Paul Rosen
paul.rosen@utah.edu
@paulrosenphd
https://cspaul.com

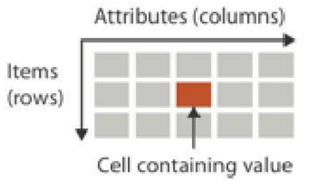
SCI www.sci.utah.edu
THE UNIVERSITY OF UTAH

Visualization for Data Science DS-4630 / CS-5630 / CS-6630

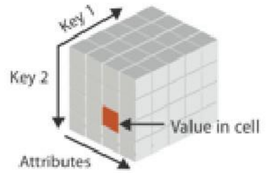
TREES & GRAPHS

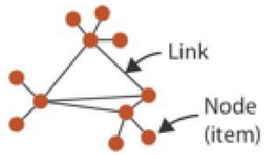
Dataset types

Tables	Networks & Trees	Fields	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Grids	Items	Items
Attributes	Links	Positions	Positions	
	Attributes	Attributes		

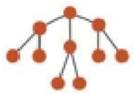


→ *Multidimensional Table*

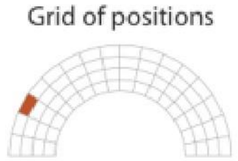


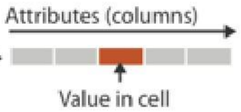


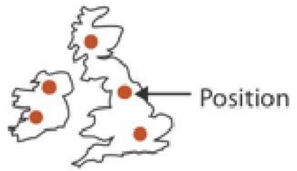
→ *Trees*

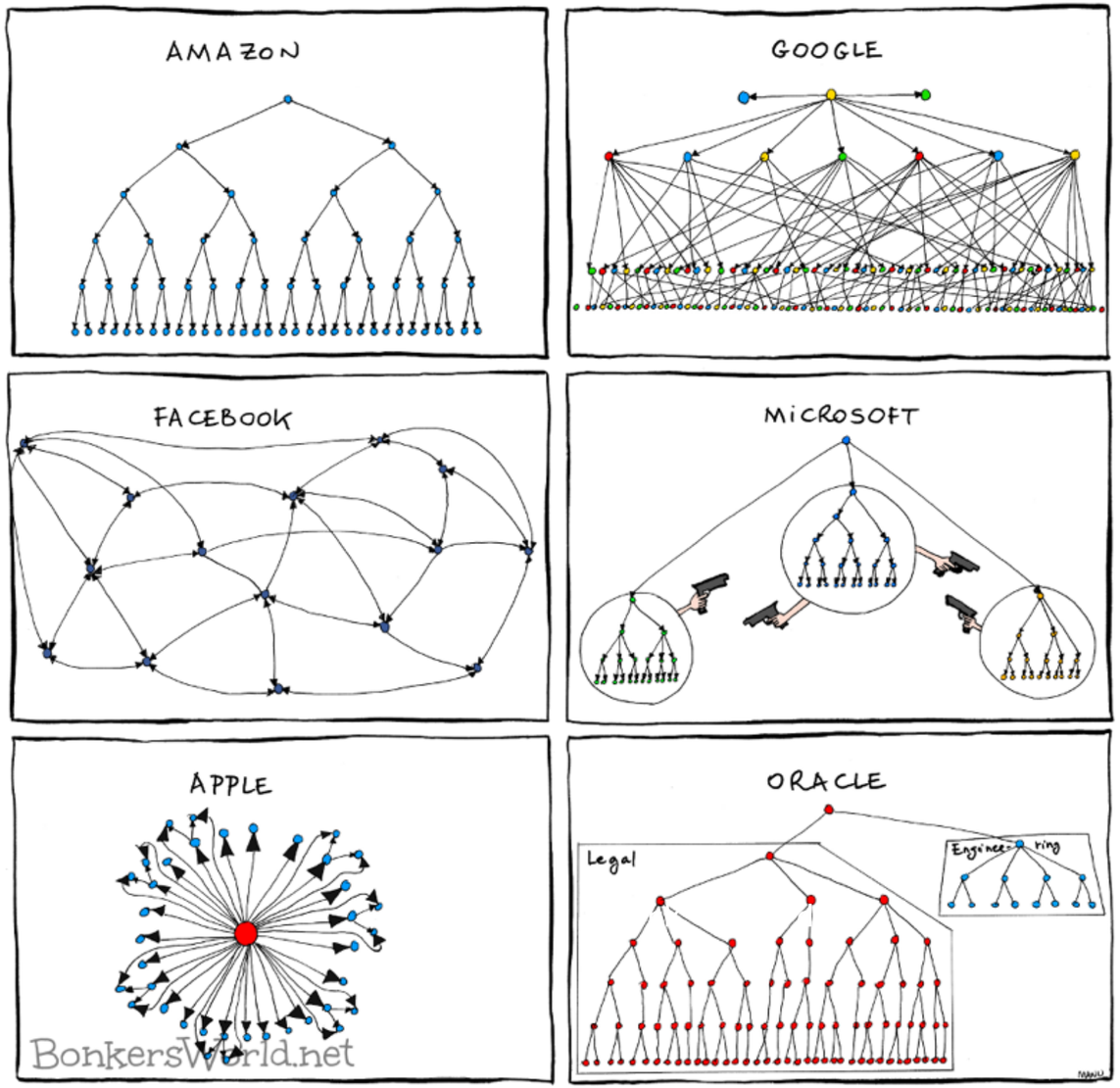


Cell





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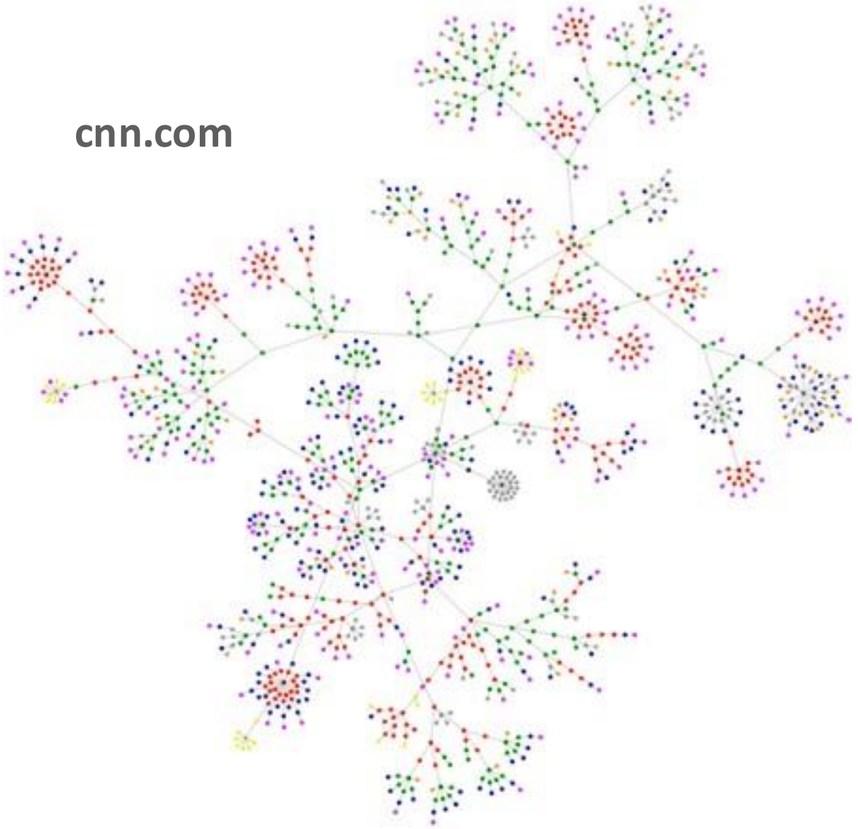

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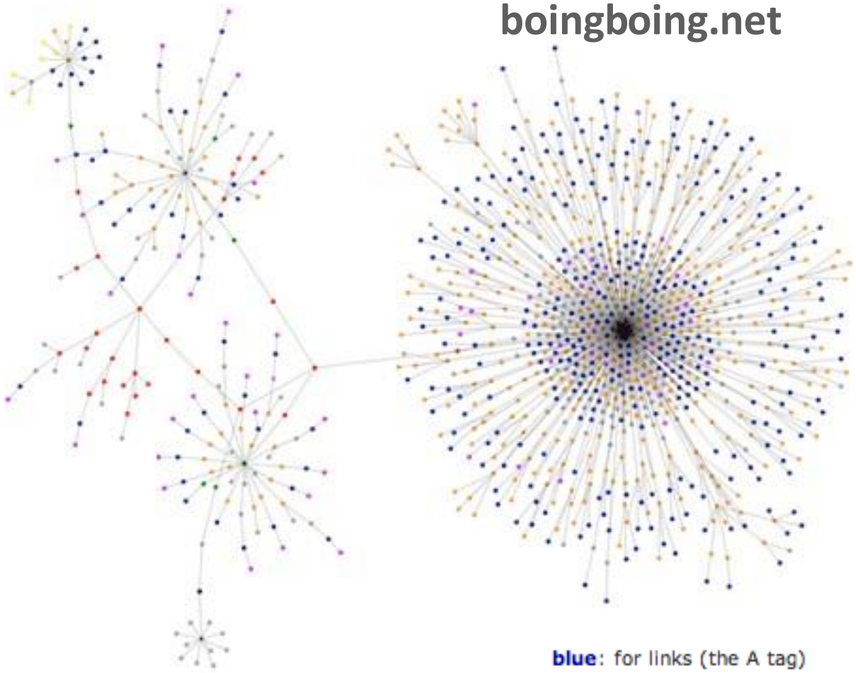
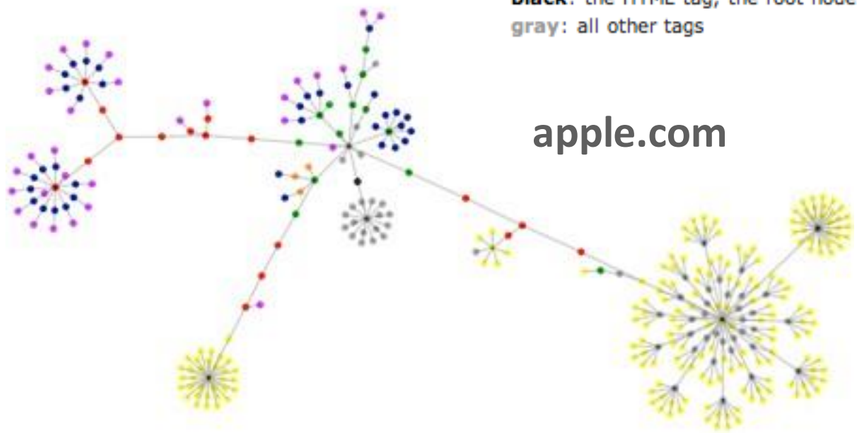


blue: for links (the A tag)
red: for tables (TABLE, TR and TD tags)
green: for the DIV tag
violet: for images (the IMG tag)
yellow: for forms (FORM, INPUT, TEXTAREA, SELECT and OPTION tags)
orange: for linebreaks and blockquotes (BR, P, and BLOCKQUOTE tags)
black: the HTML tag, the root node
gray: all other tags

wired.com



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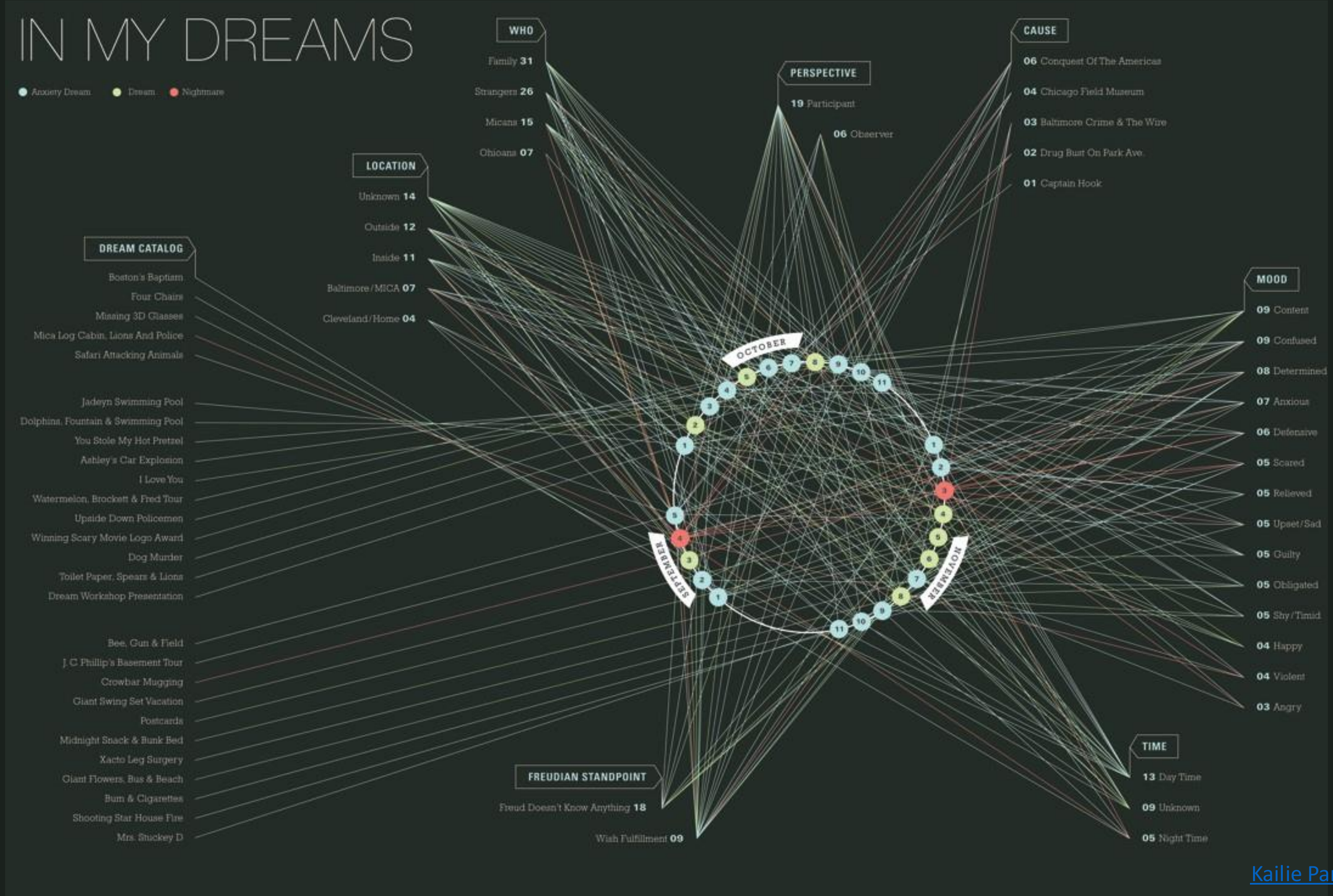


