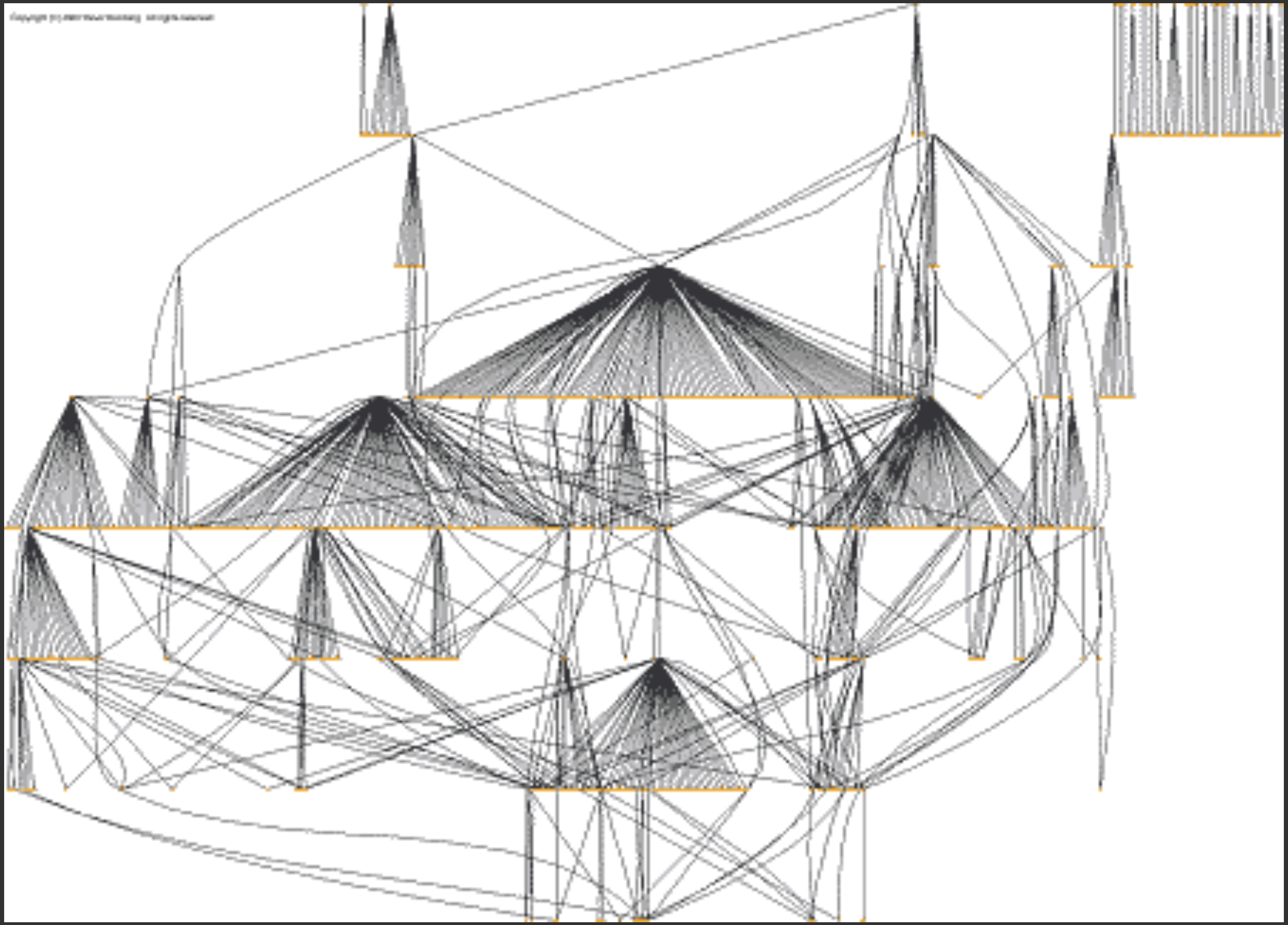
Assign nodes to hierarchy layers

Create dummy nodes to “fill in” missing layers

Arrange nodes within layer, minimize edge crossings

Route edges – layout splines if needed

Hierarchical Layout



Gnutella network

Force-Directed Layout

Optimization Techniques

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

Commonly posed as a physical system

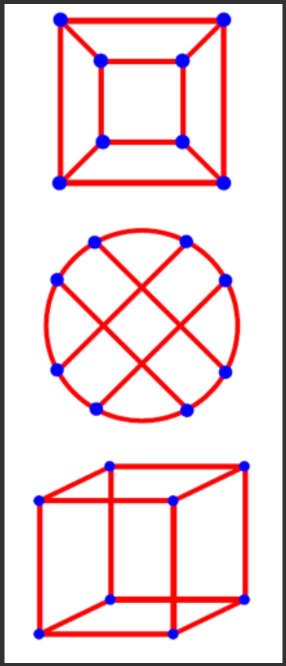
Charged particles, springs, drag force, …

We can introduce directional constraints

DiG-CoLa (Di-Graph Constr Optimization Layout) [Dwyer 05]

Iterative constraint relaxation

Optimizing Aesthetic Constraints



Minimize edge crossings

Minimize area

Minimize line bends

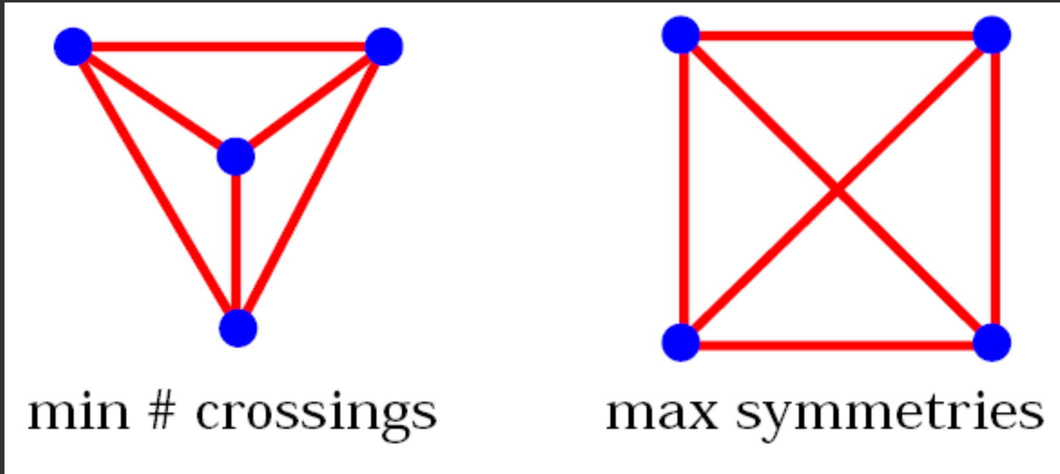
Minimize line slopes

Maximize smallest angle between edges

Maximize symmetry

but, can't do it all.

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



Force-Directed Layout

Nodes = charged particles $F = G*m_1*m_2 / (x_i - x_j)^2$

with air resistance $F = -b * v_i$

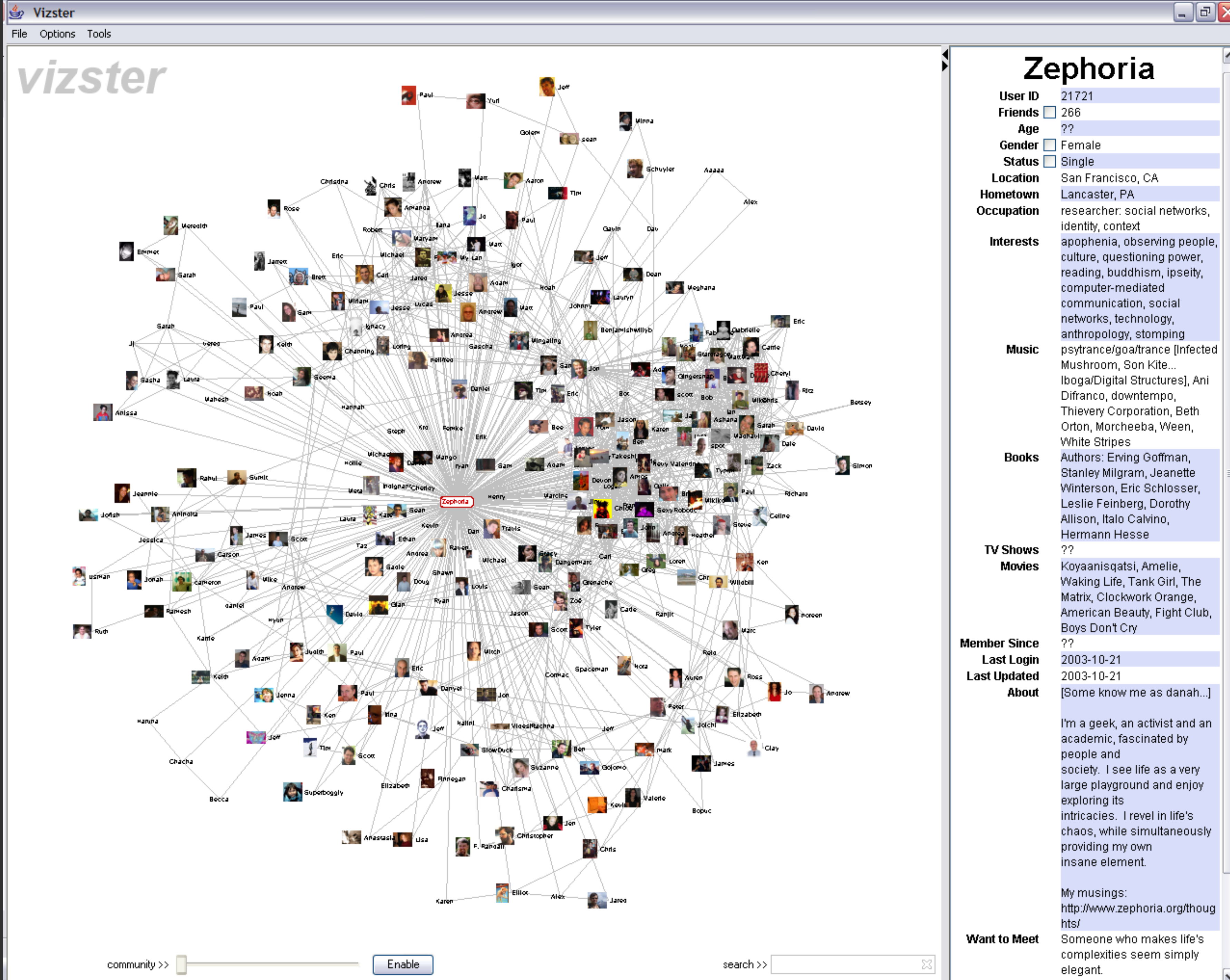
Edges = springs $F = -k * (x_i - x_j - L)$

Iteratively calculate forces, update node positions

Naïve n-body calculation is $O(N^2)$

O(N log N) using quadtree or k-d tree

Numerical integration of forces at each time step


Vizster
File Options Tools
vizster
Zephoria
community >>
Enable
search >>
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.

Constrained Optimization

Minimize stress function

$\text{stress}(X) = \Sigma_{i<j} w_{ij} (\|X_i - X_j\| - d_{ij})^2$

X: node positions, d: optimal edge length,

w: normalization constants

Says: Try to place nodes d_{ij} apart

Constrained Optimization

Minimize stress function

stress(X) = $\Sigma_{i<j}\, w_{ij}\, (\, \|X_i - X_j\| - d_{ij}\,)^2$

X: node positions, d: optimal edge length,

w: normalization constants

Says: Try to place nodes d_{ij} apart

Add hierarchy ordering constraints

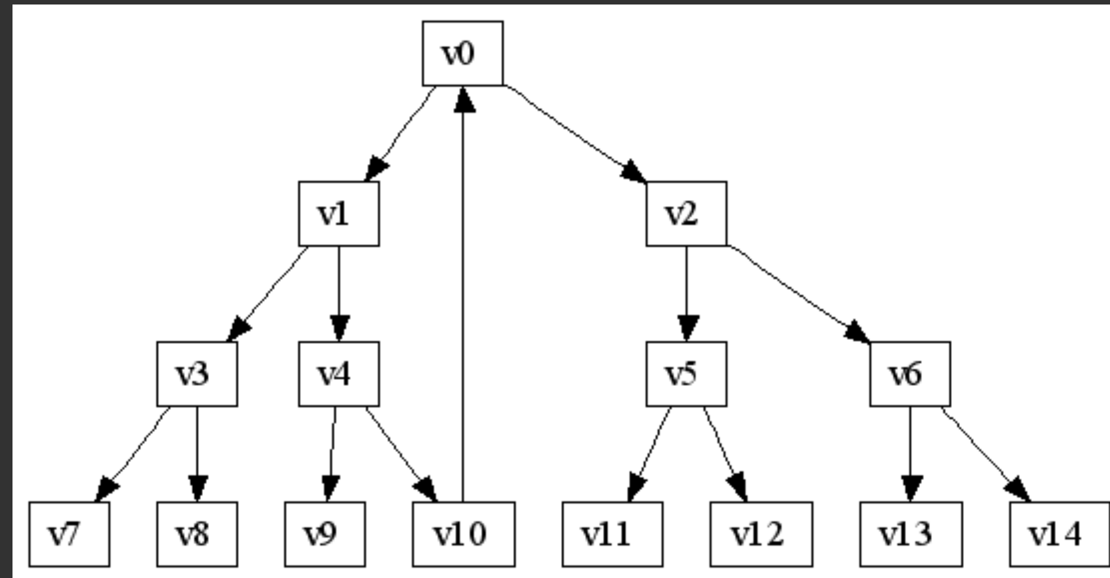
$E_H(y) = \Sigma_{(i,j)\in E}\, (\, y_i - y_j - \delta_{ij}\,)^2$

y: node y-coordinates

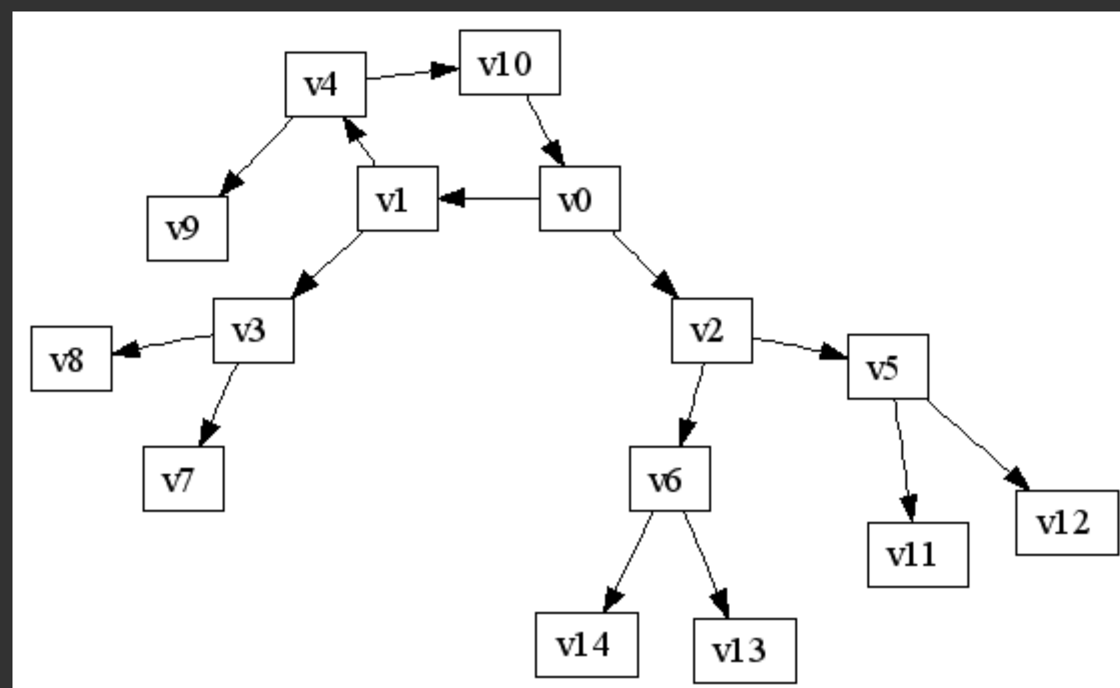
δ: edge direction (e.g., 1 for i->j, 0 for undirected)

Says: If i points to j, it should have a lower y-value

Sugiyama layout (dot)
Preserve tree structure

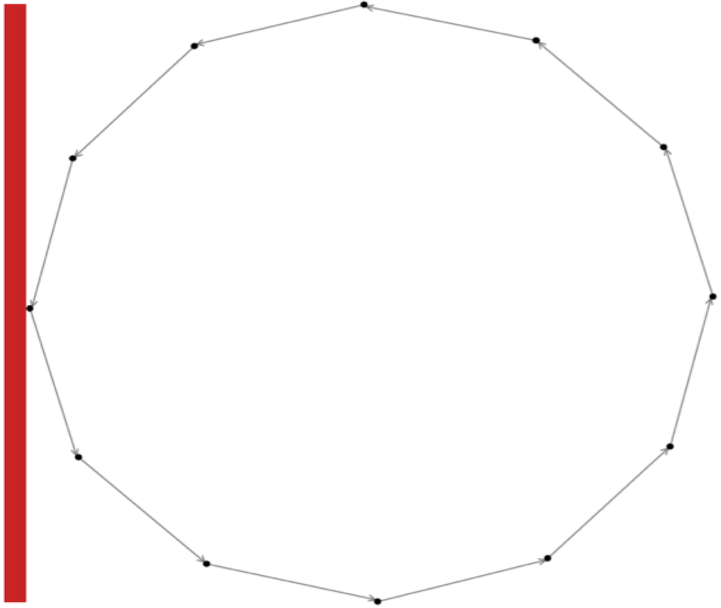


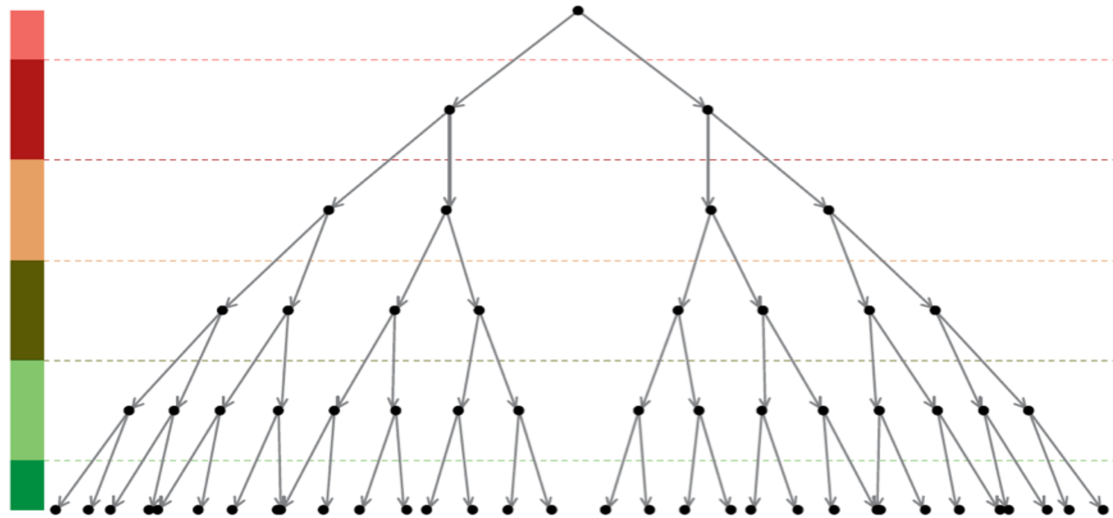
DiG-CoLa method
Preserve edge lengths

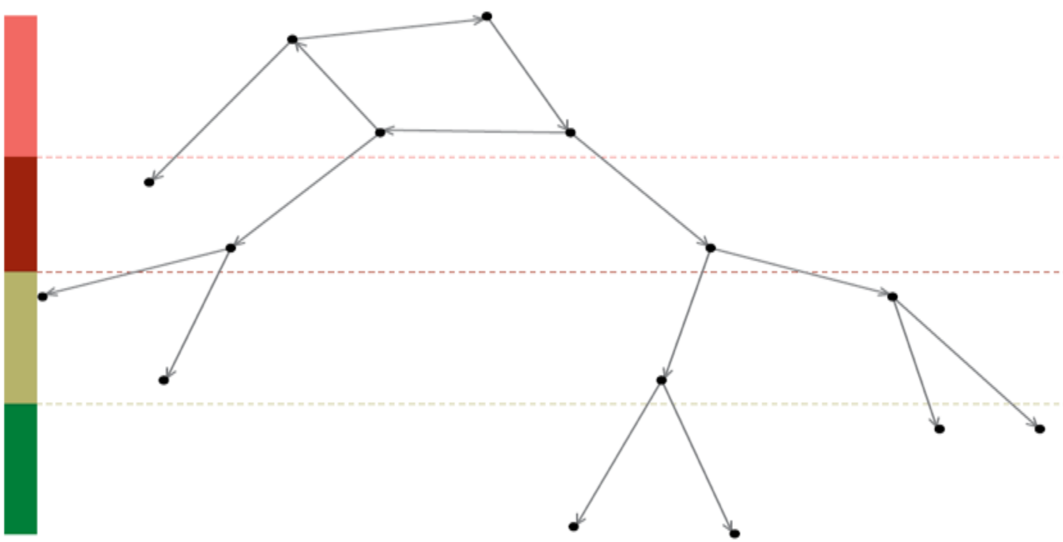


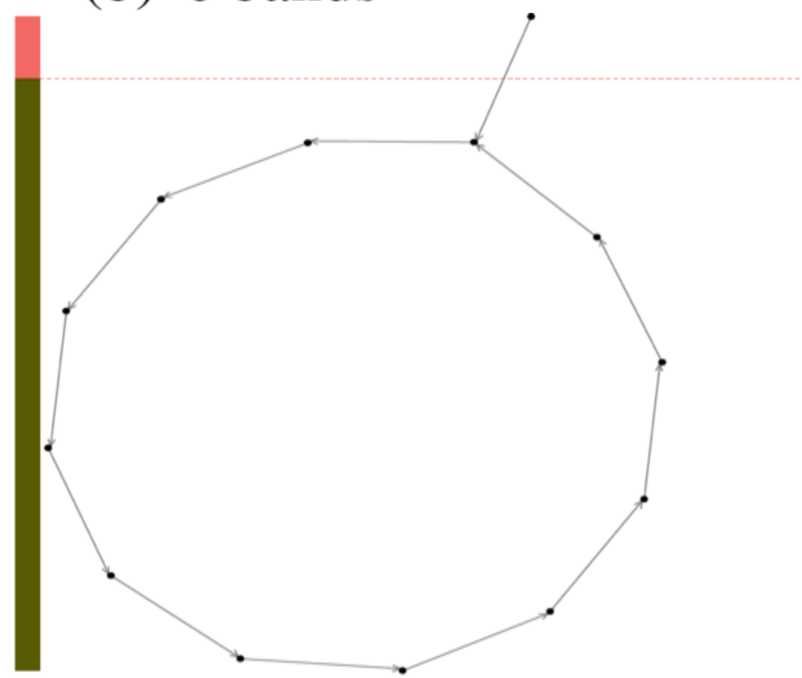
[Slide from Tim Dwyer]

[Slide from Tim Dwyer]


(a) 1 band


(b) 6 bands


(c) 4 bands


(d) 2 bands

Iterative Constraint Relaxation

Quadratic programming is complex to code and computationally costly. Is there a simpler way?