Kailie Parrish

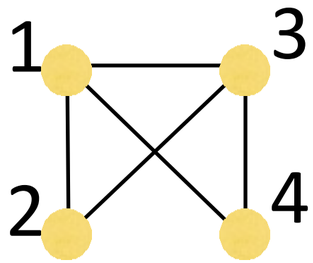
DEFINITIONS

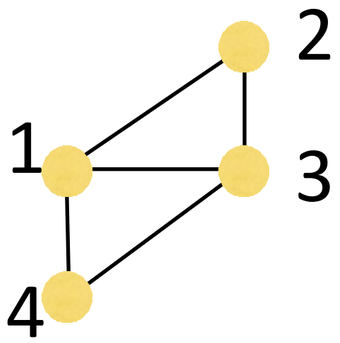
GRAPH

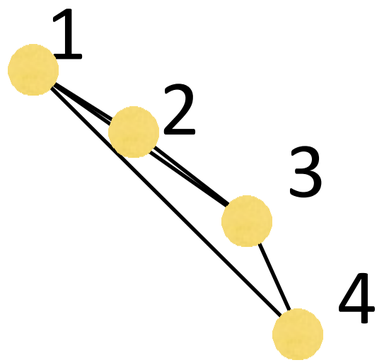
- A graph **G** consists of
  - **V** - a collection of vertices (or nodes)
  - **E** - a set of edges consisting of vertex pairs

- An edge e_{xy} = (x,y) connects two vertices x and y

- <u>Example</u>
  - V={1,2,3,4}
  - E={(1,2),(1,3),(2,3),(3,4),(4,1)}





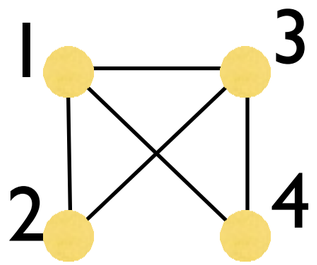


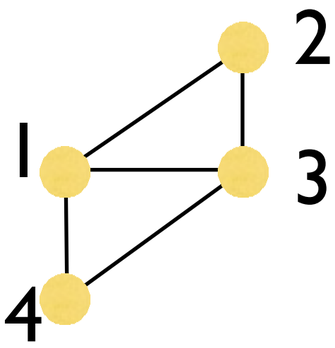
Nodes

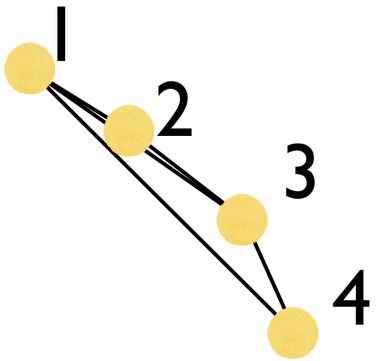
ID	Attribute 1	Attribute 2
1	3.4	Good
2	5.8	Bad
3	1.1	Ugly
4	-3.5	Really Ugly

Edges

Source	Target	Attribute 3
1	2	100
1	3	200
1	4	50
2	3	150
3	4	250





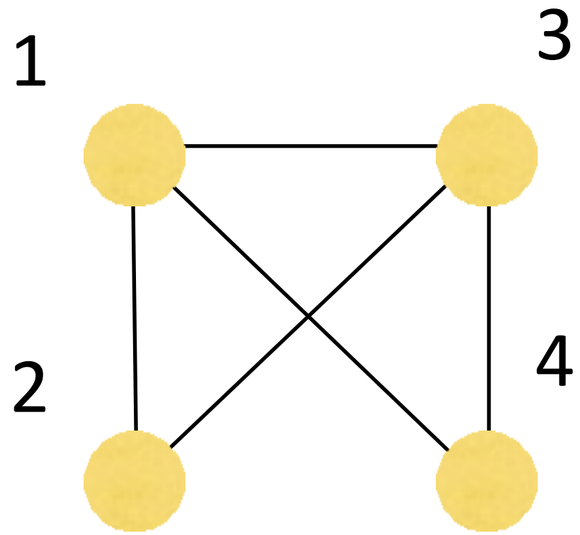


Adjacency Matrix

- A matrix that where each row/column represents a node and non-zero values represent edges

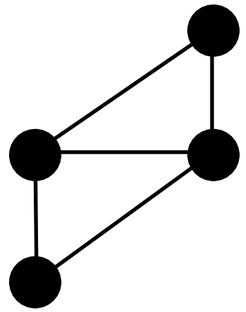
- Example

$$\begin{bmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \end{bmatrix}$$

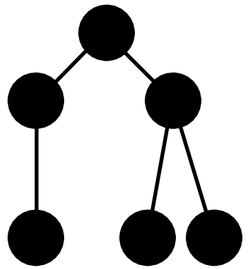


GRAPHS & TREES

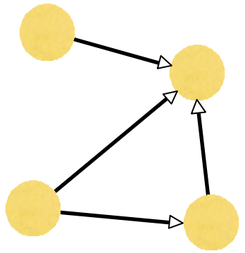
- graphs
  - model relationships about data
  - nodes and edges



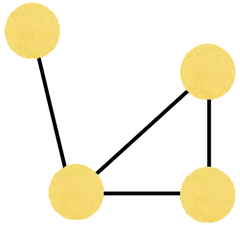
- trees
  - graphs with hierarchical structure
  - nodes as parents and children



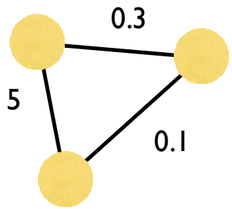
a bunch of definitions



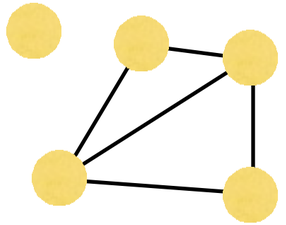
A directed graph



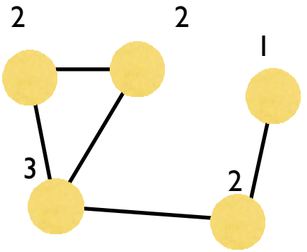
An undirected graph



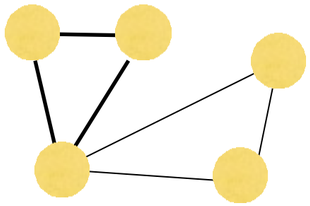
Weighted



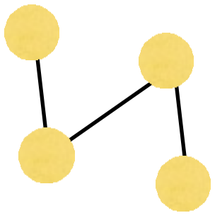
Unconnected



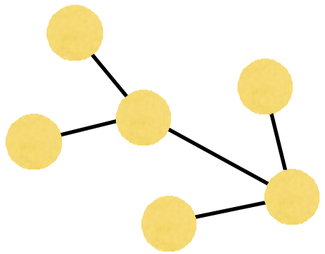
Node degrees



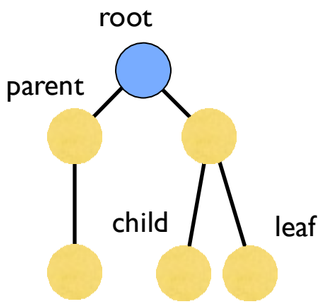
A cycle



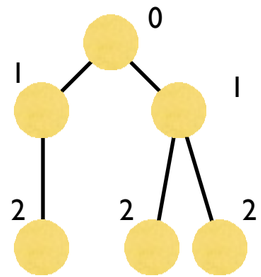
An acyclic graph



A connected acyclic graph,
a.k.a. a **tree**



A rooted tree
or hierarchy



Node depths

VISUALIZING TREES

How to cite this site?

Check out other surveys

treevis.net - A Visual Bibliography of Tree Visualization 2.0 by Hans-Jörg Schulz

v.28-AUG-2015

Dimensionality: All

Representation: All

Alignment: All

Fulltext Search

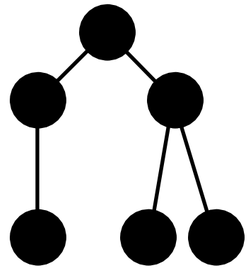
Techniques Shown: 286

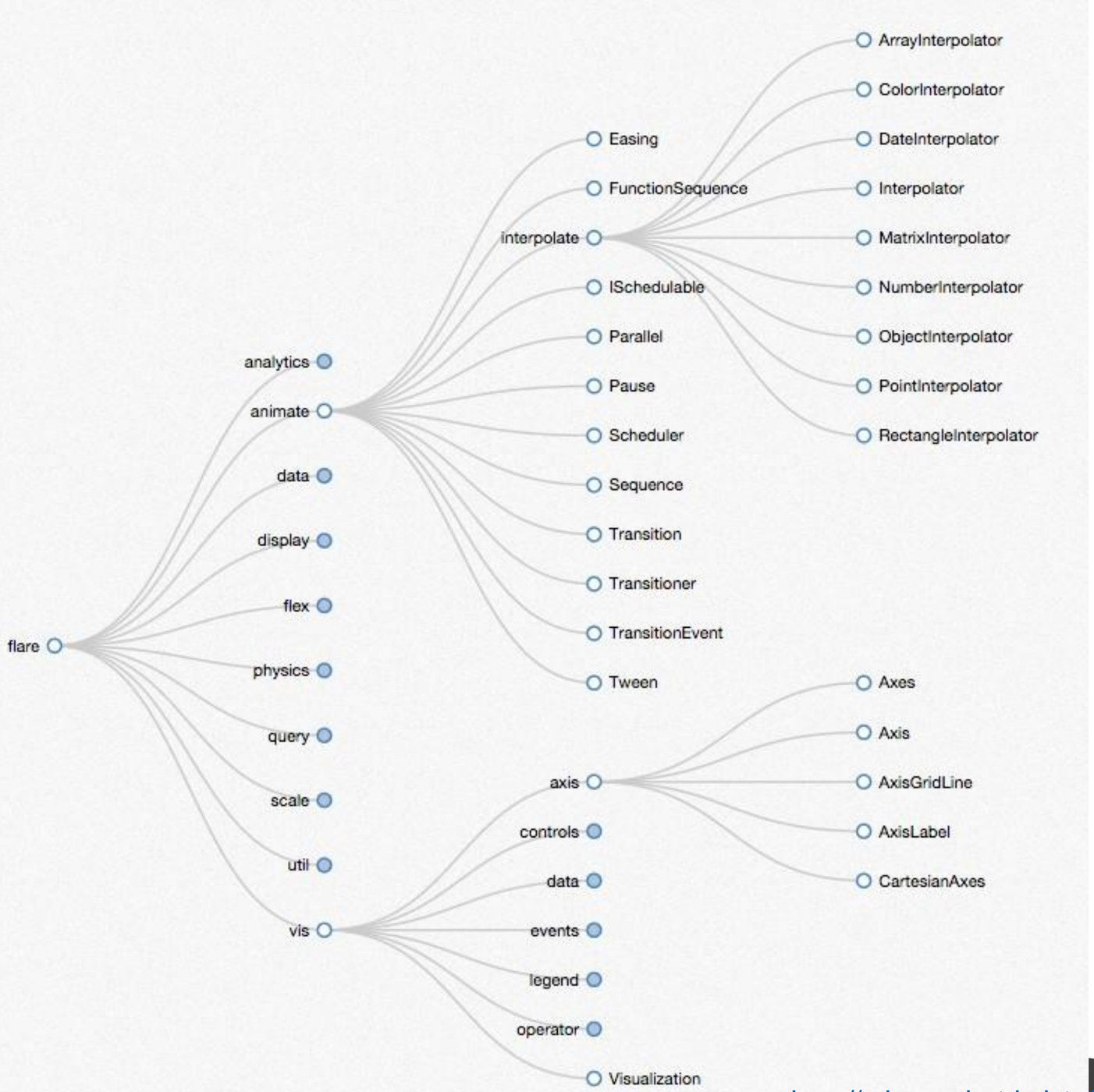
ROOTED TREES

- recursion makes it elegant and fast to draw trees
- approaches:
  - node link
  - layered
  - indentation
  - enclosure