Iteratively **relax** each constraint [Dwyer 09]

- Given a constraint (e.g., $| x_i - x_j | = 5$)
- Simply push the nodes to satisfy!

Each relaxation may **clobber** prior results

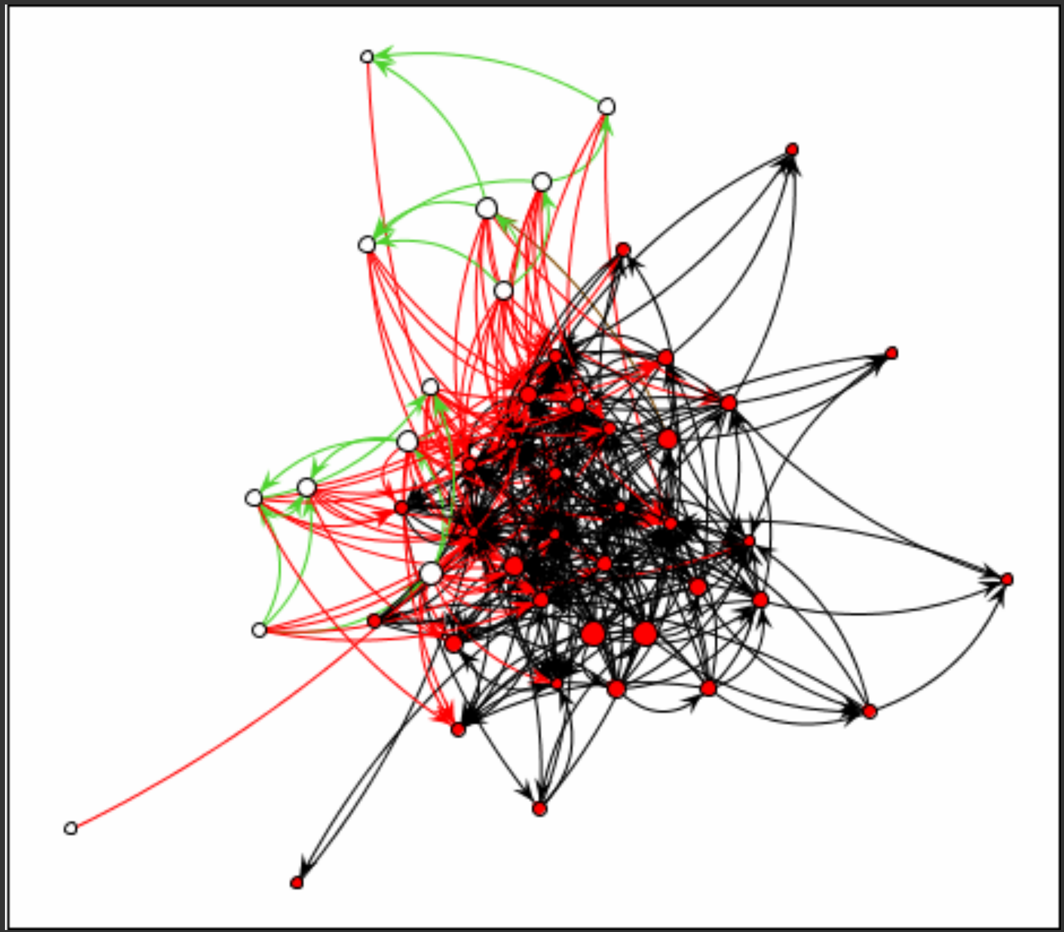
But this typically **converges quickly**

Enables **expressive constraints**!

Use the Force!

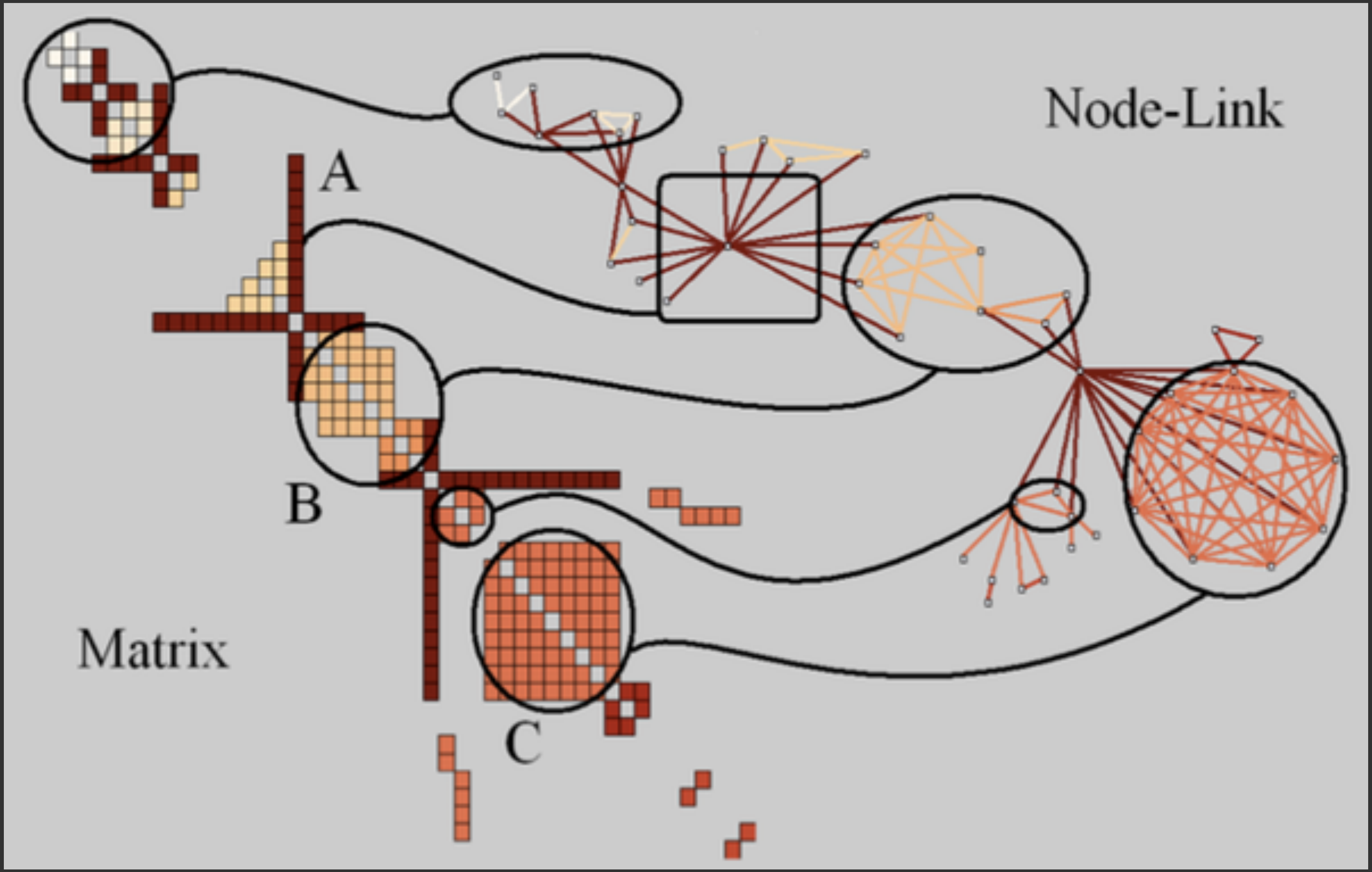
http://mbostock.github.io/d3/talk/20110921/

Limitations of Node-Link Layout

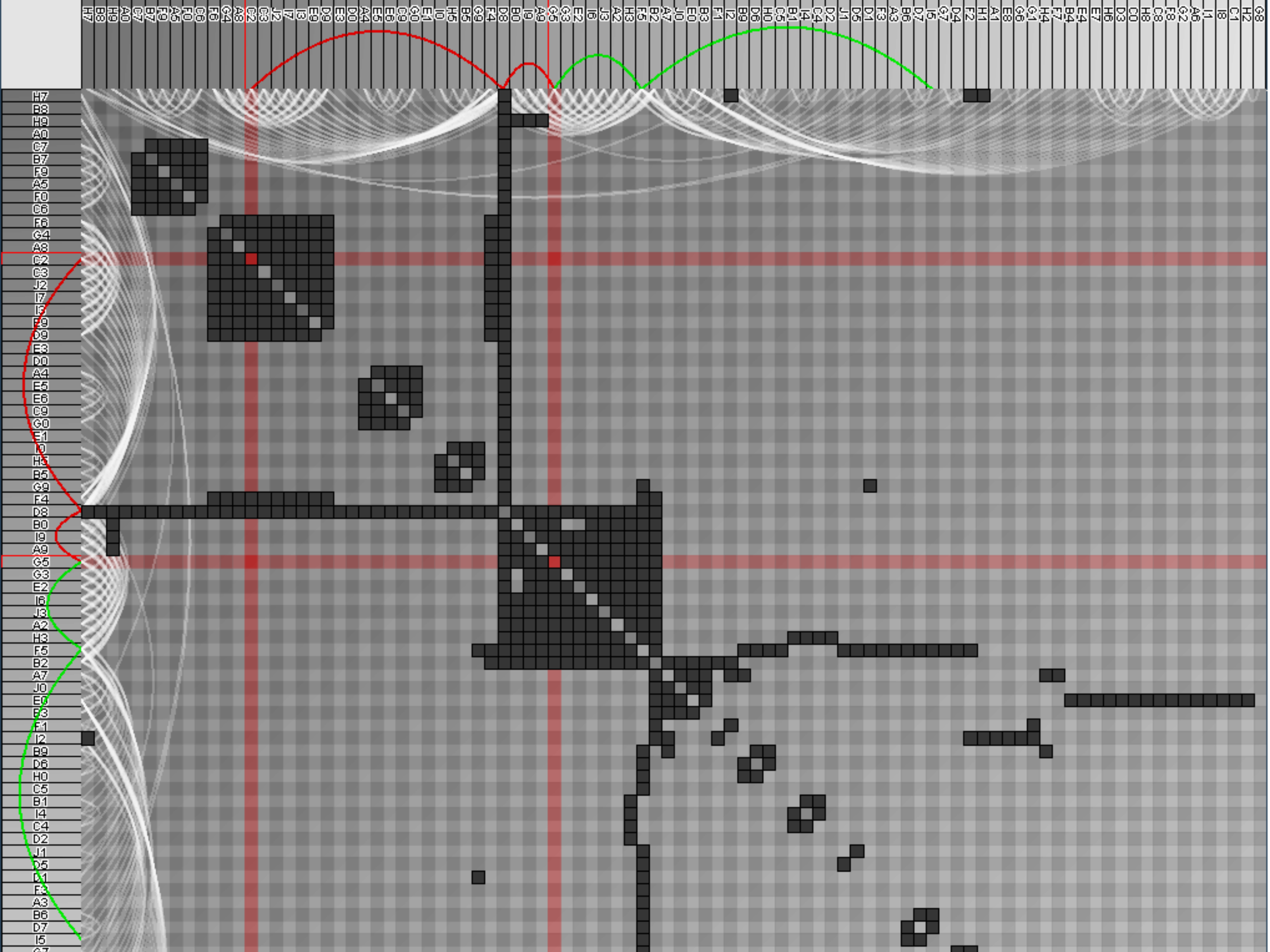


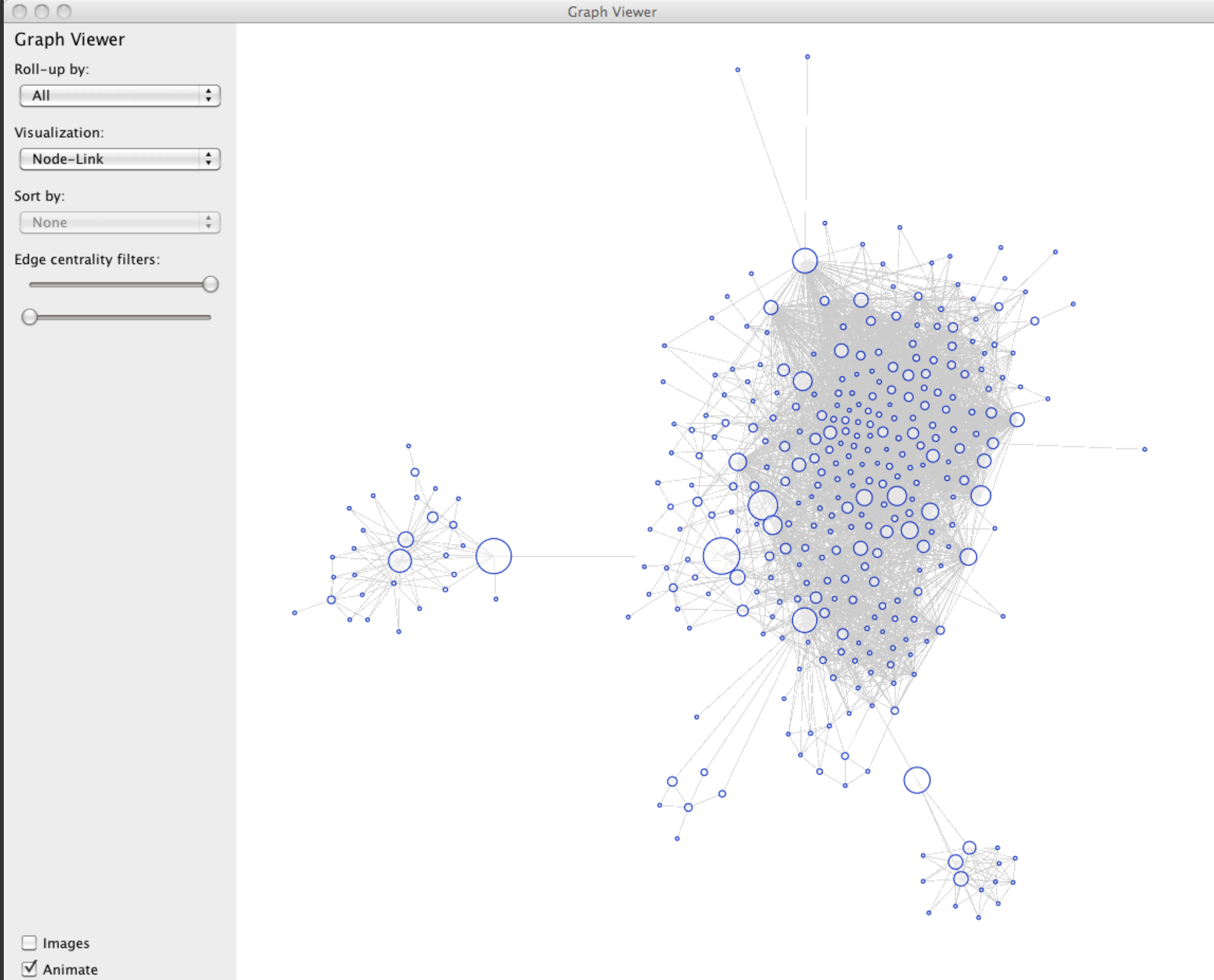
Edge-crossings and occlusion

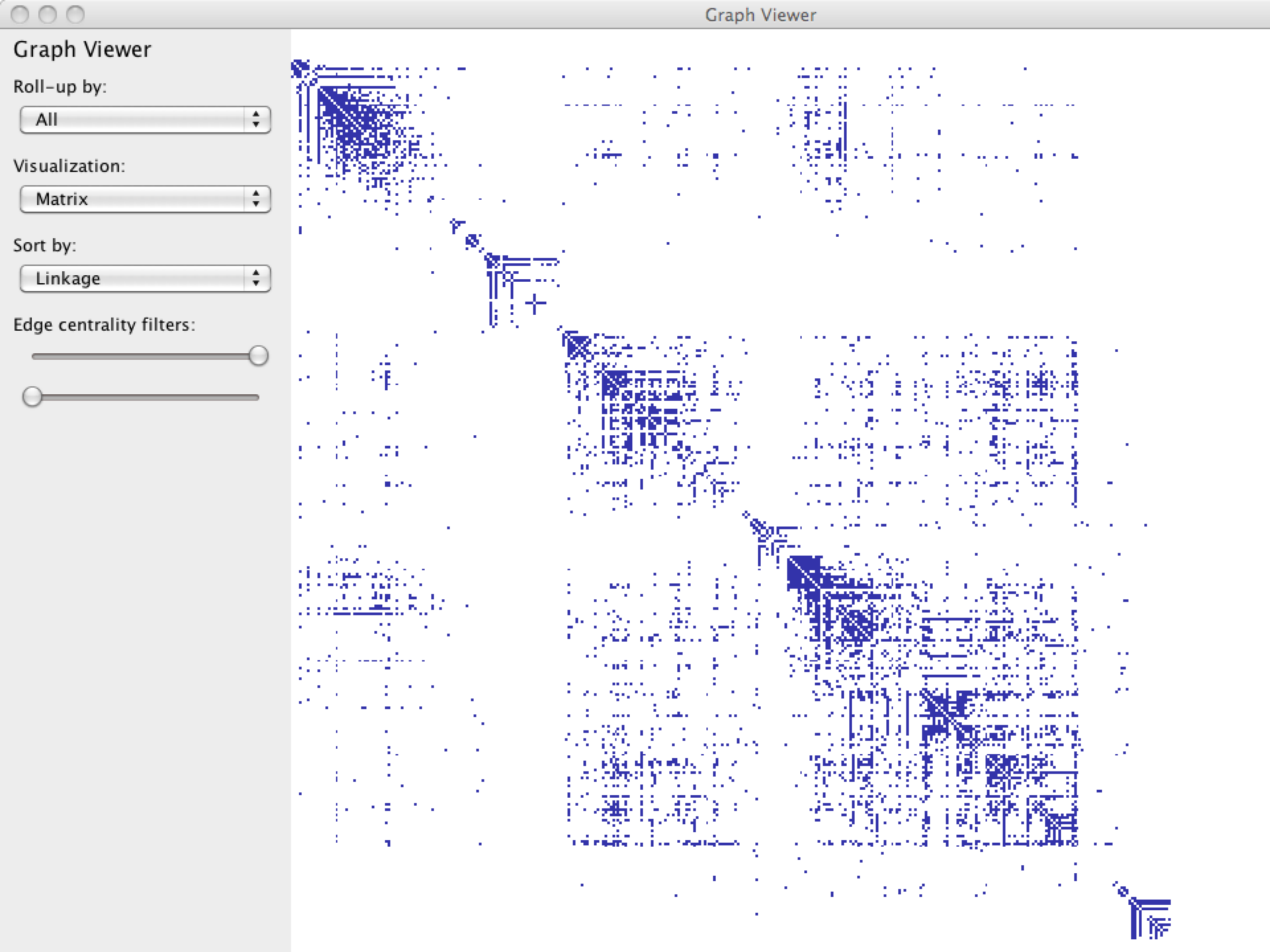
Matrix Diagrams

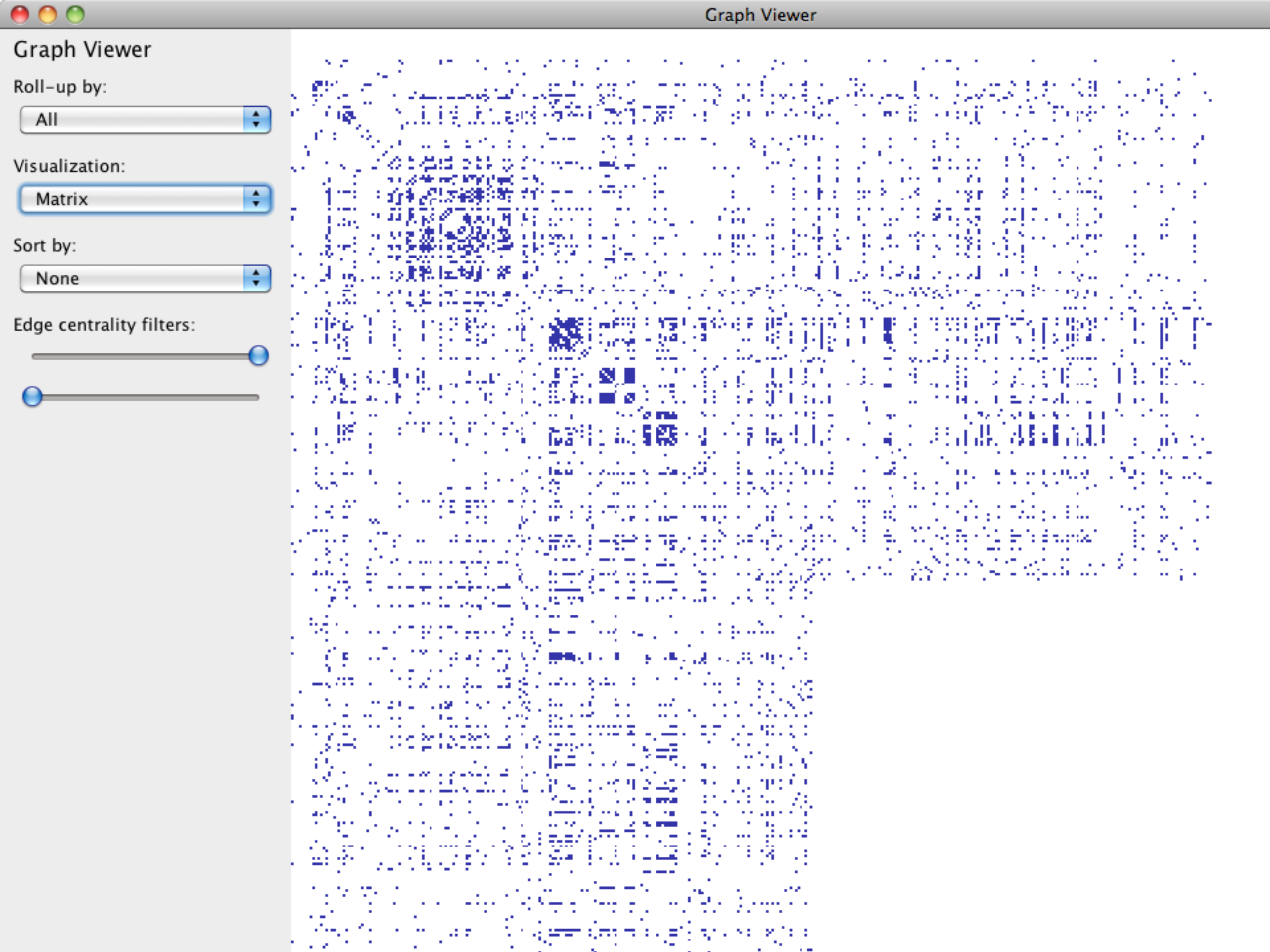


Adjacency Matrices


H7
B8
H9
A0
C7
B7
F9
A5
F0
C8
F6
G4
A8
C2
C3
J2
I7
I3
E9
D9
E3
D0
A4
E5
E6
C9
G0
E1
I0
H5
B5
G9
F4
D8
B0
I9
A9
G5
G3
E2
I6
J3
A2
H3
F5
B2
A7
J0
E0
B3
F1
I2
B9
D6
H0
C5
B1
I4
C4
D2
J1
D5
D1
F3
A3
B6
D7
I5


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:

Attribute-Driven Layout

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

Dynamic queries / brushing to explore…

Attribute-Driven Layout

The "Skitter" Layout

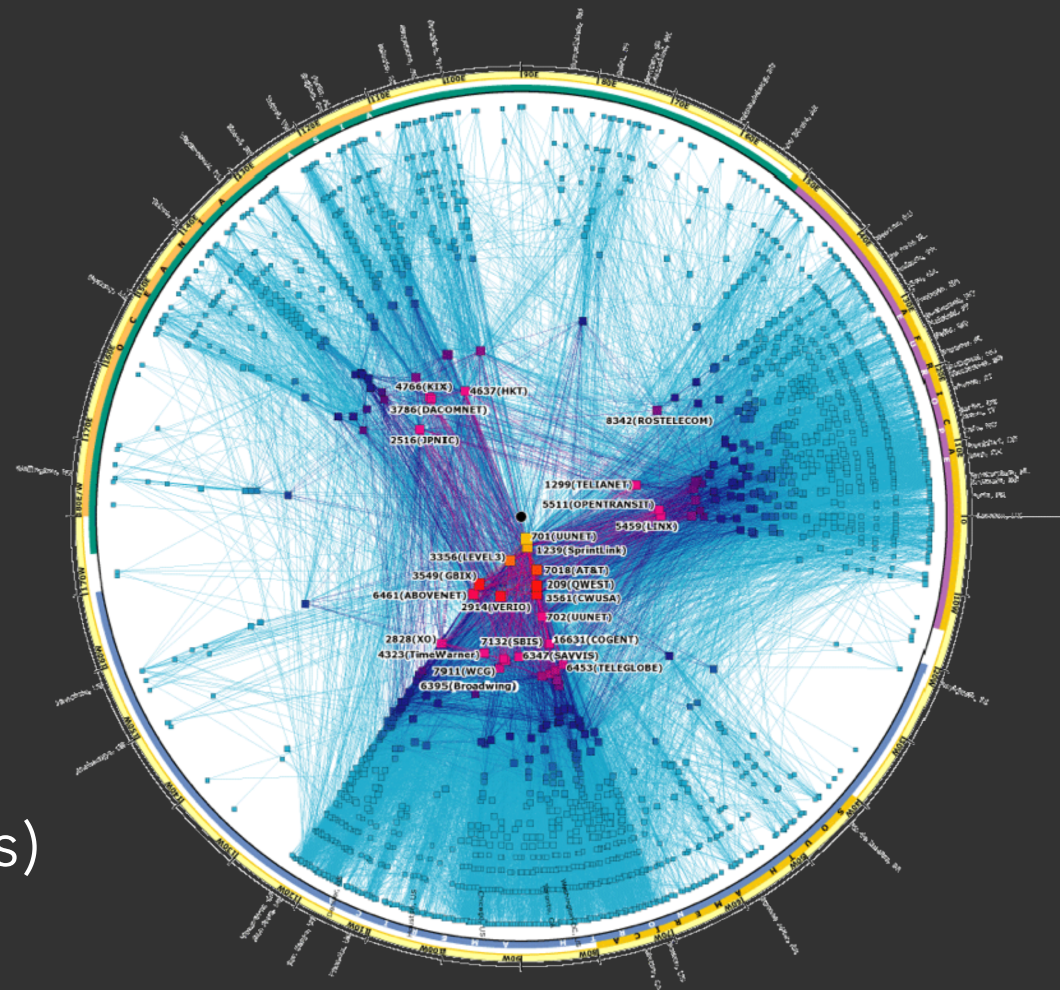
- Internet Connectivity
- Radial Scatterplot

Angle = Longitude

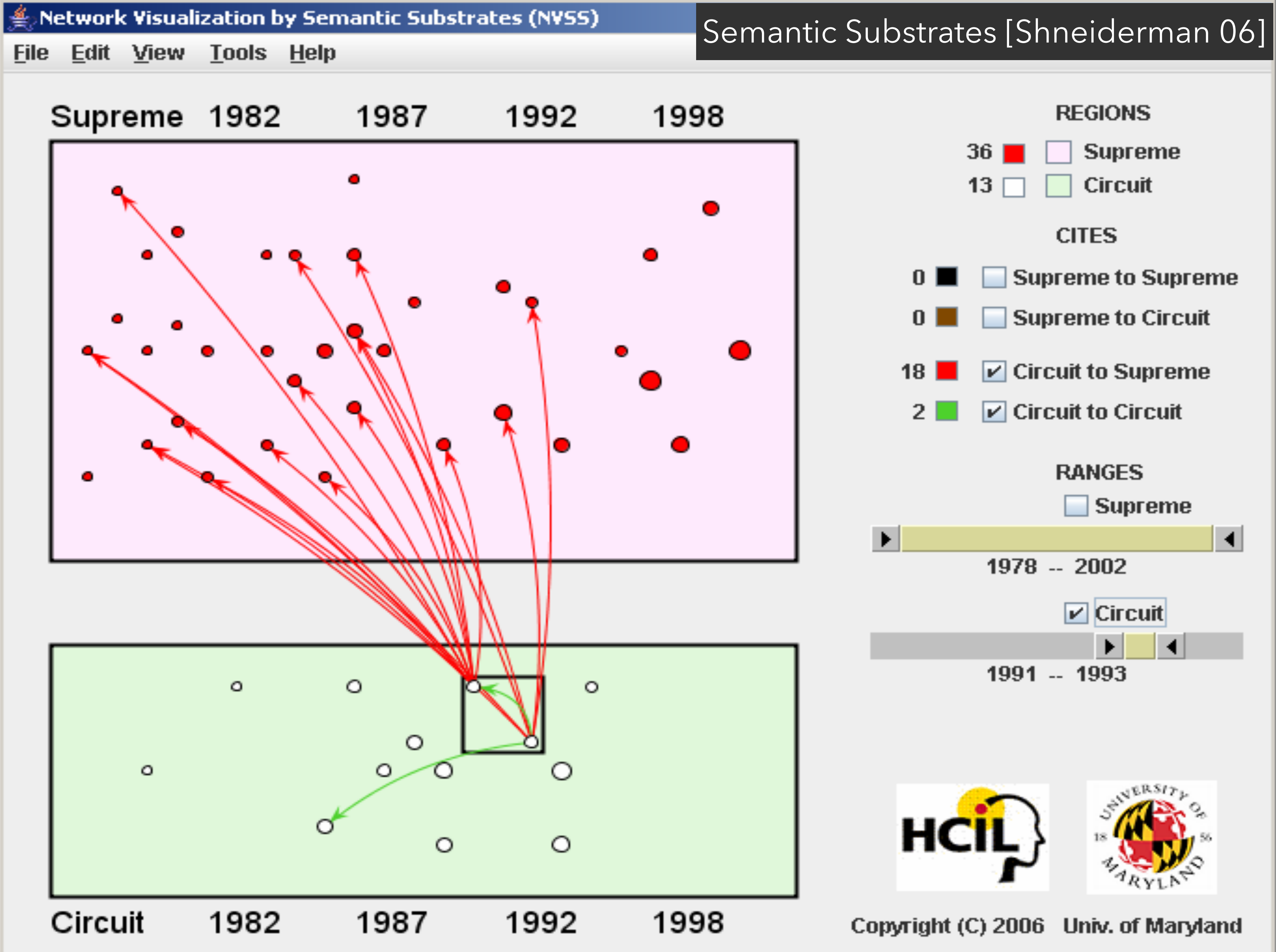
- Geography

Radius = Degree

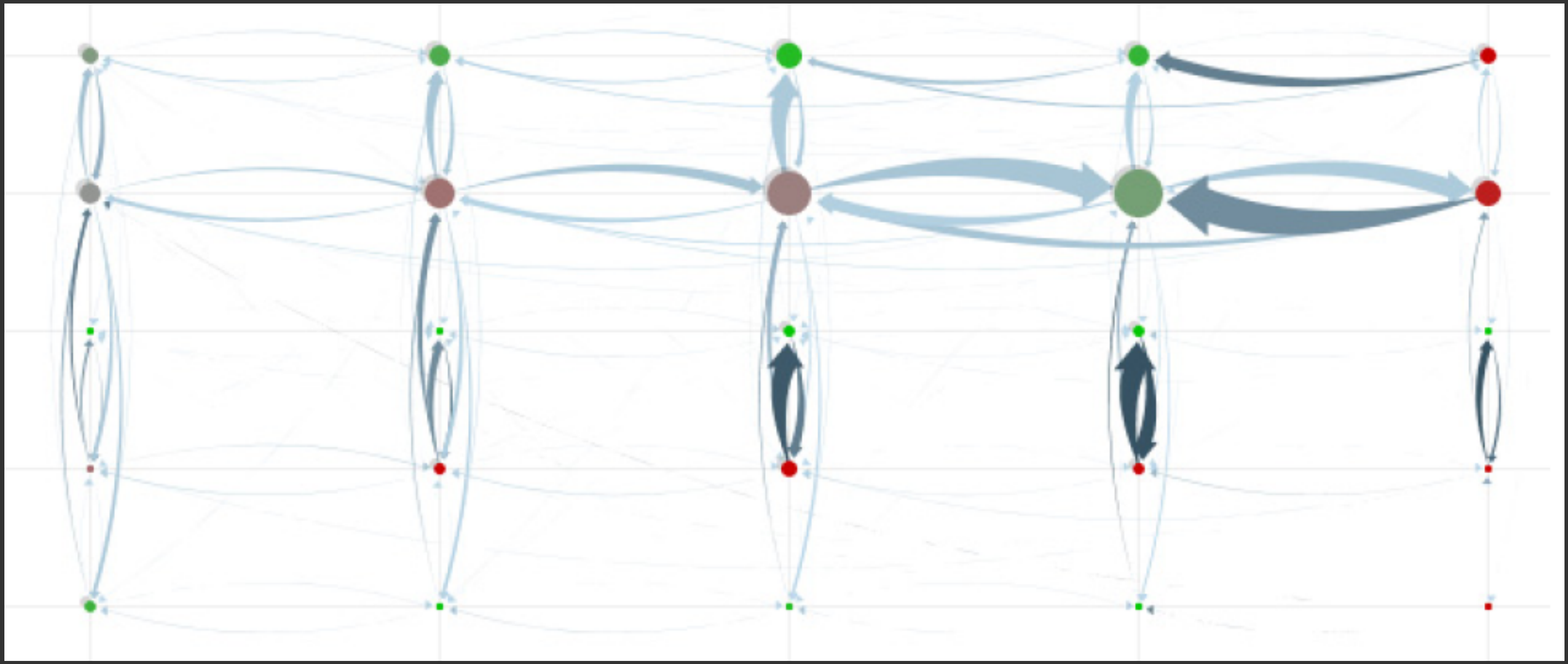
- # of connections
- (a statistic of the nodes)



Semantic Substrates [Shneiderman 06]