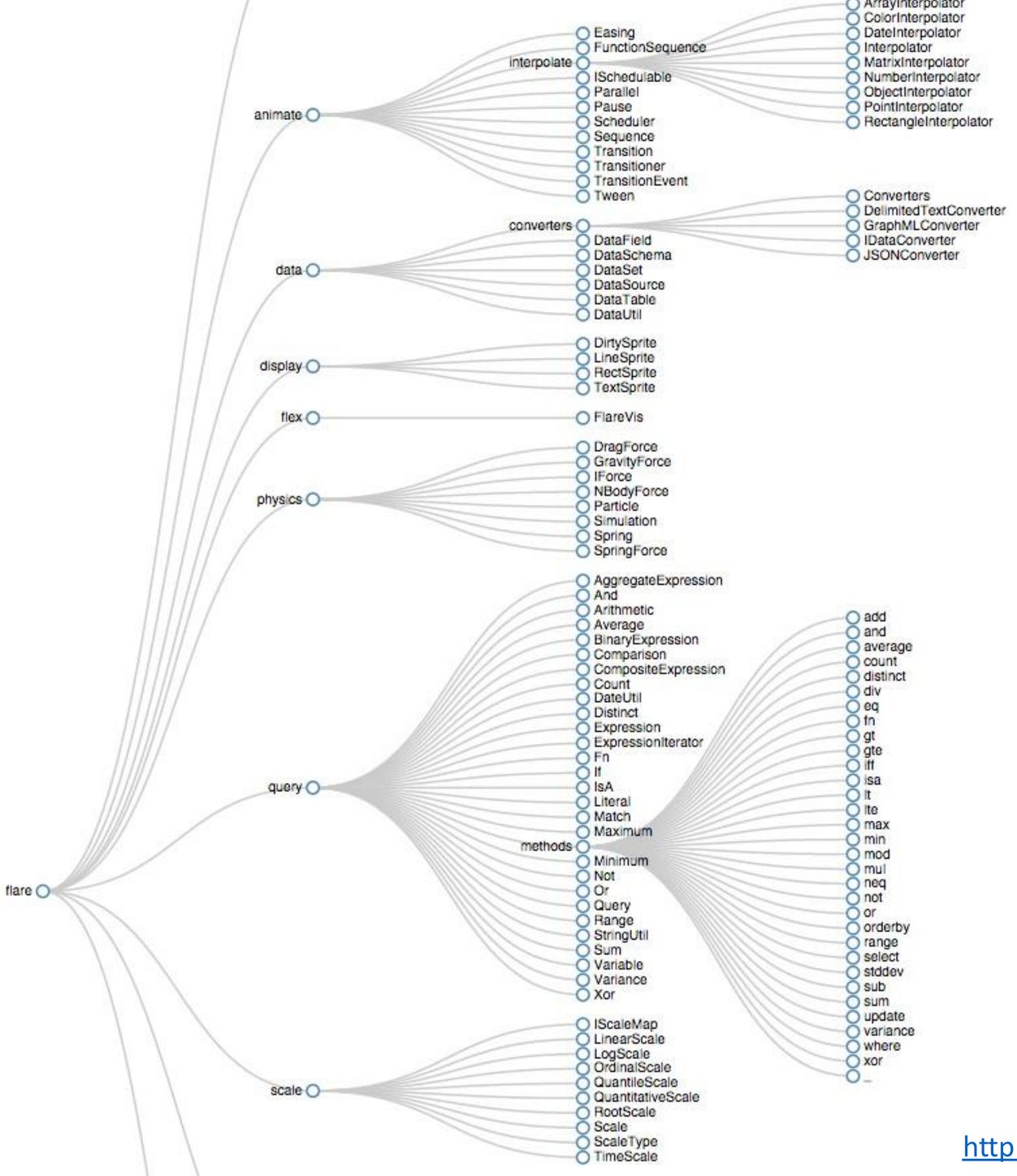
NODE-LINK DIAGRAMS

- 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





http://mbostock.github.io/d3/talk/20111018/tree.html



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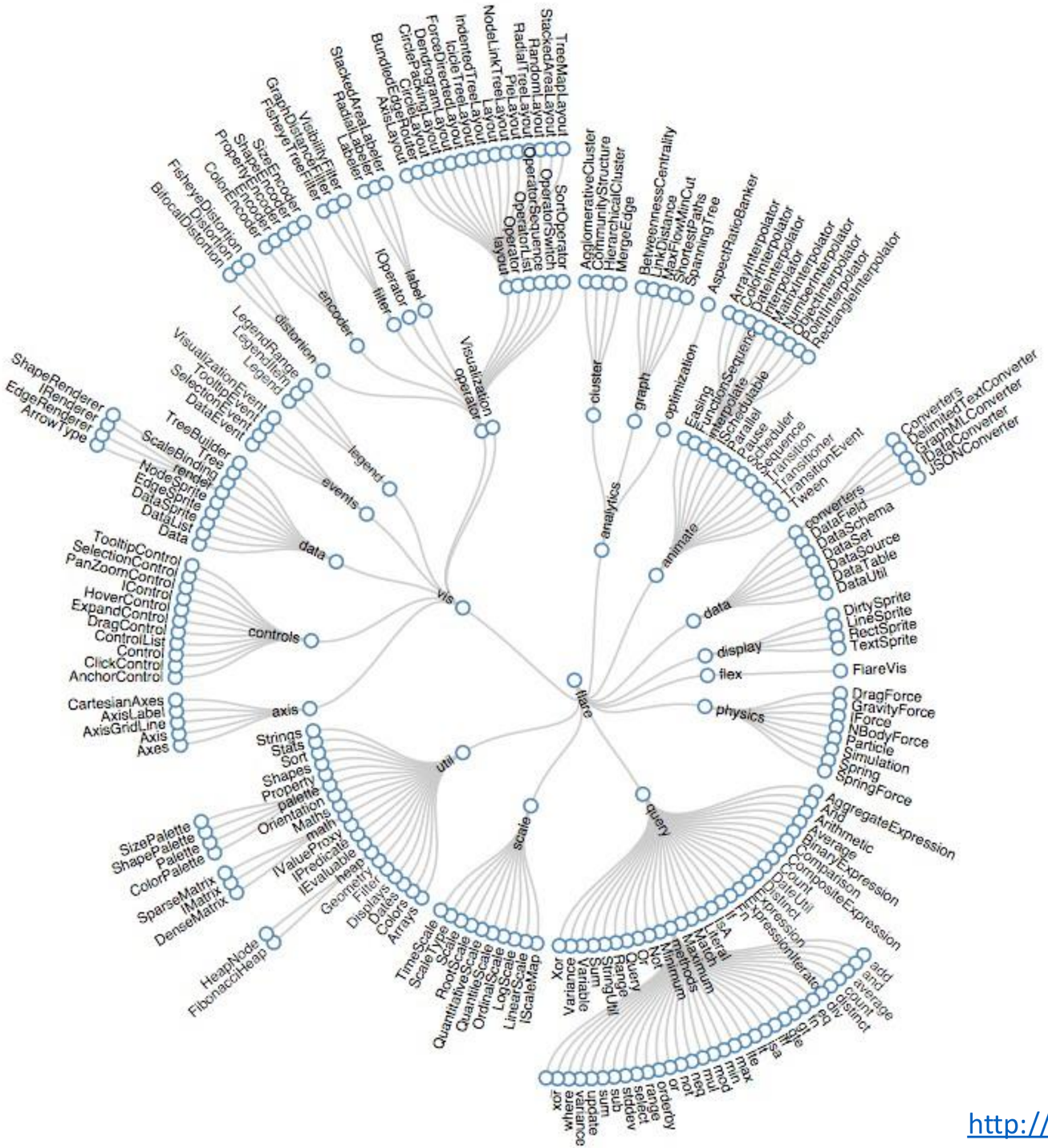
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AgglomerativeCluster
CommunityStructure
HierarchicalCluster
MergeEdge
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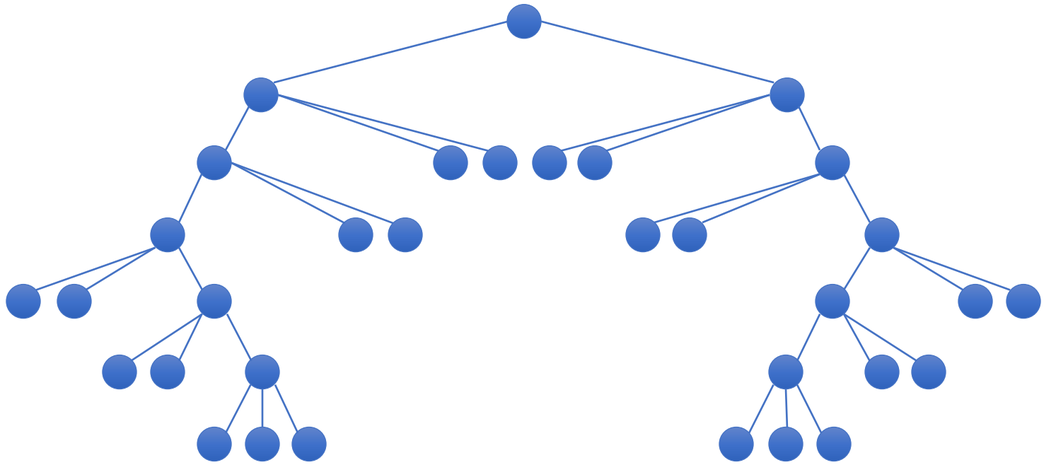
BetweennessCentrality
LinkDistance
MaxFlowMinCut
ShortestPaths
SpanningTree
optimization
AspectRatioBanker
ArrayInterpolator
ColorInterpolator
DateInterpolator
Interpolator
MatrixInterpolator
NumberInterpolator
ObjectInterpolator
PointInterpolator
RectangleInterpolator

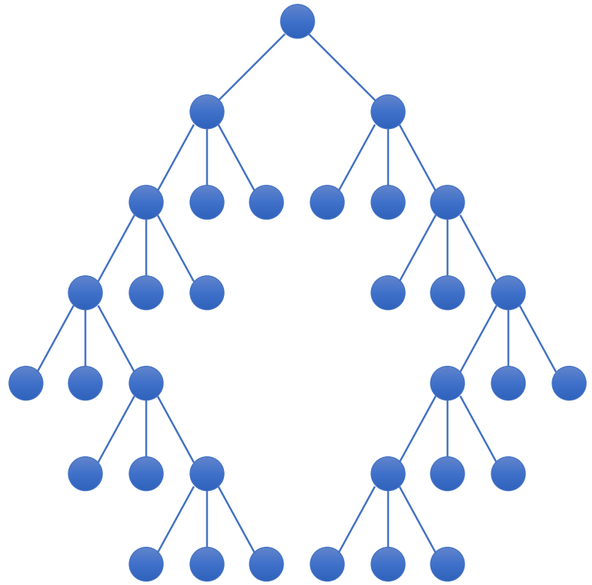
REINGOLD-TILFORD

- repeatedly divide space for subtrees by leaf count
  - breadth of tree along one dimension
  - depth along the other dimension



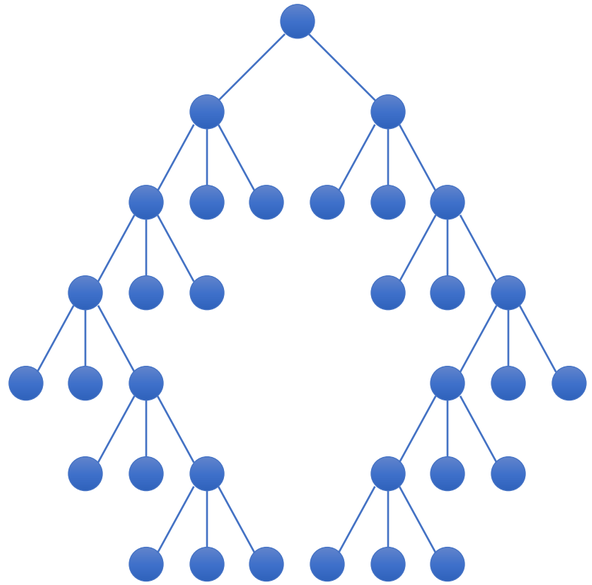
REINGOLD-TILFORD

- goal
  - make smarter use of space
  - maximize density and symmetry



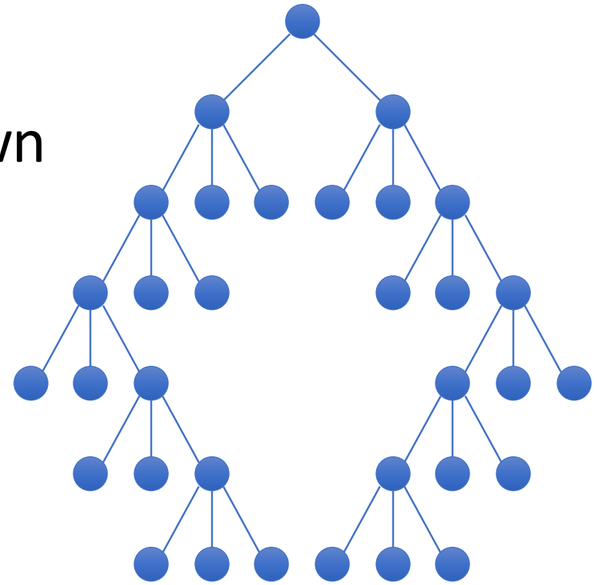
REINGOLD-TILFORD

- design concerns
  - clearly encode depth level
  - no edge crossings
  - isomorphic subtrees drawn identically
  - compact



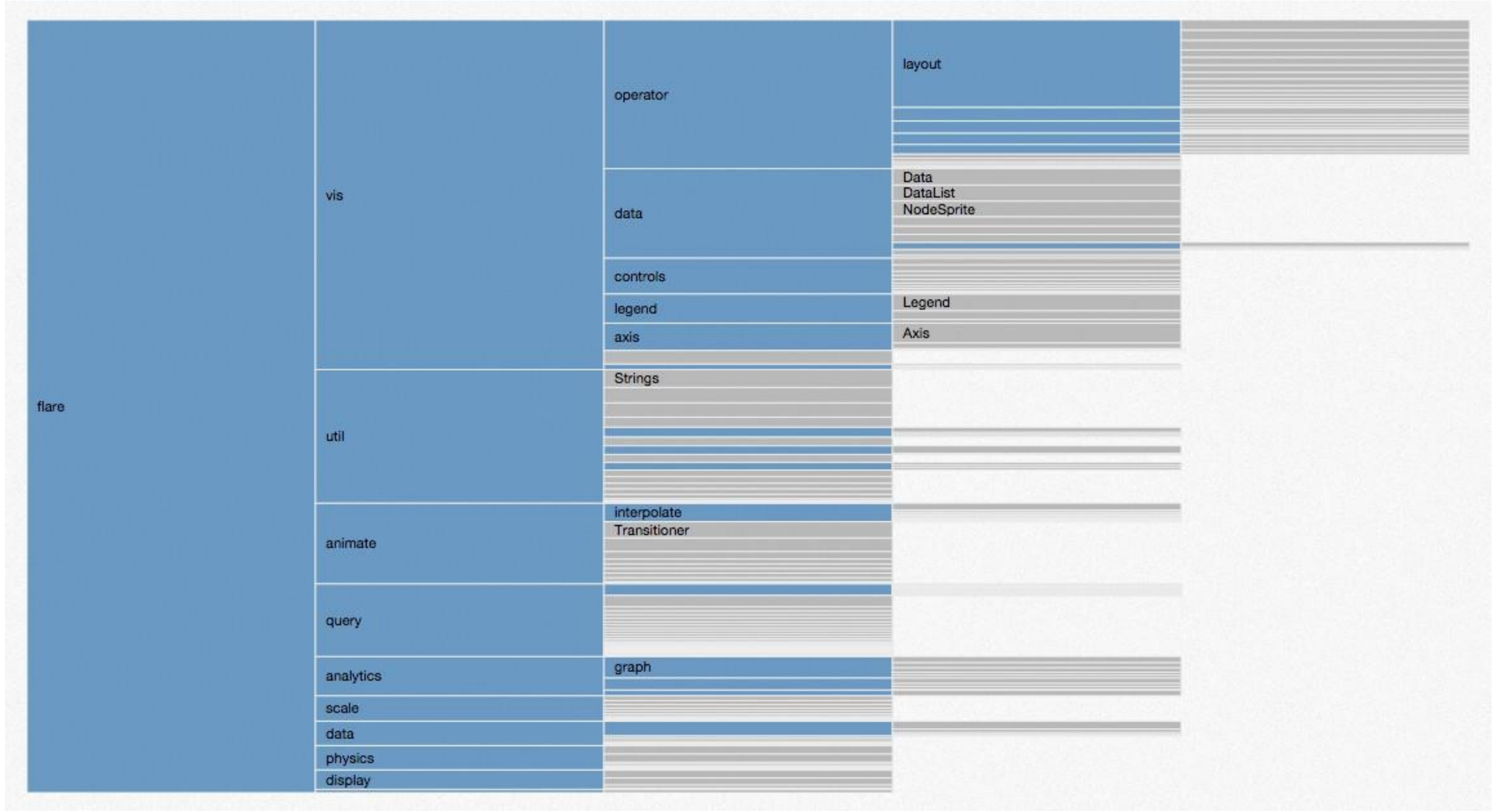
REINGOLD-TILFORD

- approach
  - bottom up recursive approach
  - for each parent make sure every subtree is drawn
  - pack subtrees as closely as possible
  - center parent over subtrees