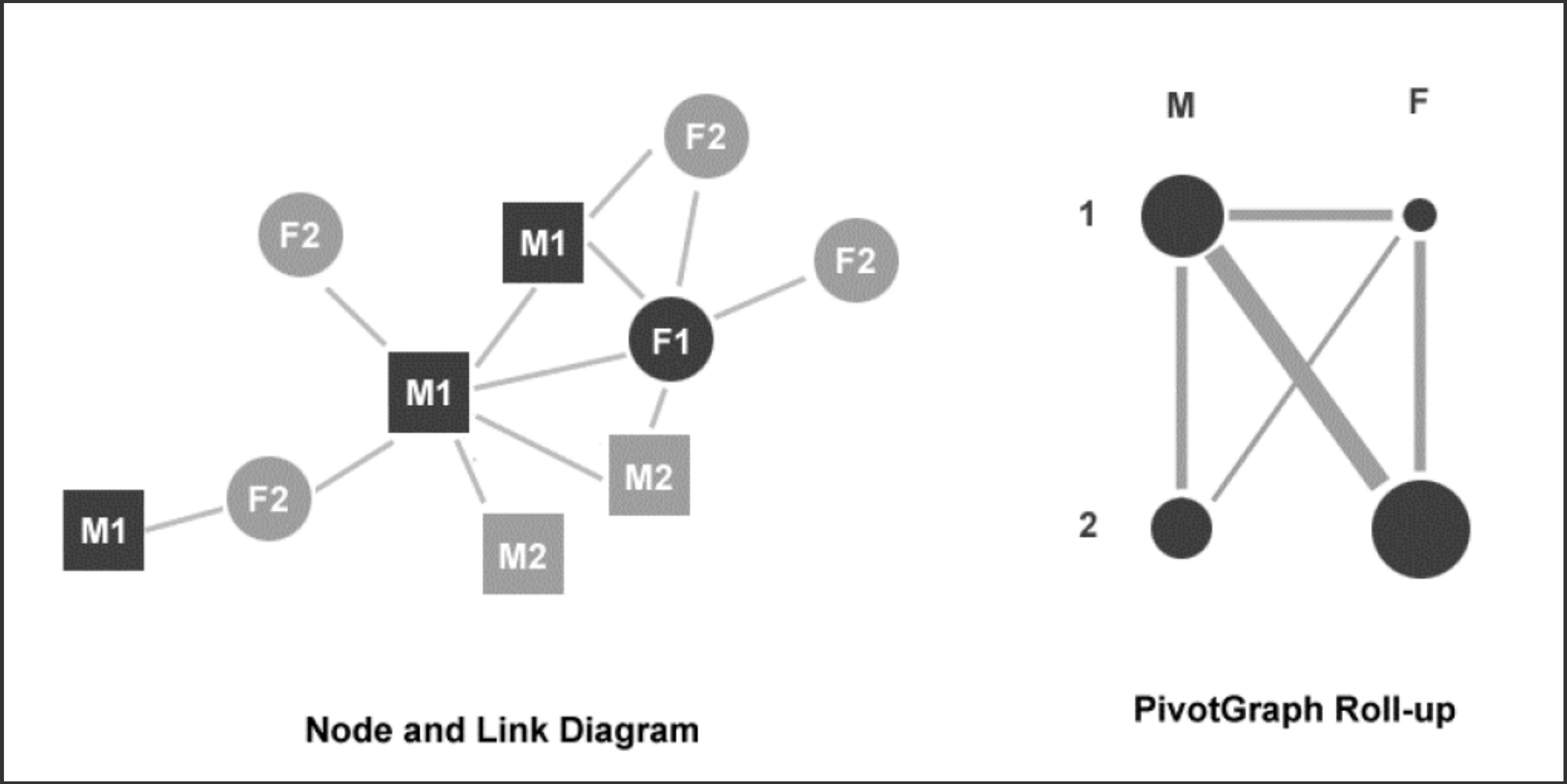


PivotGraph [Wattenberg'06]

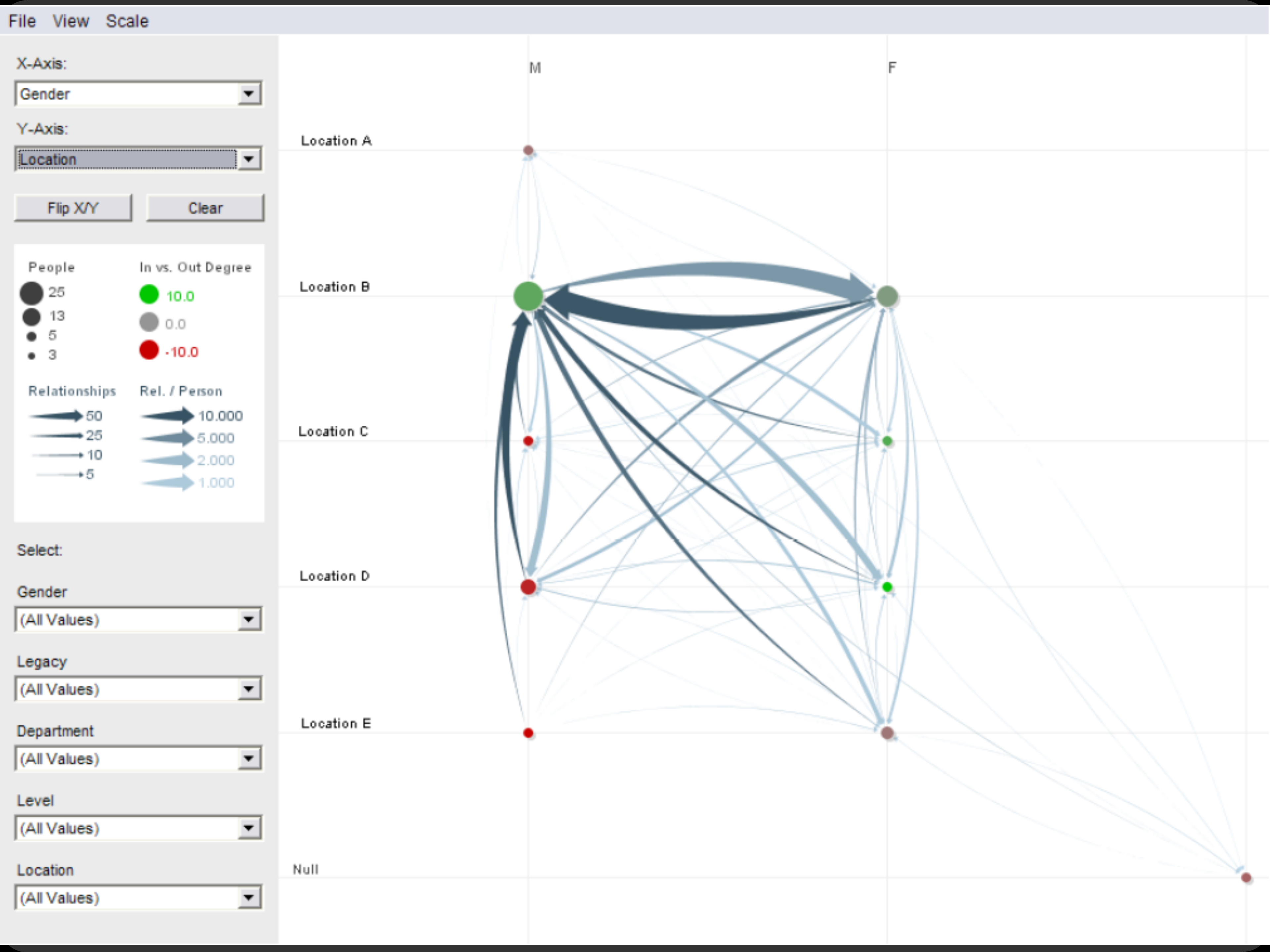


Layout aggregate graphs using node attributes.
Analogous to pivot tables and trellis display.

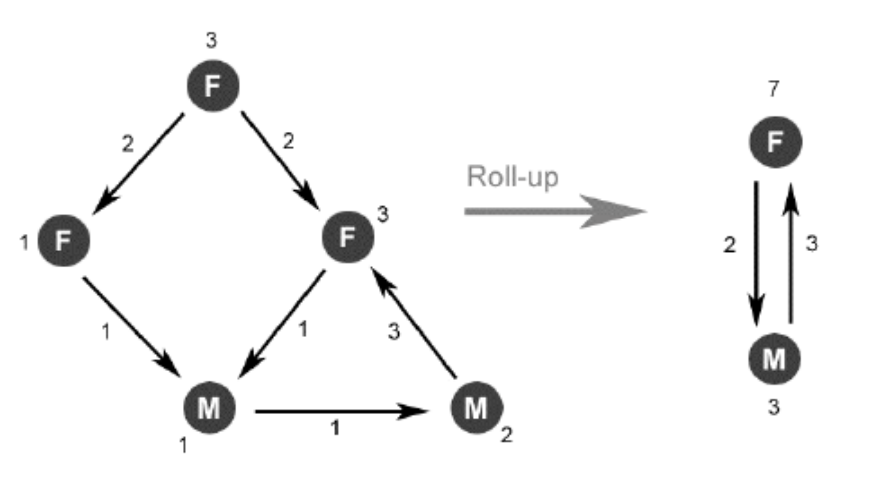
PivotGraph

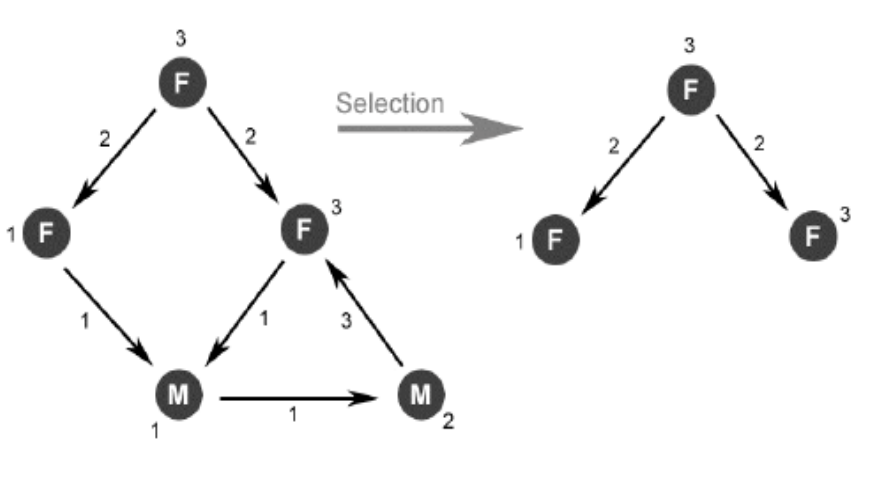


F2
F2
M1
F2
F1
M1
F2
M1
M2
M2
Node and Link Diagram
M
F
1
2
PivotGraph Roll-up


File
View
Scale
X-Axis:
Gender
Y-Axis:
Location
Flip X/Y
Clear
People
25
13
5
3
In vs. Out Degree
10.0
0.0
-10.0
Relationships
50
25
10
5
Rel. / Person
10.000
5.000
2.000
1.000
Select:
Gender
(All Values)
Legacy
(All Values)
Department
(All Values)
Level
(All Values)
Location
(All Values)
M
F
Location A
Location B
Location C
Location D
Location E
Null

Operators



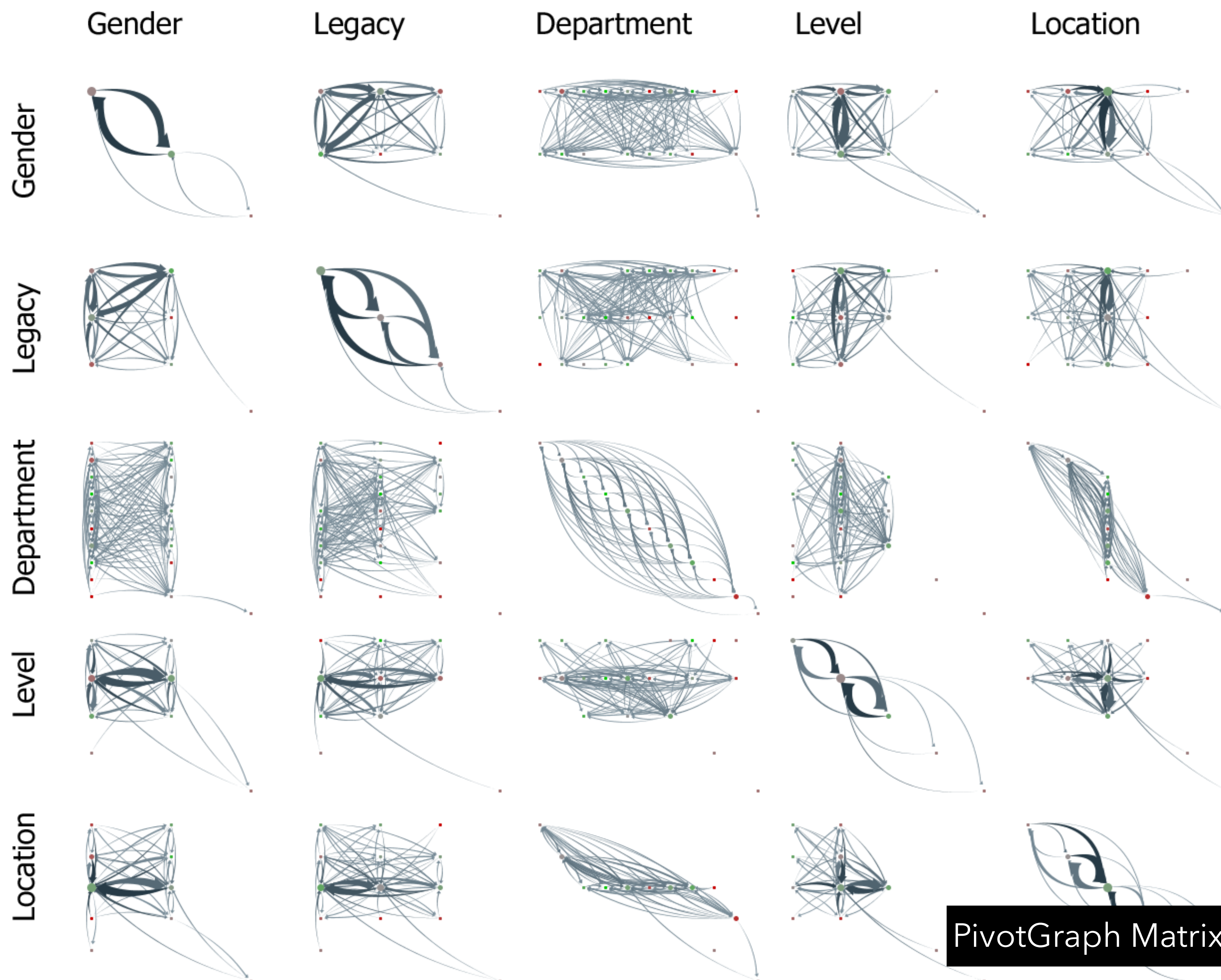


Roll-Up

Aggregate items with matching data values

Selection

Filter on data values



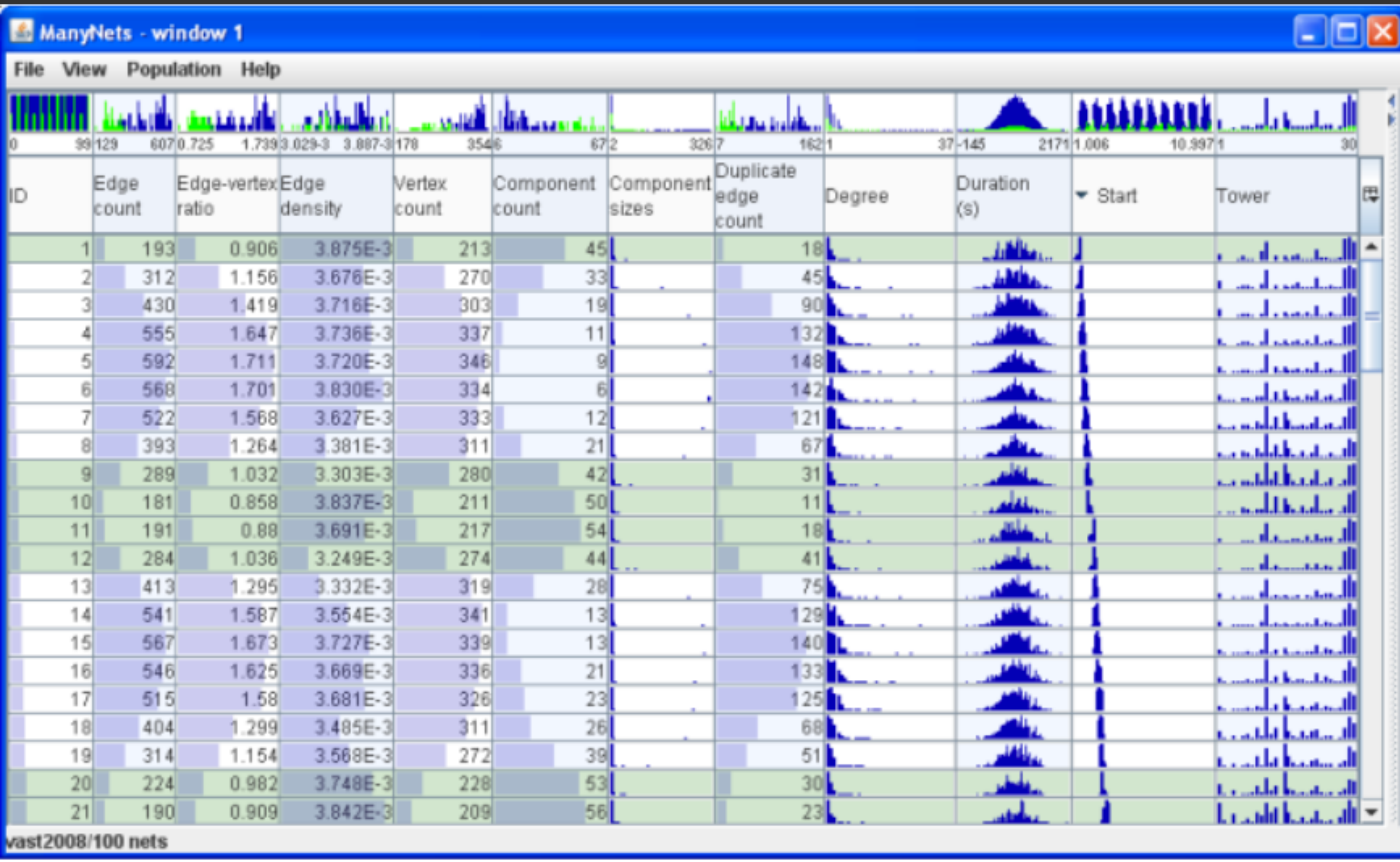
PivotGraph Matrix

Limitations of PivotGraph

Only 2 variables (no nesting as in Tableau)

Doesn't support continuous variables

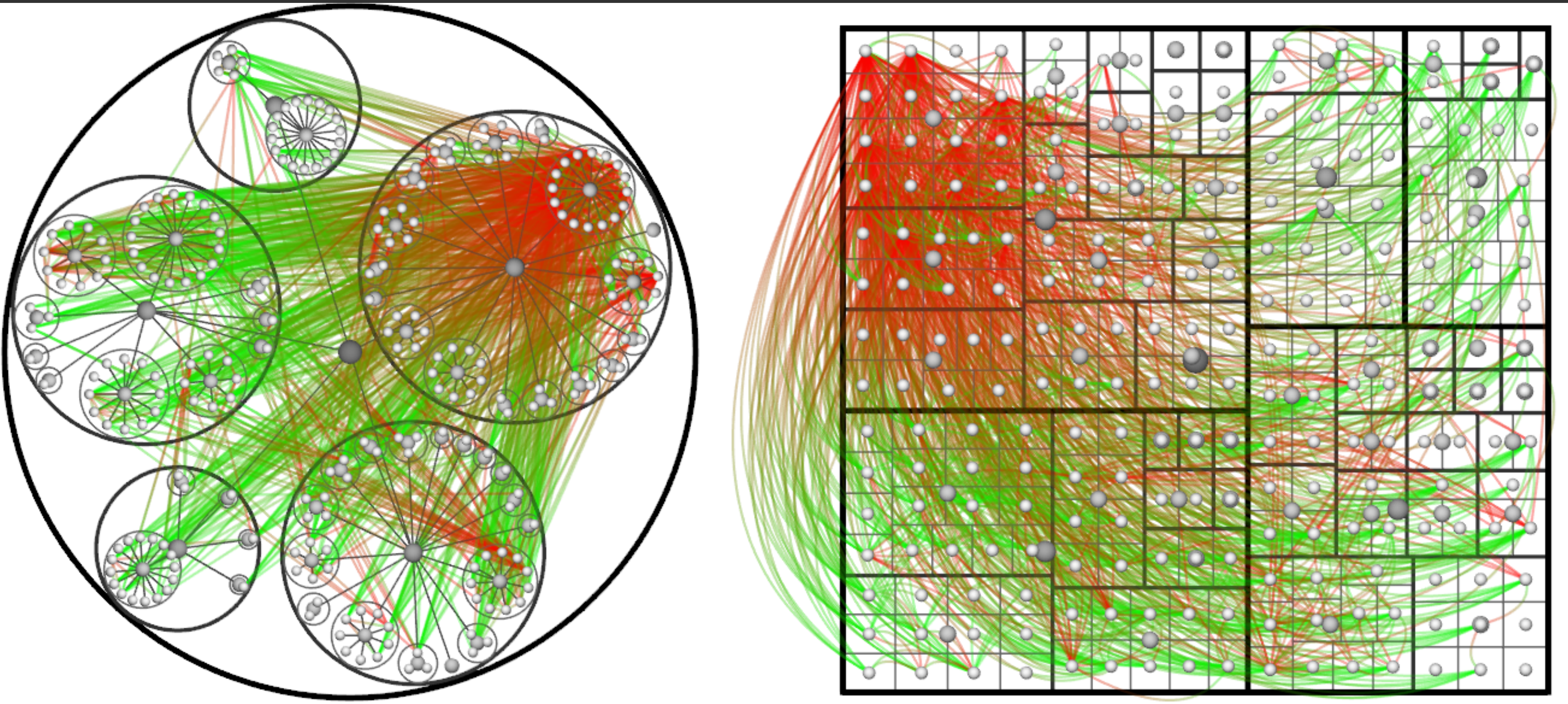
Multivariate edges?


ManyNets - window 1
File View Population Help
0 99 129 607 0.725 1.739 3.029-3 3.887-3 178 354 6 67 2 326 7 162 1 37 -145 2171 1.006 10.997 1 30
ID | Edge count | Edge-vertex ratio | Edge density | Vertex count | Component count | Component sizes | Duplicate edge count | Degree | Duration (s) | Start | Tower
1 193 0.906 3.875E-3 213 45 18
2 312 1.156 3.676E-3 270 33 45
3 430 1.419 3.716E-3 303 19 90
4 555 1.647 3.736E-3 337 11 132
5 592 1.711 3.720E-3 346 9 148
6 568 1.701 3.830E-3 334 6 142
7 522 1.568 3.627E-3 333 12 121
8 393 1.264 3.381E-3 311 21 67
9 289 1.032 3.303E-3 280 42 31
10 181 0.858 3.837E-3 211 50 11
11 191 0.88 3.691E-3 217 54 18
12 284 1.036 3.249E-3 274 44 41
13 413 1.295 3.332E-3 319 28 75
14 541 1.587 3.554E-3 341 13 129
15 567 1.673 3.727E-3 339 13 140
16 546 1.625 3.669E-3 336 21 133
17 515 1.58 3.681E-3 326 23 125
18 404 1.299 3.485E-3 311 26 68
19 314 1.154 3.568E-3 272 39 51
20 224 0.982 3.748E-3 228 53 30
21 190 0.909 3.842E-3 209 56 23
vast2008/100 nets