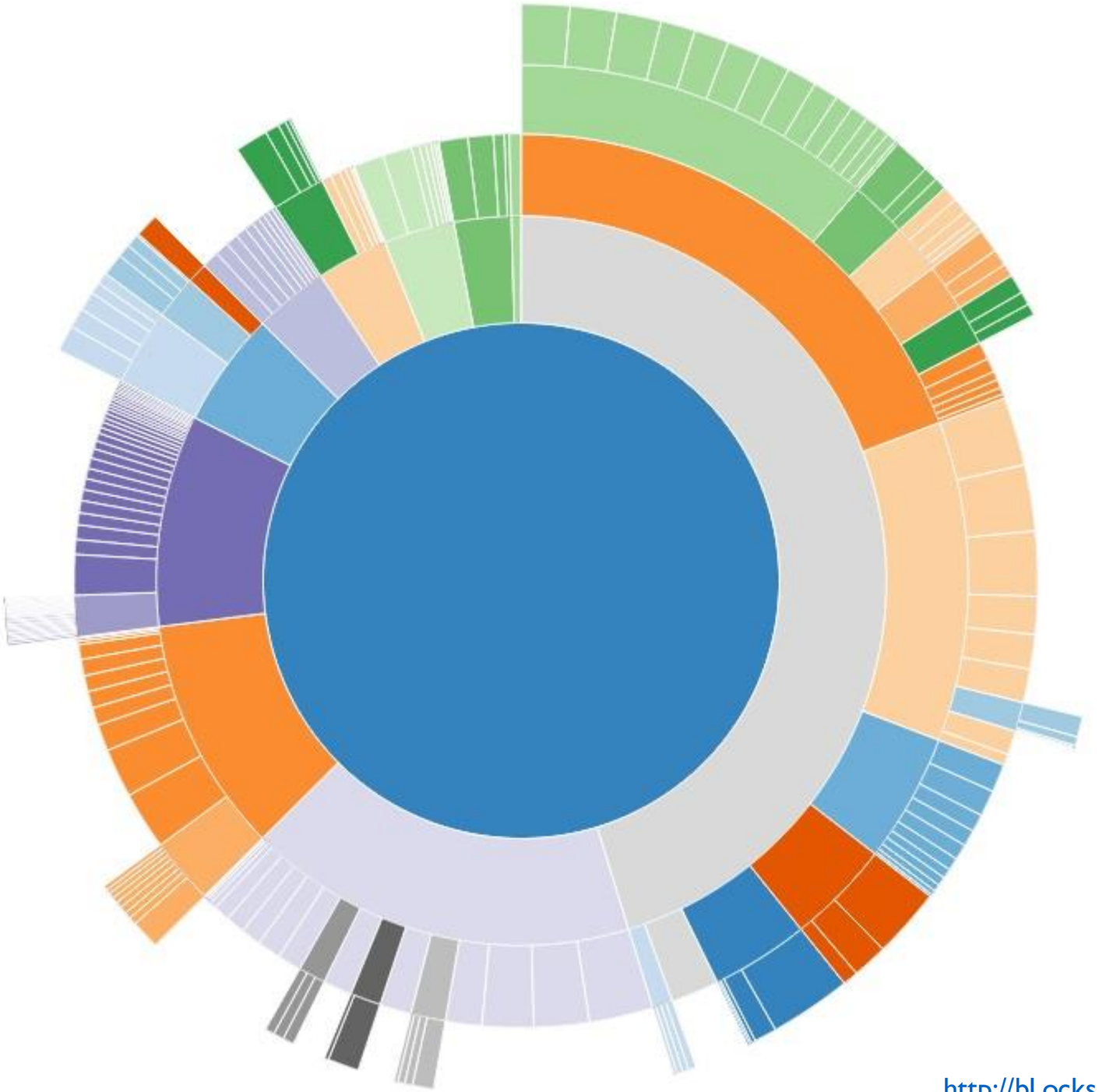


LAYERED DIAGRAMS

- recursive subdivision of space
- structure encoded using:
  - layering
  - adjacency
  - alignment



http://mbostock.github.io/d3/talk/20111018/partition.html



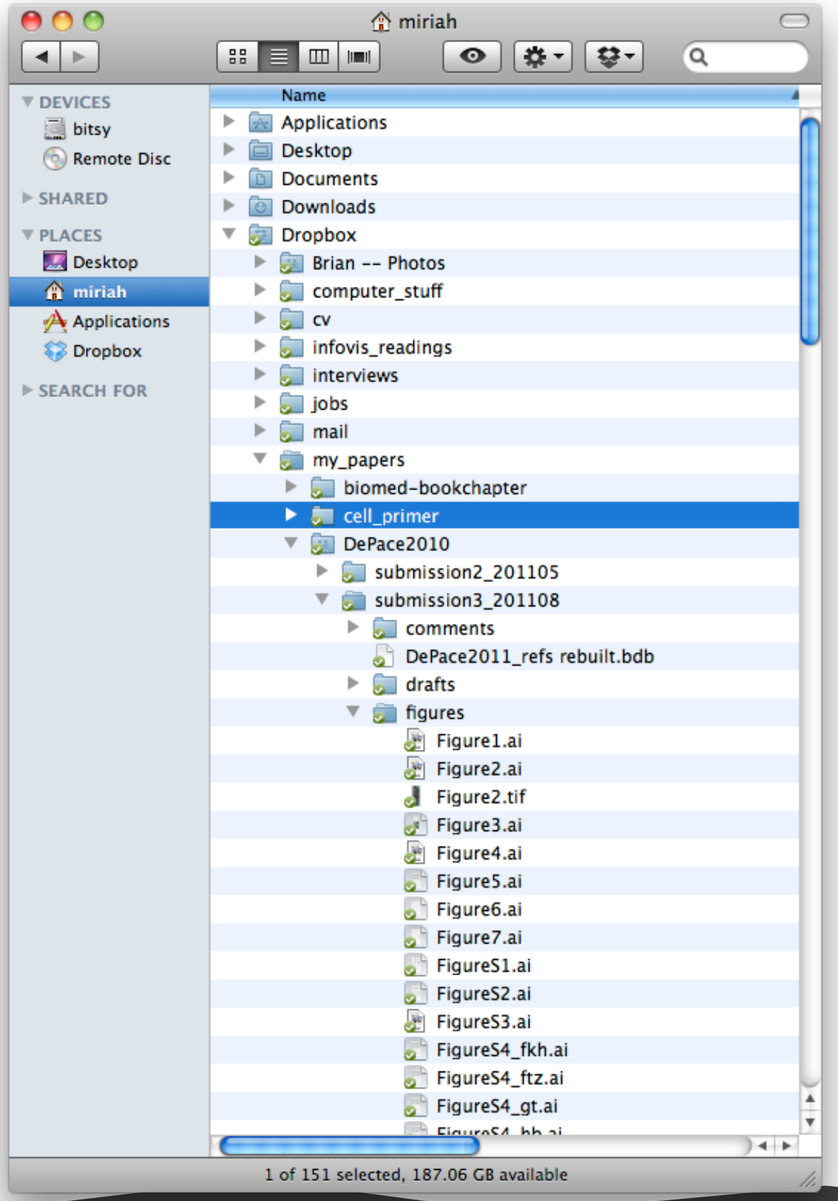
http://bl.ocks.org/mbostock/raw/4348373/

SCALE PROBLEM

- tree breadth often grows exponentially—quickly run out of space!
- solutions
  - scrolling or panning
  - filtering or zooming
  - hyperbolic layout

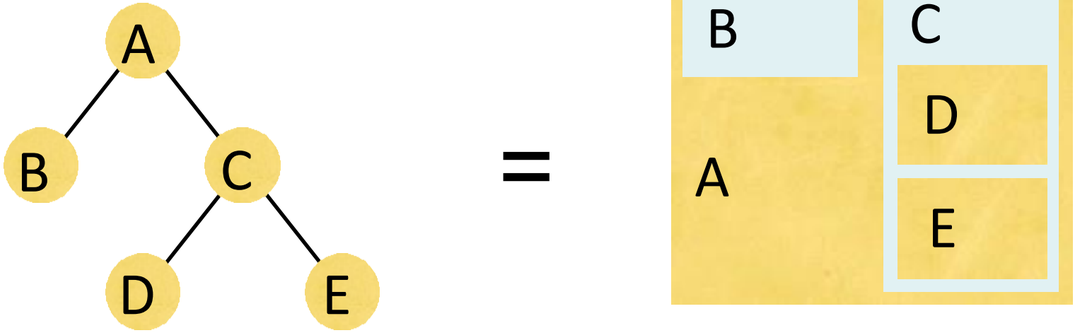
INDENTATION

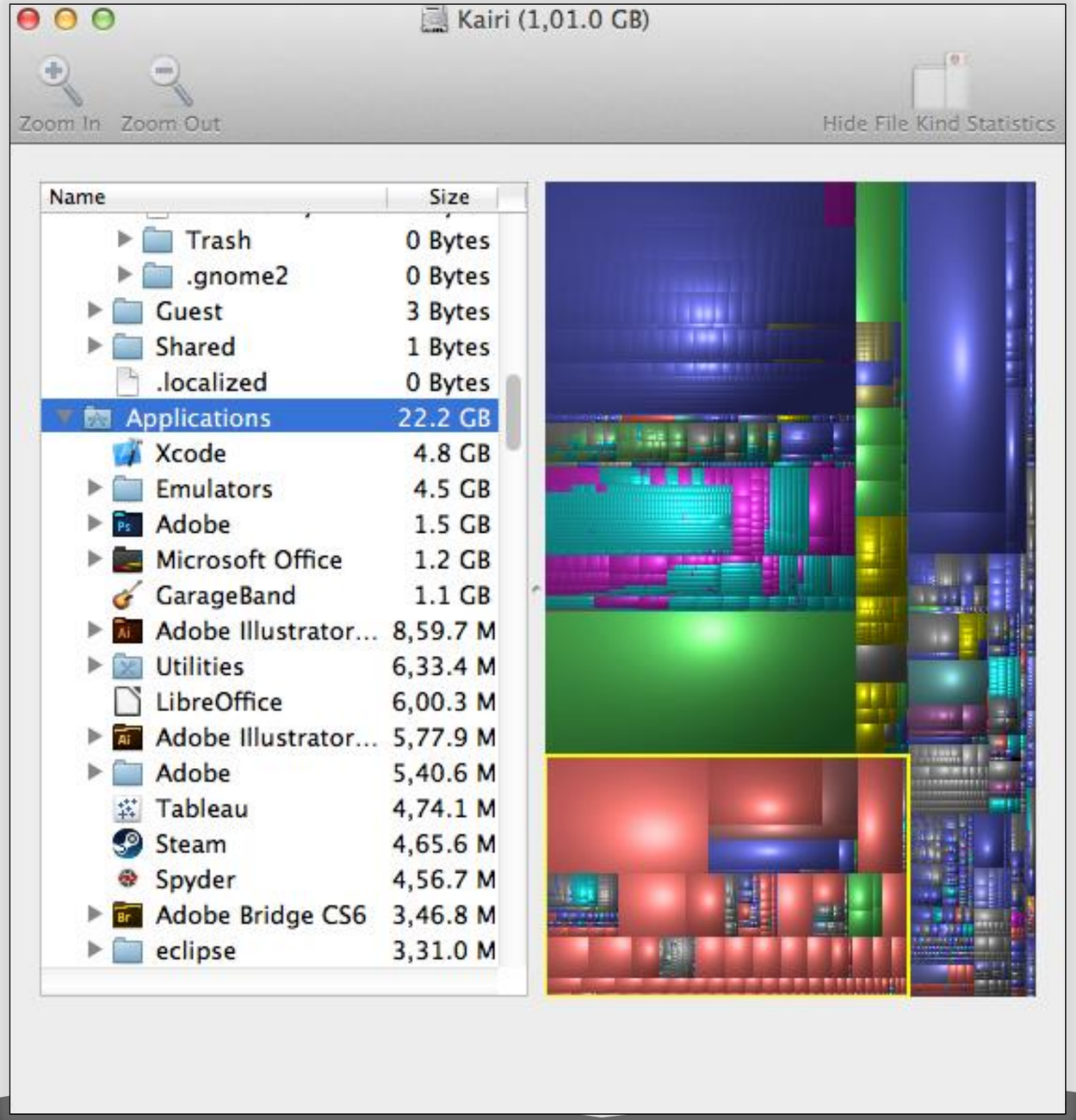
- indentation used to show parent/child relationships
- breadth and depth contend for space
- problem: often requires a great deal of scrolling



ENCLOSURE DIAGRAMS

- encode structure using spatial enclosure
  - often referred to as treemaps
- benefits
  - provides single view of entire tree
  - easier to spot small / large nodes
- problems
  - difficult to accurately read depth

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Microsoft Office 1.2 GB
GarageBand 1.1 GB
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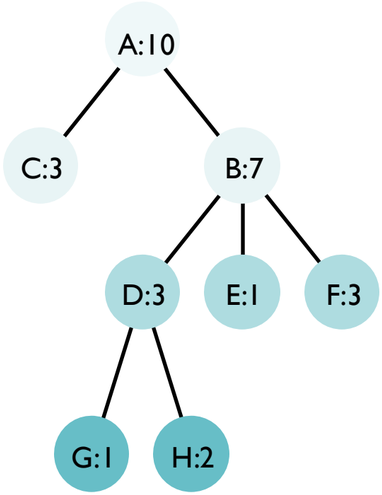
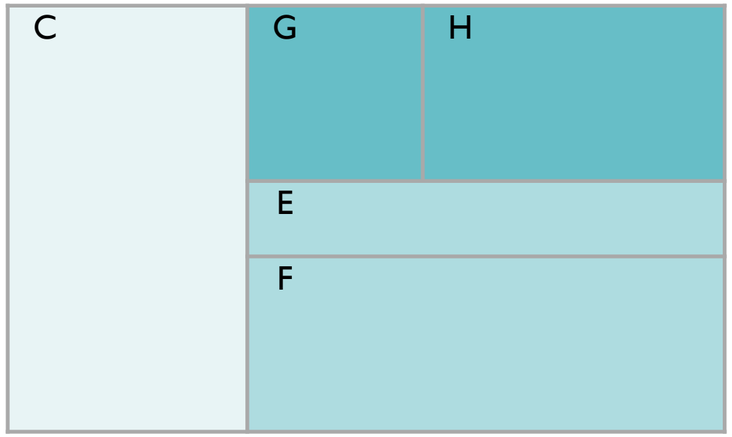
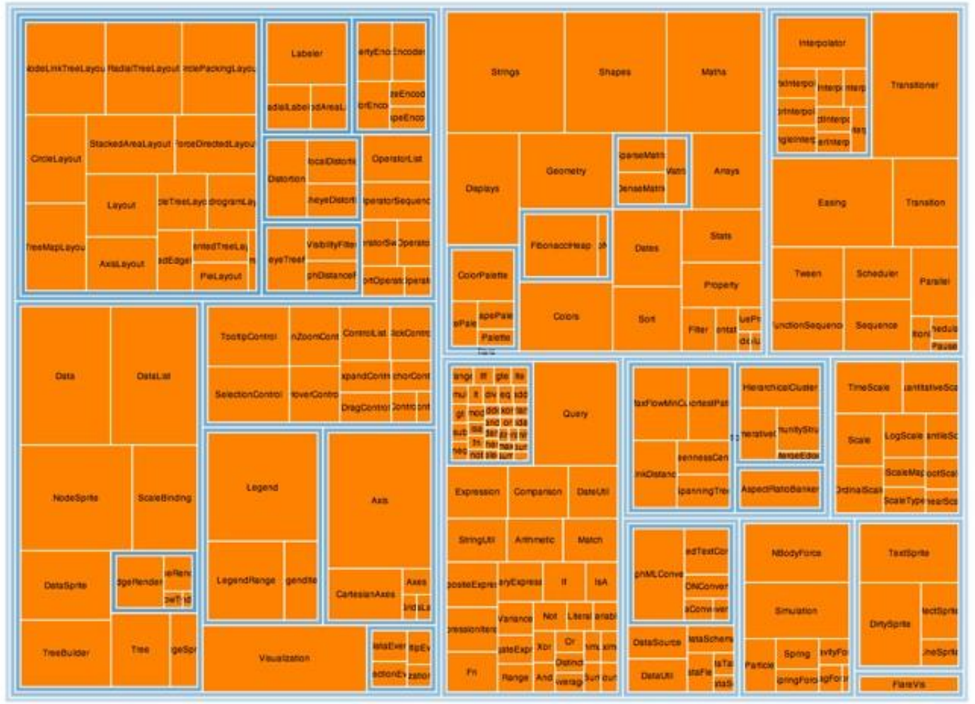
Adobe 5,40.6 M
Tableau 4,74.1 M
Steam 4,65.6 M
Spyder 4,56.7 M
Adobe Bridge CS6 3,46.8 M
eclipse 3,31.0 M

TREEMAPS

- recursively fill space based on a size metric for nodes
- enclosure indicates hierarchy
- additional measures can control aspect ratio of cells
- most often use rectangles, but other shapes possible
  - square, circle, voronoi tessellation



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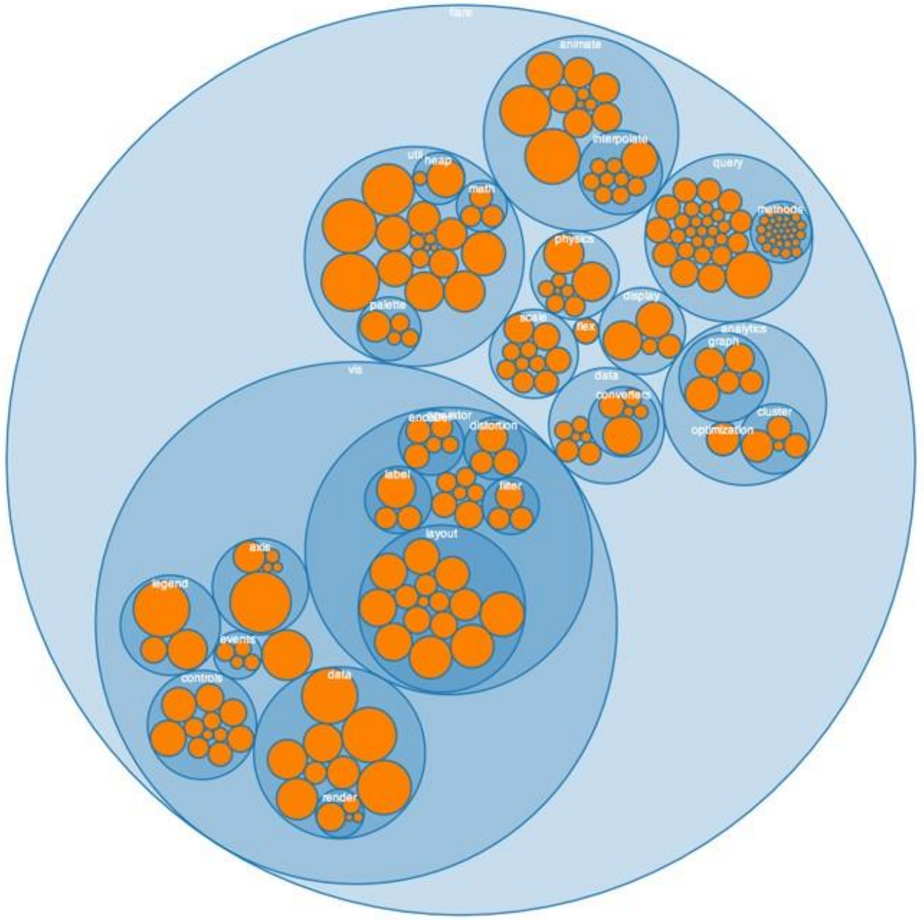
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‘What Do You Think Is the Most Important Problem Facing This Country Today?’

By GREGOR AISCH and ALICIA PARLAPIANO FEB. 27, 2017

Since the presidency of Franklin D. Roosevelt, the Gallup polling organization has asked Americans an open-ended question: “What do you think is the most important problem facing this country today?”

As Donald J. Trump prepares for his first major address to the nation on Tuesday, he has a unique set of issues to tackle. But there is not one singular issue that is dominating the American consciousness.

January 2015

The biggest problems cited by Americans this month:

https://www.nytimes.com/interactive/2017/02/27/us/politics/most-important-problem-gallup-polling-question.html?smid=pl-share

VISUALIZING GRAPHS

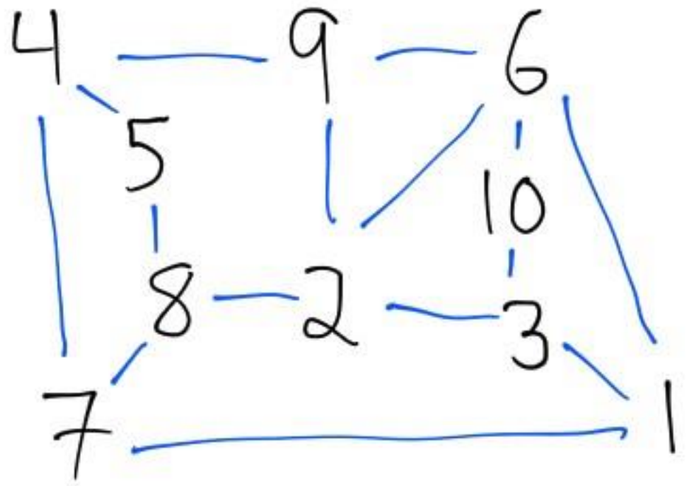
Graph Drawing Exercise

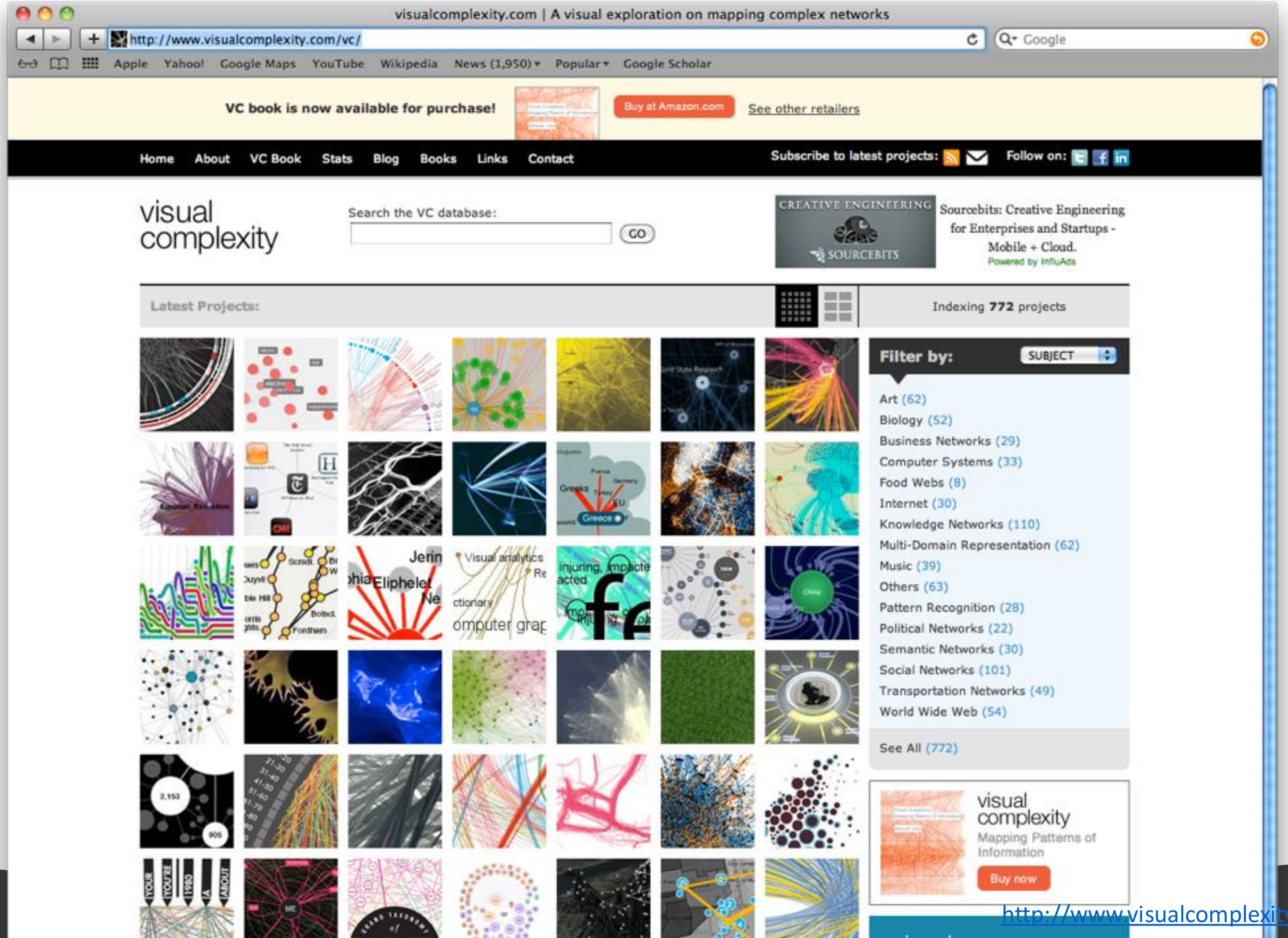
- create an aesthetically pleasing **node-link diagram** representation

	1	2	3	4	5	6	7	8	9	10
1	0	0	1	0	0	1	1	0	0	0
2	0	0	1	0	0	1	0	1	1	0
3	1	1	0	0	0	0	0	0	0	1
4	0	0	0	0	1	0	1	0	1	0
5	0	0	0	1	0	0	0	1	0	0
6	1	1	0	0	0	0	0	0	1	1
7	1	0	0	1	0	0	0	1	0	0
8	0	1	0	0	1	0	1	0	0	0
9	0	1	0	1	0	1	0	0	0	0
10	0	0	1	0	0	1	0	0	0	0

GRAPH DRAWING EXERCISE

- create an aesthetically pleasing **node-link diagram** representation





http://www.visualcomplexity.com/vc/

VISUALIZING GRAPHS

- node link layouts
  - Reingold-Tilford (discussed previously)
  - Sugiyama (directed acyclic graphs)
  - Force directed
  - Attribute-based
- adjacency matrices
- aggregate views
  - Motif Glyphs
  - PivotGraph

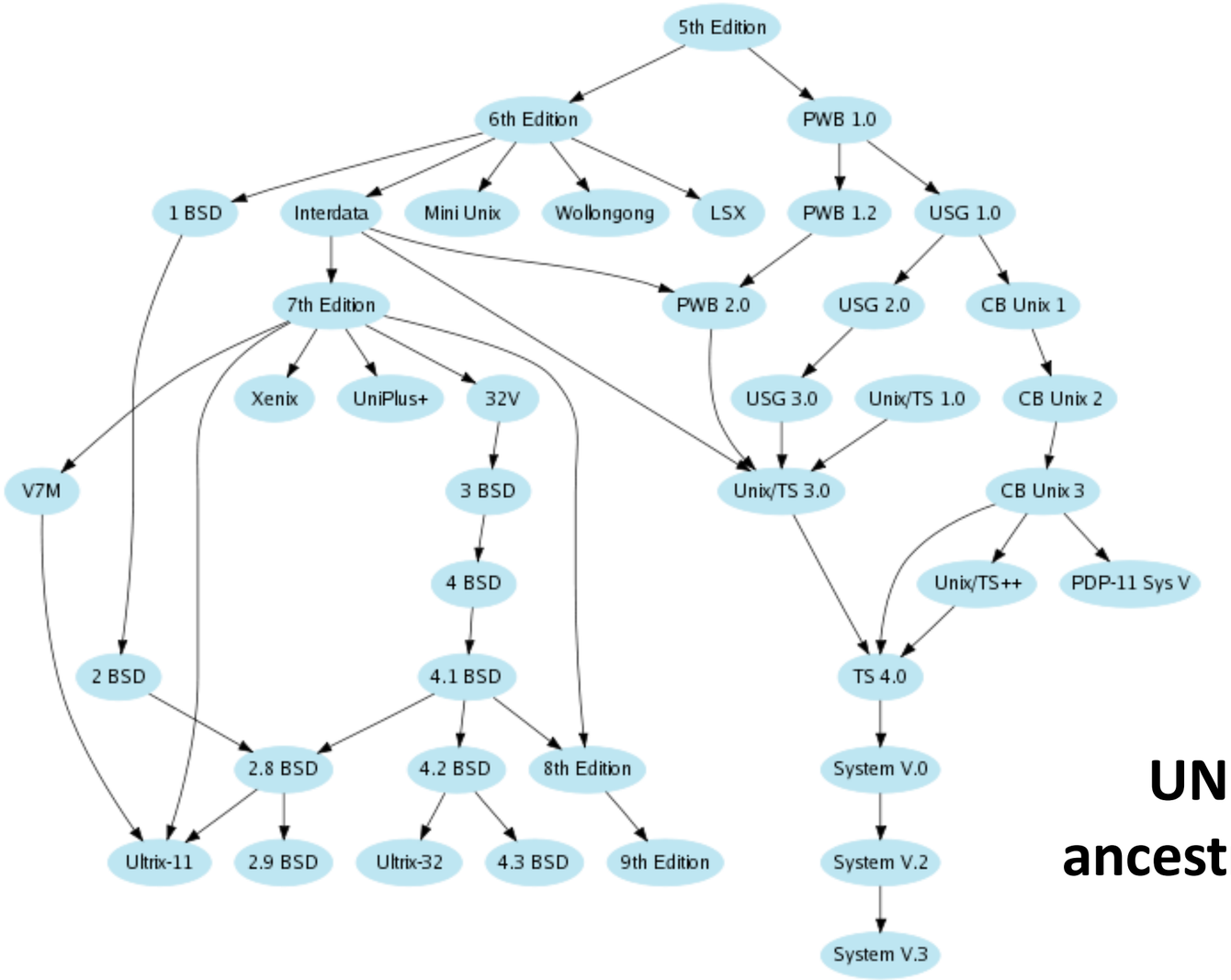
SPATIAL LAYOUT

- primary concern of graph drawing is the spatial layout 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)

SUGIYAMA

- great for graphs that have an intrinsic ordering
- depth not strictly encoded

- What is the depth of V7M?