ManyNets

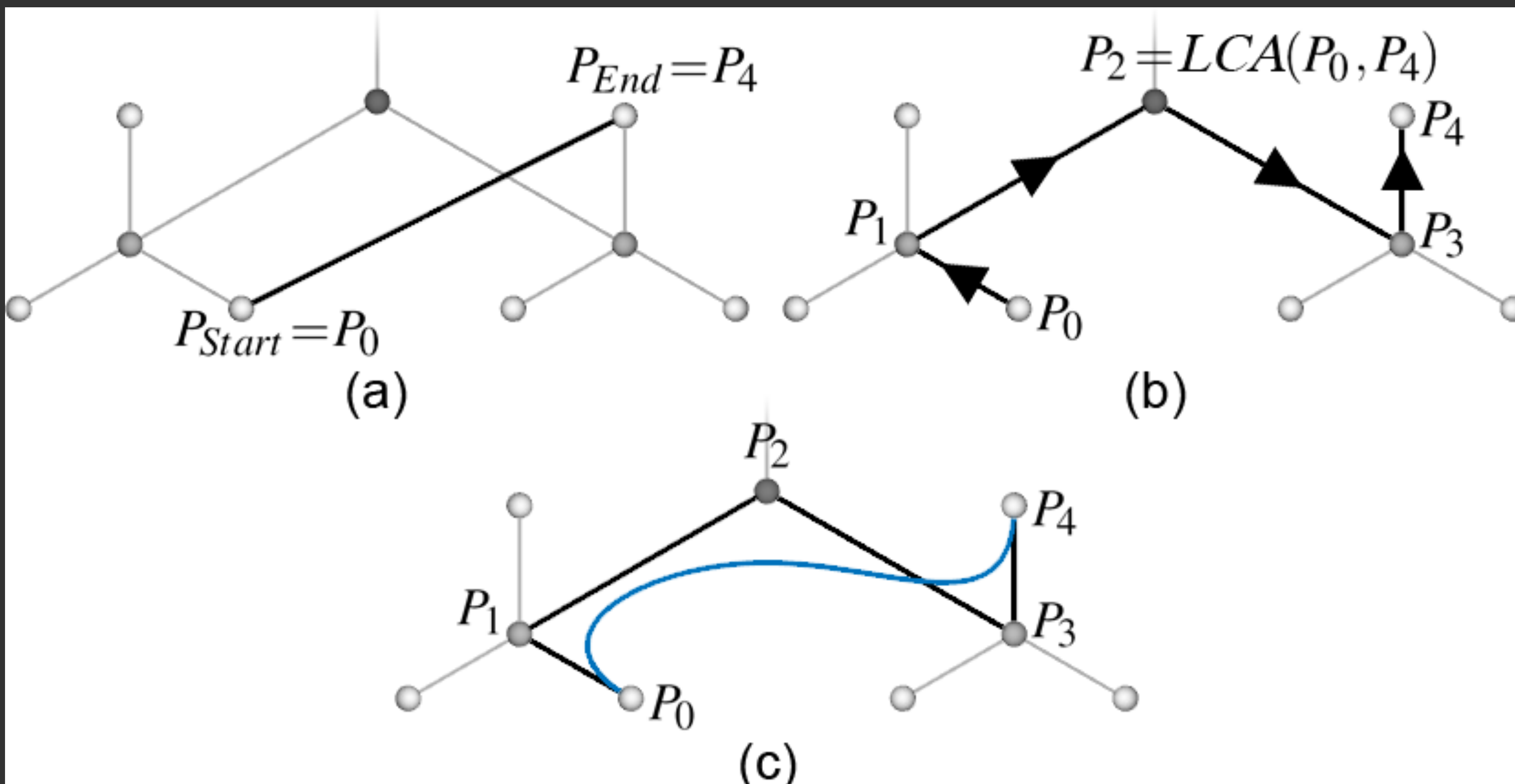
Hierarchical Edge Bundling

Trees with Adjacency Relations

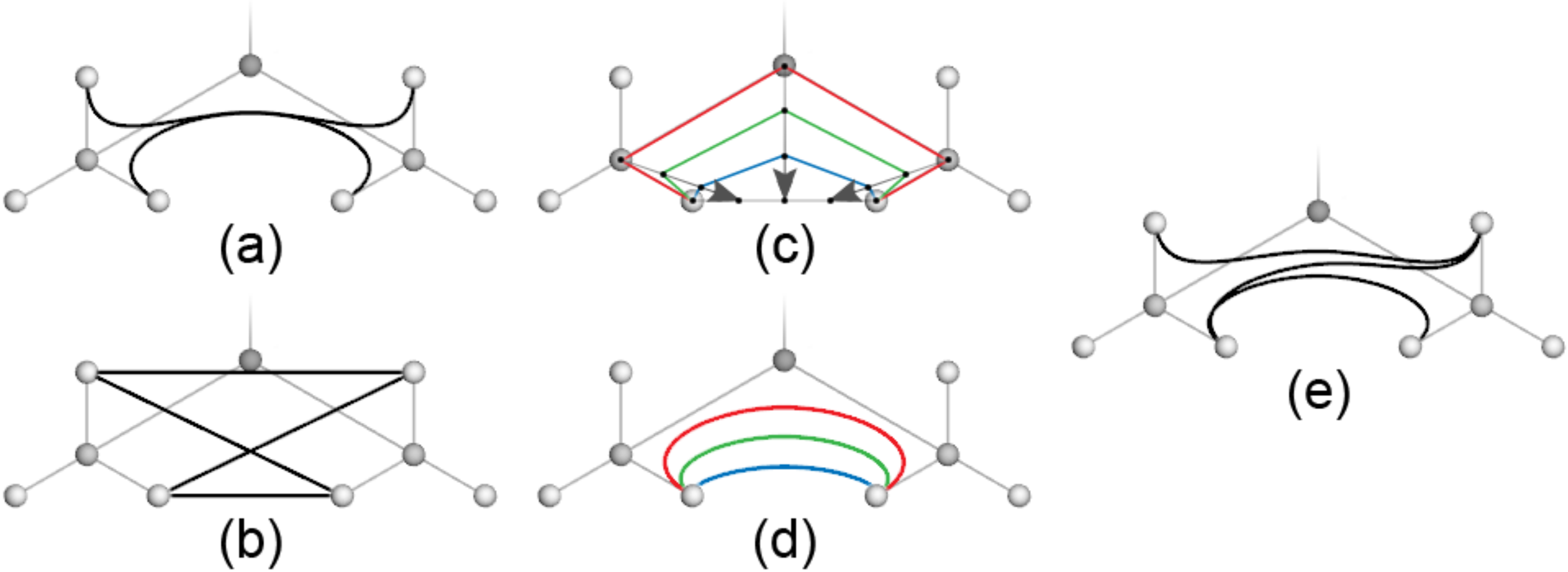


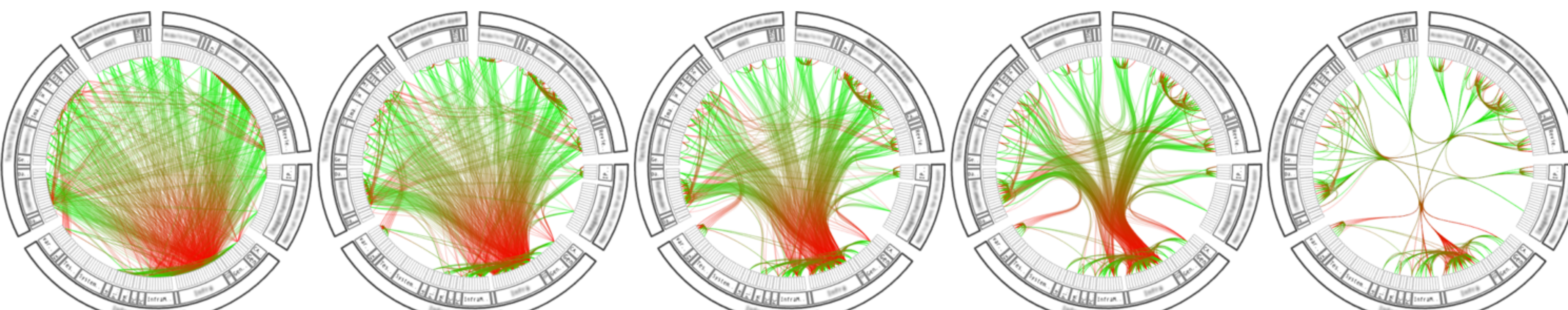
(a) (b)

Bundle Edges Along Hierarchy

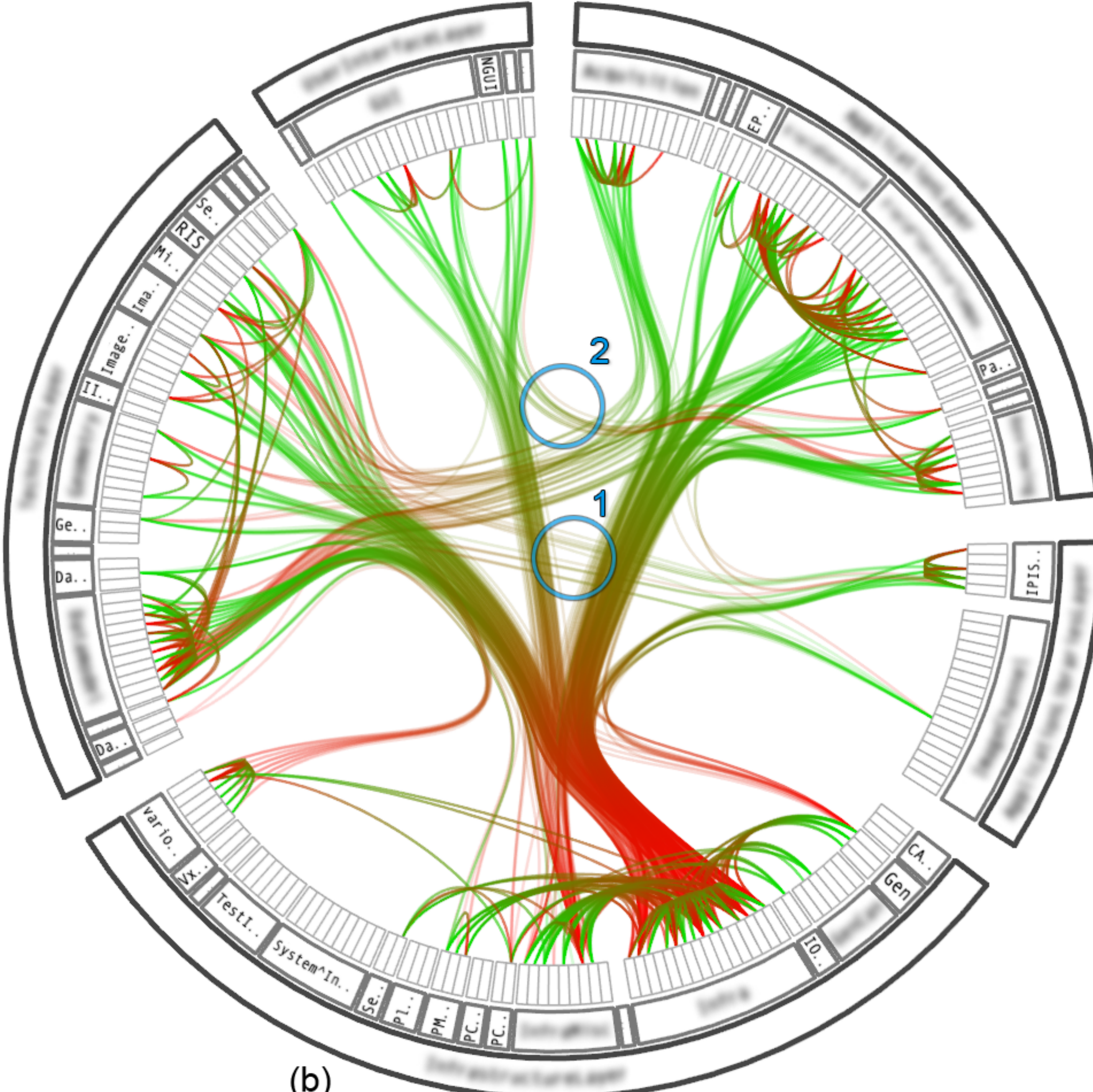


Configuring Edge Tension





$\beta = 0$ $\beta = 0.25$ $\beta = 0.5$ $\beta = 0.75$ $\beta = 1$


NGUI
EP..
Pa..
IPIS..
CA..
Gen
IO..
System^In..
TestI..
Vx..
vario..
Se..
Pl..
PM..
PC..
PC..
Da..
Da..
Ge..
II..
Image..
Ima..
Mi..
RIS
Se..
2
1
(b)

Summary




Tree Layout

Indented / Node-Link / Enclosure / Layers

Focus+Context techniques for scale

Graph Layout

Spanning Tree Layout

Hierarchical “Sugiyama” Layout

Optimization (Force-Directed Layout)

Matrix Diagrams

Attribute-Driven Layout