UNIX ancestry

SUGIYAMA

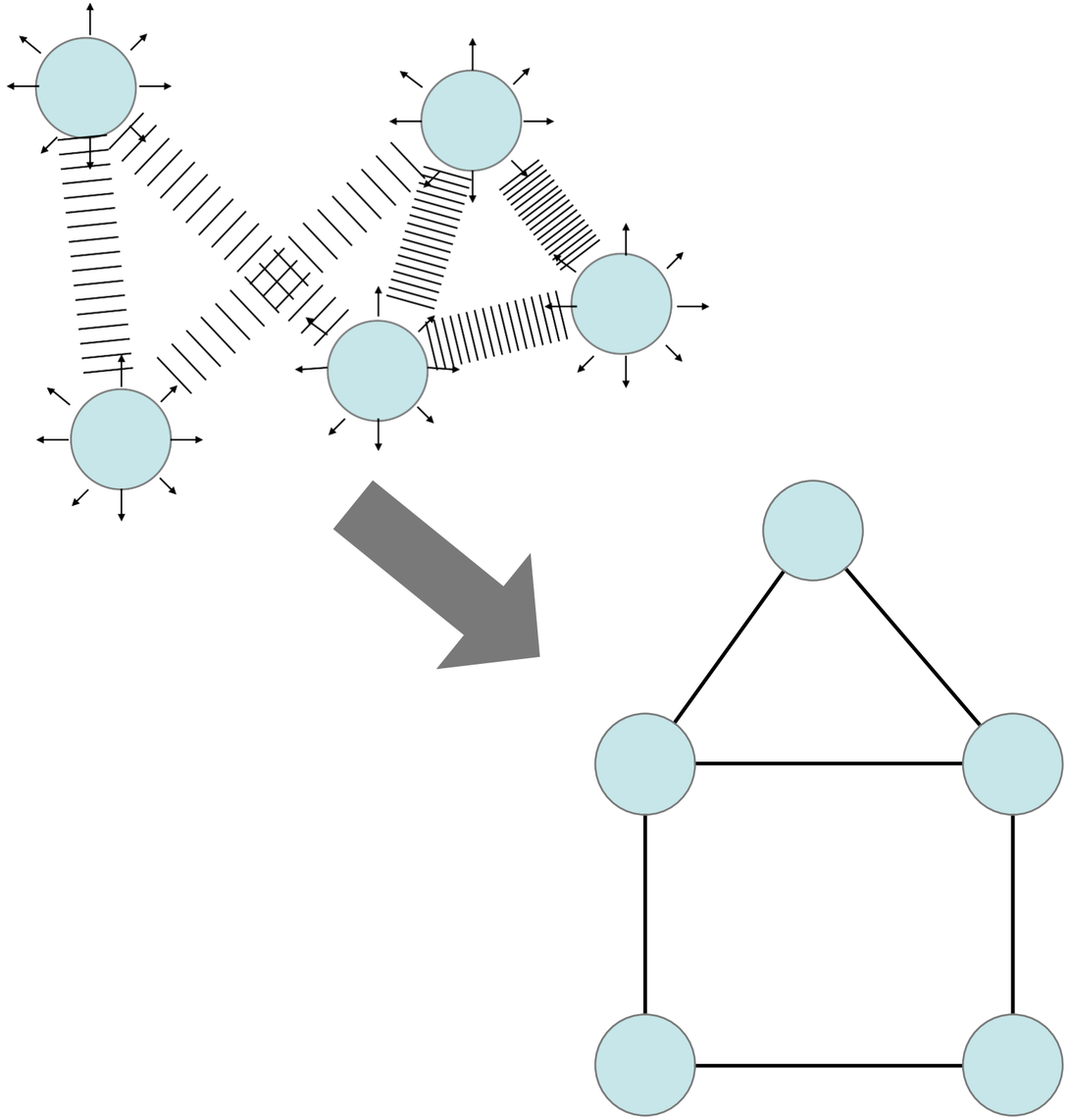
- + nice, readable top down flow
- + relatively fast (depending on heuristic used for crossing minimization)

- - not really suitable for graphs that don’t have an intrinsic top down structure
- - hard to implement

- use free graphviz lib: http://www.graphviz.org

FORCE-DIRECTED

- no intrinsic layering, now what?
- physically-based model

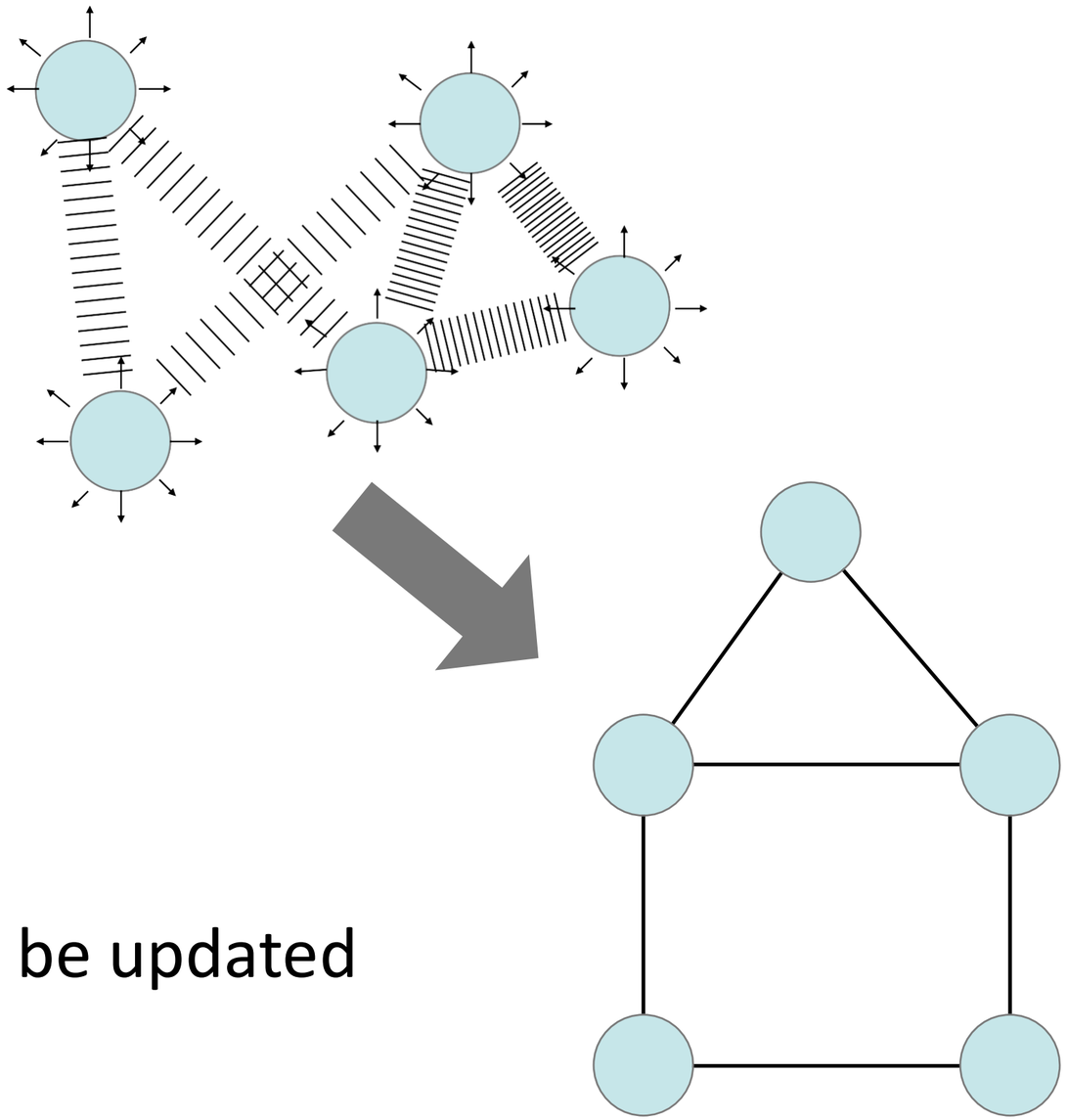


FORCE-DIRECTED

- many variations, but usually physical analogy of repulsion and attraction

- Generally…
  - edges = springs
  - nodes = repulsive particles

- Requires an iterative calculation, should be updated each time the draw loop is called



Physics Review

- $F = ma$
  - (Force = mass * acceleration)

- $\Delta v = a\ \Delta t$
  - (change in velocity = acceleration * time step)

- $p' = p + v\ \Delta t + \frac{1}{2} a \Delta t^2$
  - (new position = old position + velocity * time step)

For a Given Node i

- $\overrightarrow{a_i'} = \frac{\overrightarrow{F_i}}{m_i}$
  - (acceleration = Force / mass)

- $\overrightarrow{v_i'} = \overrightarrow{v_i} + \overrightarrow{a_i'}\Delta t$
  - (new velocity = old velocity + acceleration * time step)

- $\dot{p_i'} = \dot{p_i} + \overrightarrow{v_i'}\Delta t + \frac{1}{2}\overrightarrow{a_i'}\Delta t^2$
  - (new position = old position + new velocity * time step + ½ acceleration* time step2)

FORCE MODEL

- Use force to update acceleration
- Use acceleration to update velocity
- Use velocity and acceleration to update position

FORCE MODEL

- many variations, but usually physical analogy of repulsion and attraction

- Every node feels repulsion (or attraction) to every other node

FORCE MODEL: Repulsive Forces

- $f_R(d) = \frac{C_R\, m_1\, m_2}{d^2}$
  - C_R is a strength constant
  - $m_1,\ m_2$ are node masses
  - d is a distance between nodes

FORCE MODEL: Attractive Forces

- $f_A(d) = C_A * (d - L)$
  - C_A is a strength constant
  - d is a distance between nodes
  - L is the rest length of the spring (i.e. Hooke's Law)

FORCE MODEL: Attractive Forces

- $f_A(d) = \mathrm{C_A} \cdot max(0, \mathrm{d} - \mathrm{L})$
  - C_A is a strength constant
  - d is a distance between nodes
  - L is the rest length of the spring (i.e. Hooke's Law)

FORCE MODEL

- Every node feels repulsion to every other node
- Only **connected** nodes feel attracted

FORCE MODEL

- Repulsive force:
  - $F_R(P) = \Sigma_{\text{all neighbors}(Q)} f_R(||Q-P||) * (Q-P)$

- Attractive force:
  - $F_A(P) = \Sigma_{\text{connected neighbors }(Q)} f_A(||P-Q||) * (P-Q)$

ALGORITHM

- start from random layout
- (global) loop:
  - for every node pair compute repulsive force
  - for every edge compute attractive force
  - accumulate forces per node and update velocity
  - update each node position in direction of velocity
- stop when layout is ‘good enough’

What values do we set for…

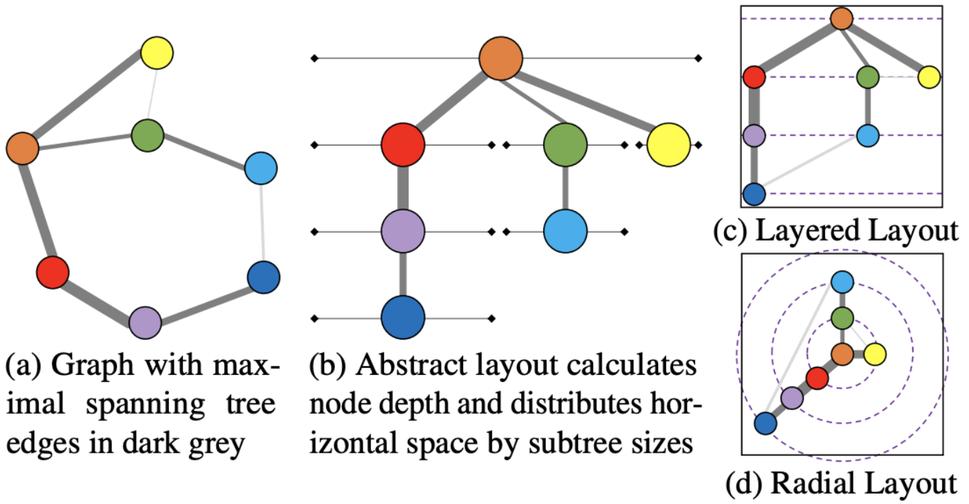
- time step Δt ?
- initial position p_i ?
- initial velocity v_i ?
- mass m_i ?
- Force F_i ?

What values do we set for…

- time step Δt ?
  - Fixed timestep, time since last frame was drawn, …
- initial position p_i ?
  - Start with a random position
- initial velocity v_i ?
  - Zero
- mass m_i ?
  - Depends, however, the heavier it is, the slower it moves
- Force F_i ?
  - That is what we still need to calculate…

Improving initial starting position

- Use concepts from topology to initialize a graph
- Graph initialized in a 2-step process that lays out the maximal spanning tree in a layered or radial configuration



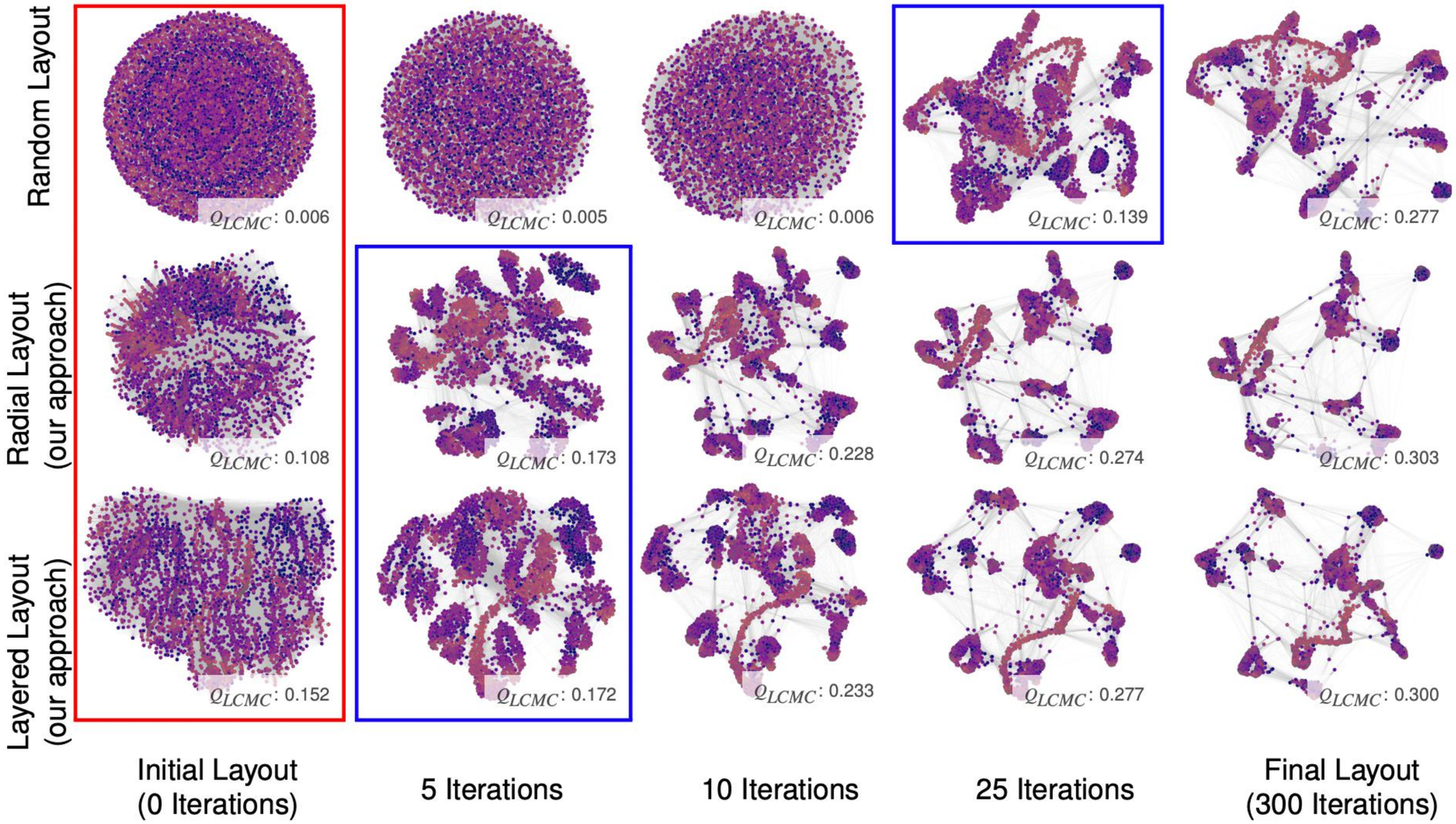
(a) Graph with maximal spanning tree edges in dark grey

(b) Abstract layout calculates node depth and distributes horizontal space by subtree sizes

(c) Layered Layout

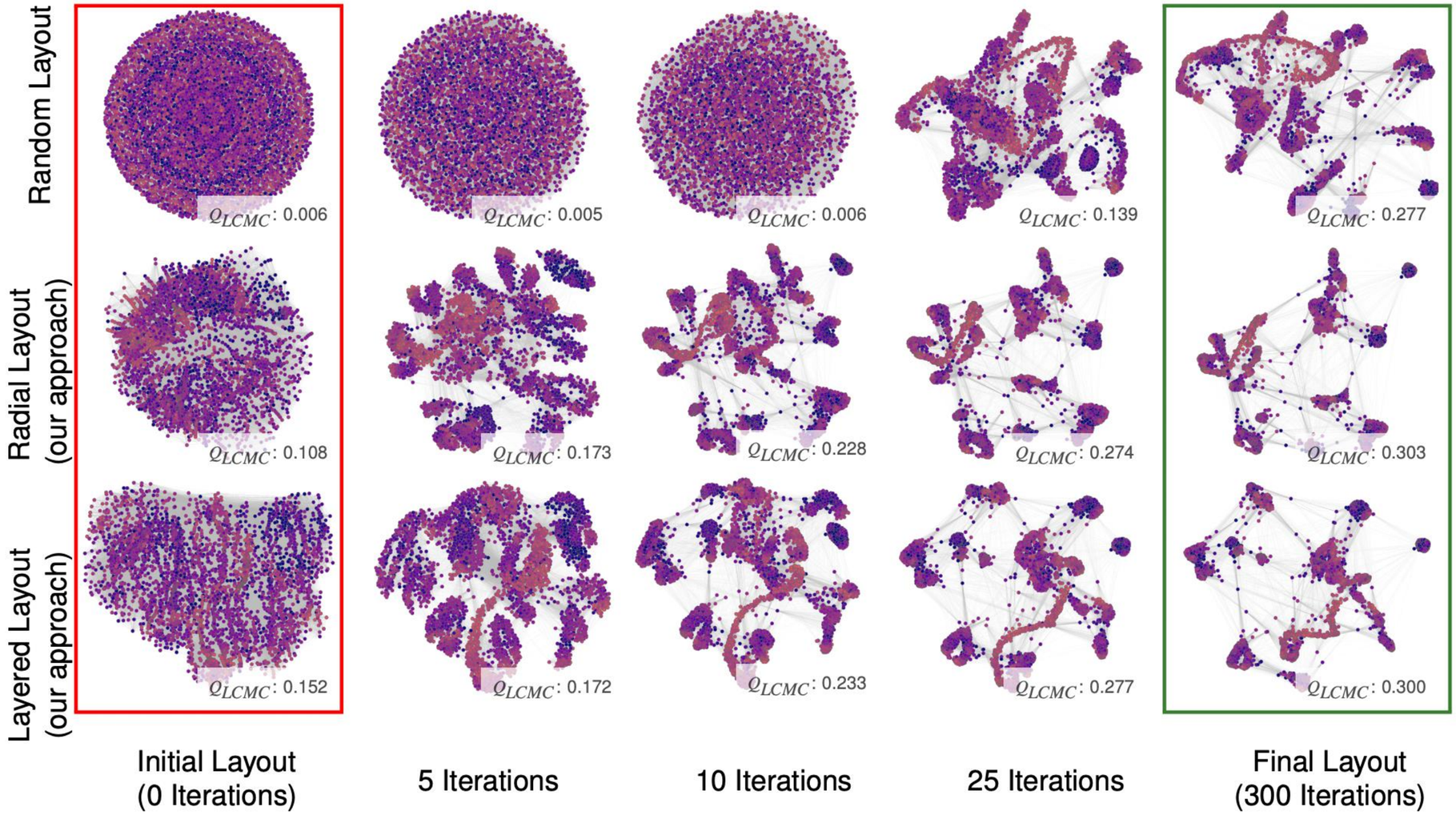
(d) Radial Layout

Example: Rate of Convergence



Doppalapudi et al. “Untangling Force-Directed Layouts Using Persistent Homology”, TopoInVis 2022.

Example: Convergence Quality



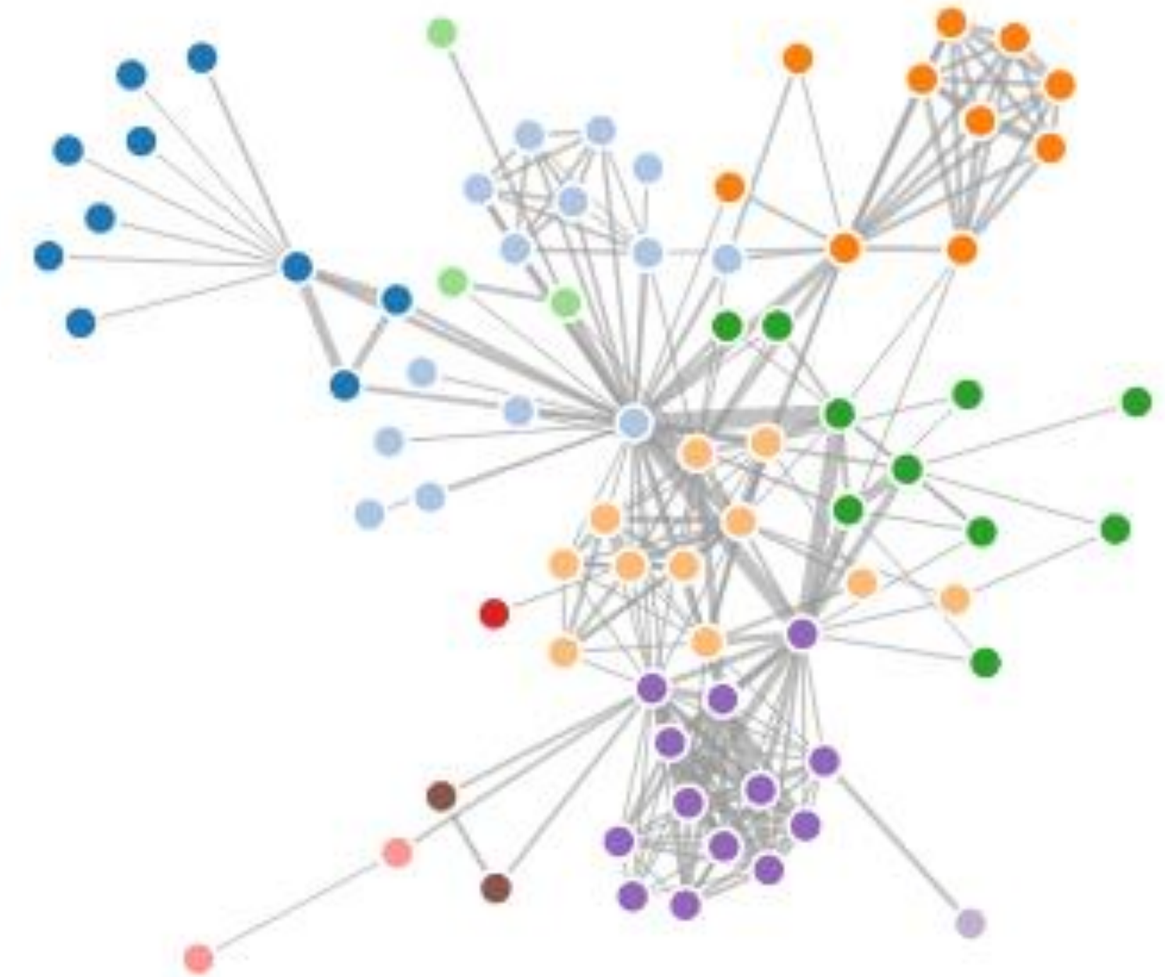
Doppalapudi et al. “Untangling Force-Directed Layouts Using Persistent Homology”, TopoInVis 2022.

What values for…

- Repulsive constant C_R ?
- Attractive constant C_A ?
- Rest length of the spring L ?

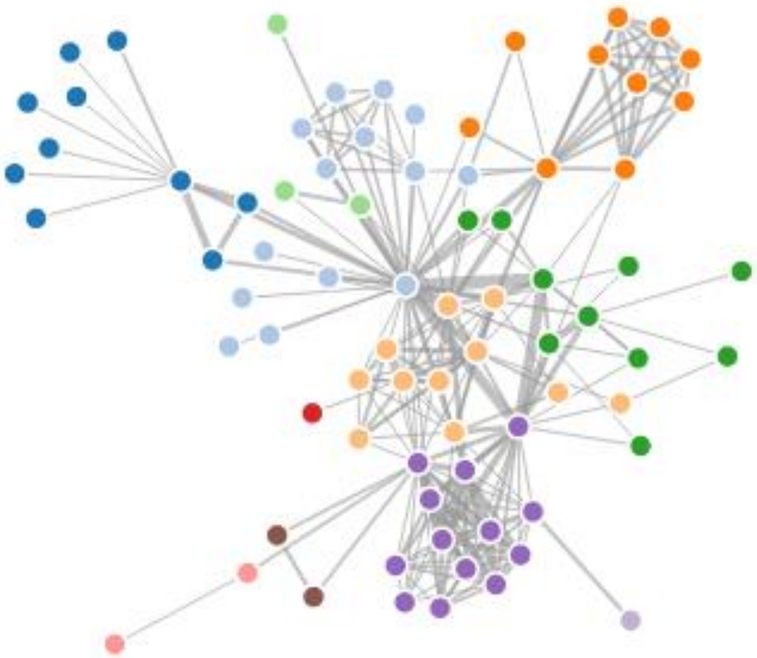
What values for…

- Repulsive constant C_R ?
  - Start with something small (weaker force)
- Attractive constant C_A ?
  - Start with something small (weaker force)
- Rest length of the spring L ?
  - Closest you would *like* 2 nodes to be together (they will be closer) – 10-20 pixels is a good start



FORCE DIRECTED

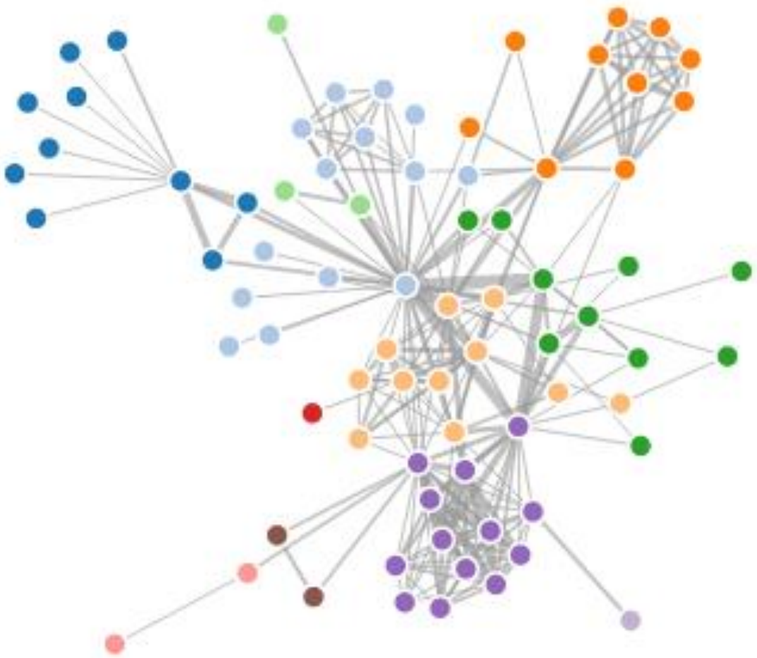
- + very flexible, aesthetic layouts on many types of graphs
- + can add custom forces
- + relatively easy to implement



http://bl.ocks.org/mbostock/4062045

FORCE DIRECTED

- - repulsion loop is O(n2) per iteration
  - can speed up to O(n log n) using quadtree or k-d tree
- - prone to local minima
  - can use simulated annealing
- - doesn’t work well on highly connected (low diameter) graphs



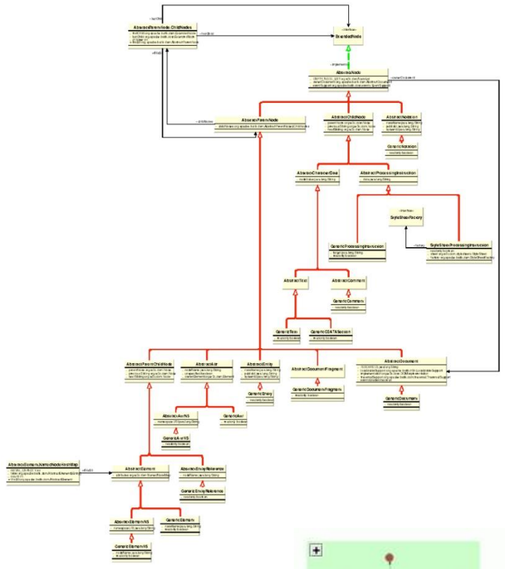
http://bl.ocks.org/mbostock/4062045

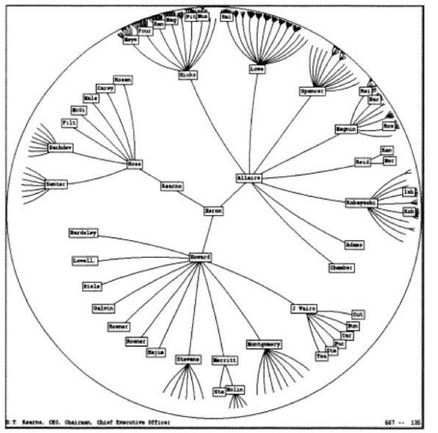
Ideas to make it better

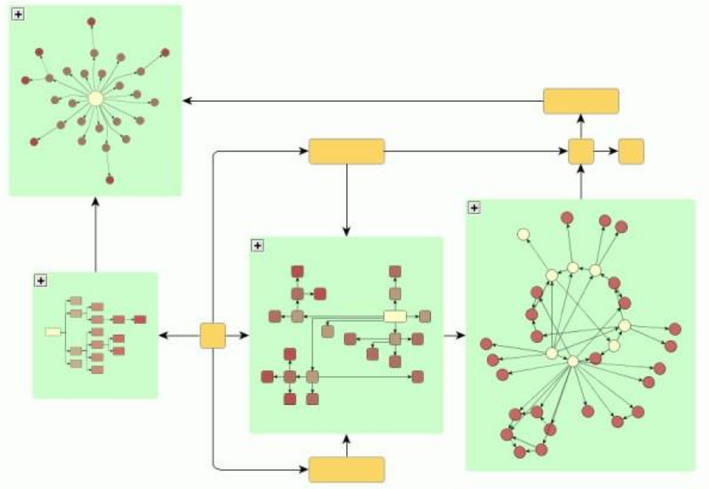
- Add extra forces, such as repulsion from the boundary or attraction to the center of the screen.
- Allow overriding node positions using the mouse (dragging vertices)
- Allow fixing the position of certain nodes

OTHER LAYOUTS

- orthogonal
  - great for UML diagrams
  - algorithmically complex
- circular layouts
  - emphasizes ring topologies
  - used in social network diagrams
- nested layouts
  - recursively apply layout algorithms
  - great for graphs with hierarchical structure
- Attribute driven layouts
  - Use “extra data” to help inform layout
  - (more next lecture)







Gephi, an open source graph visualization and manipulation software

http://gephi.org/ — hookes law

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Gephi
makes graphs handy

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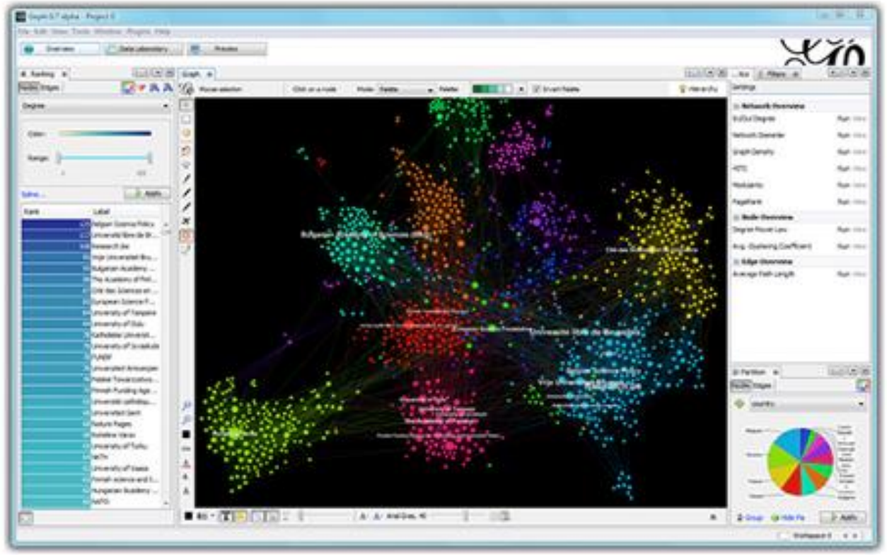
The Open Graph Viz Platform

Gephi is an interactive visualization and exploration platform for all kinds of networks and complex systems, dynamic and hierarchical graphs.

Runs on Windows, Linux and Mac OS X. Gephi is open-source and free.

Learn More on Gephi Platform »



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Gephi 0.8 beta

Release Notes | System Requirements

- Features
- Quick start
- Screenshots
- Videos

Gephi 0.8 beta has been released! Discover a new Preview and dynamic features, start building commercial applications with the new open source license.

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APPLICATIONS

- **Exploratory Data Analysis**: intuition-oriented analysis by networks manipulations in real time.
- **Link Analysis**: revealing the underlying structures of associations between objects, in particular in scale-free networks.
- **Social Network Analysis**: easy creation of social data connectors to map community organizations and small-world networks.
- **Biological Network analysis**: representing patterns of biological data.
- **Poster creation**: scientific work promotion with hi-quality printable maps.

Learn More »

“Like Photoshop™ for graphs.

— the Community

LATEST NEWS

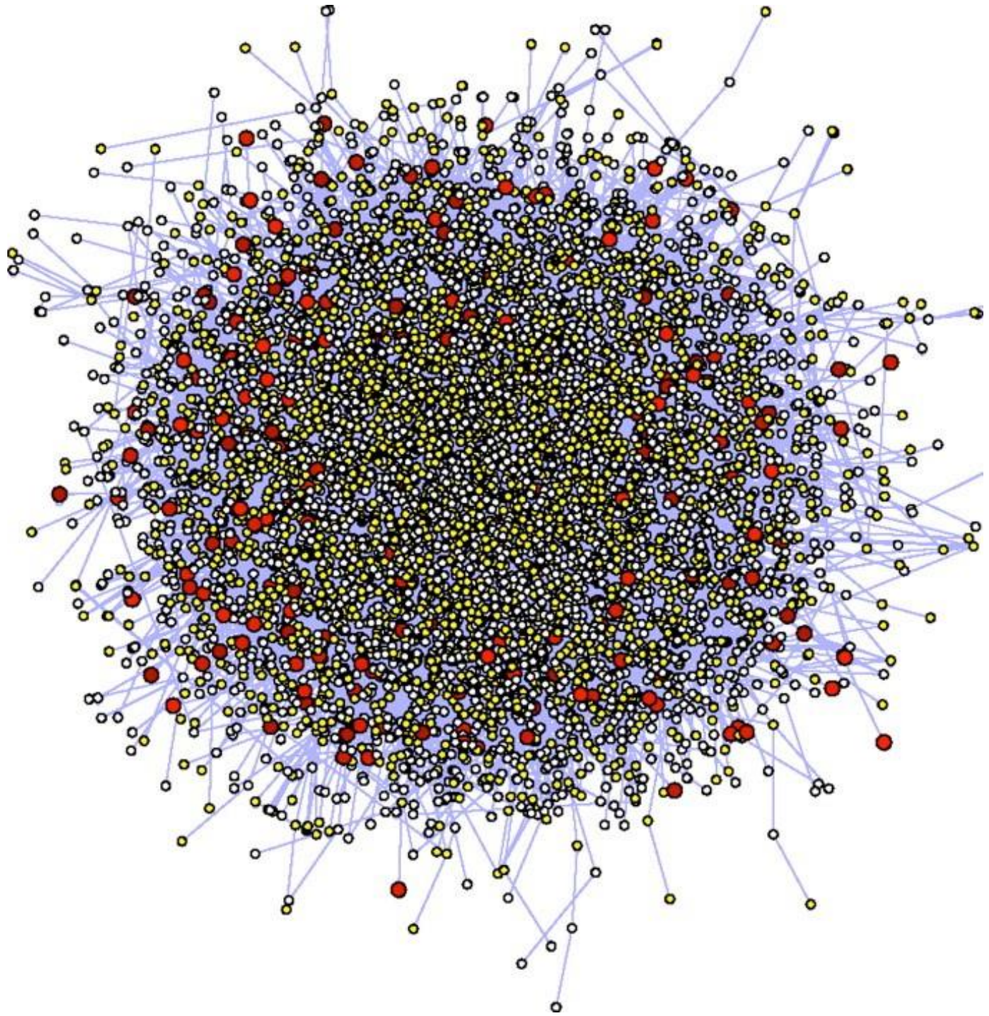
- Weekly news
  February 27, 2012
- Annual report 2011
  February 25, 2012
- Gephi-Neo4j presentation at FOSDEM
  February 20, 2012
- Gephi meet-up #4 in Berlin
  February 2, 2012
- Introducing the Gephi Plugins Bootcamp
  January 12, 2012

PAPERS

NODE LINK

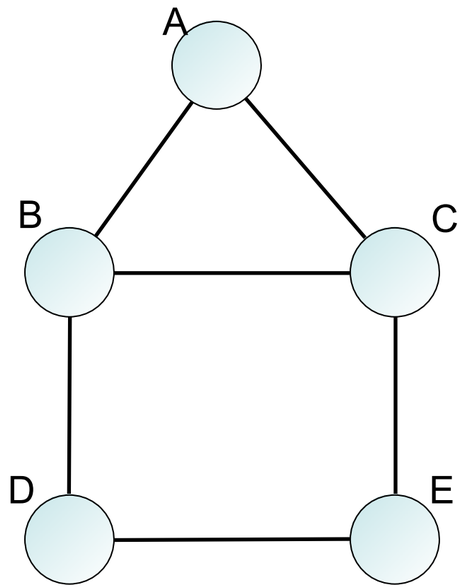
- + understandable visual mapping
- + can show overall structure, clusters, paths
- + flexible, many variations

- - all but the most trivial algorithms are > $O(n^2)$
- - not good for dense graphs
  - hairball problem!



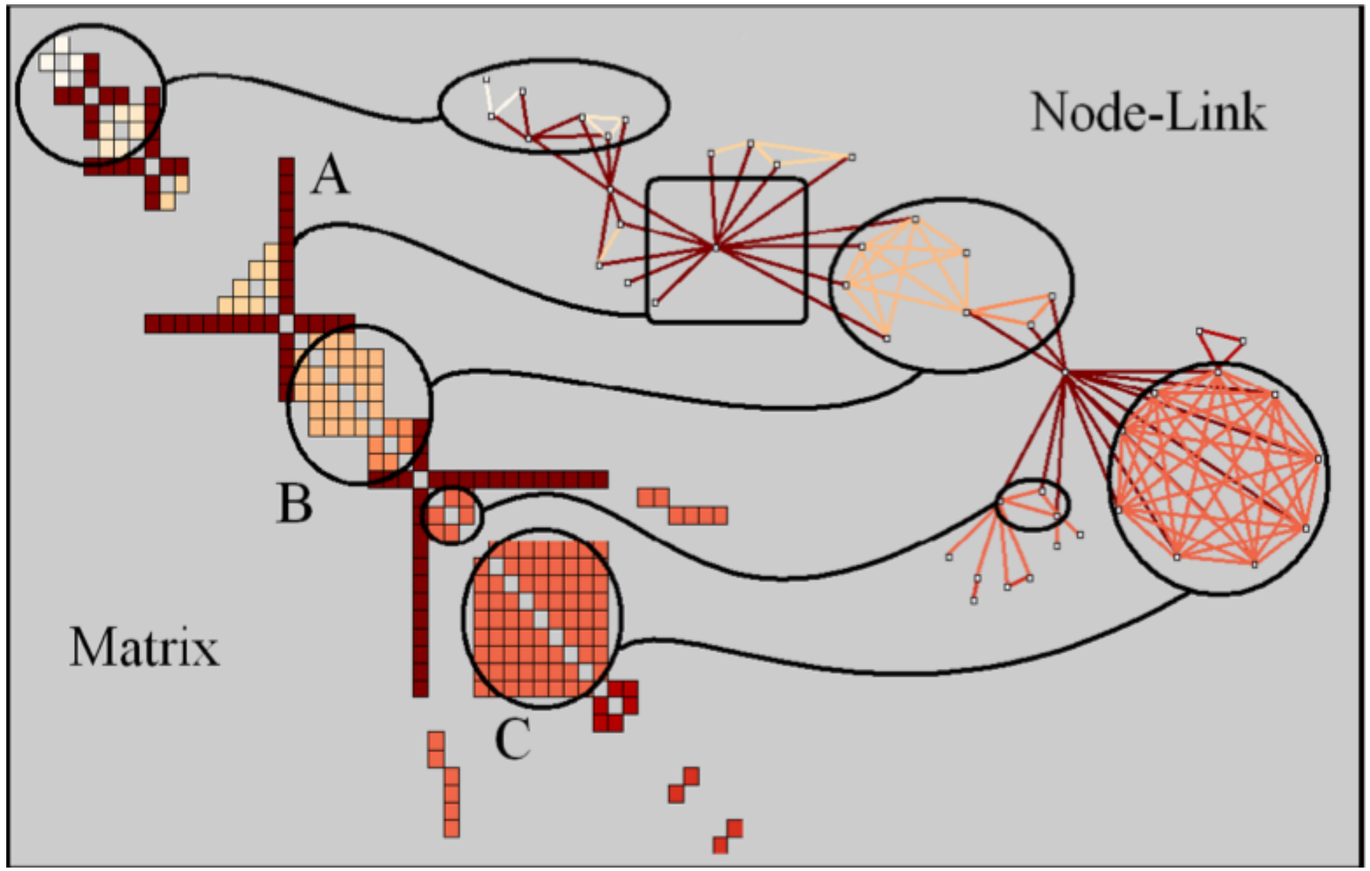
ALTERNATIVE: ADJACENCY MATRIX

- instead of node link diagram, use adjacency matrix representation



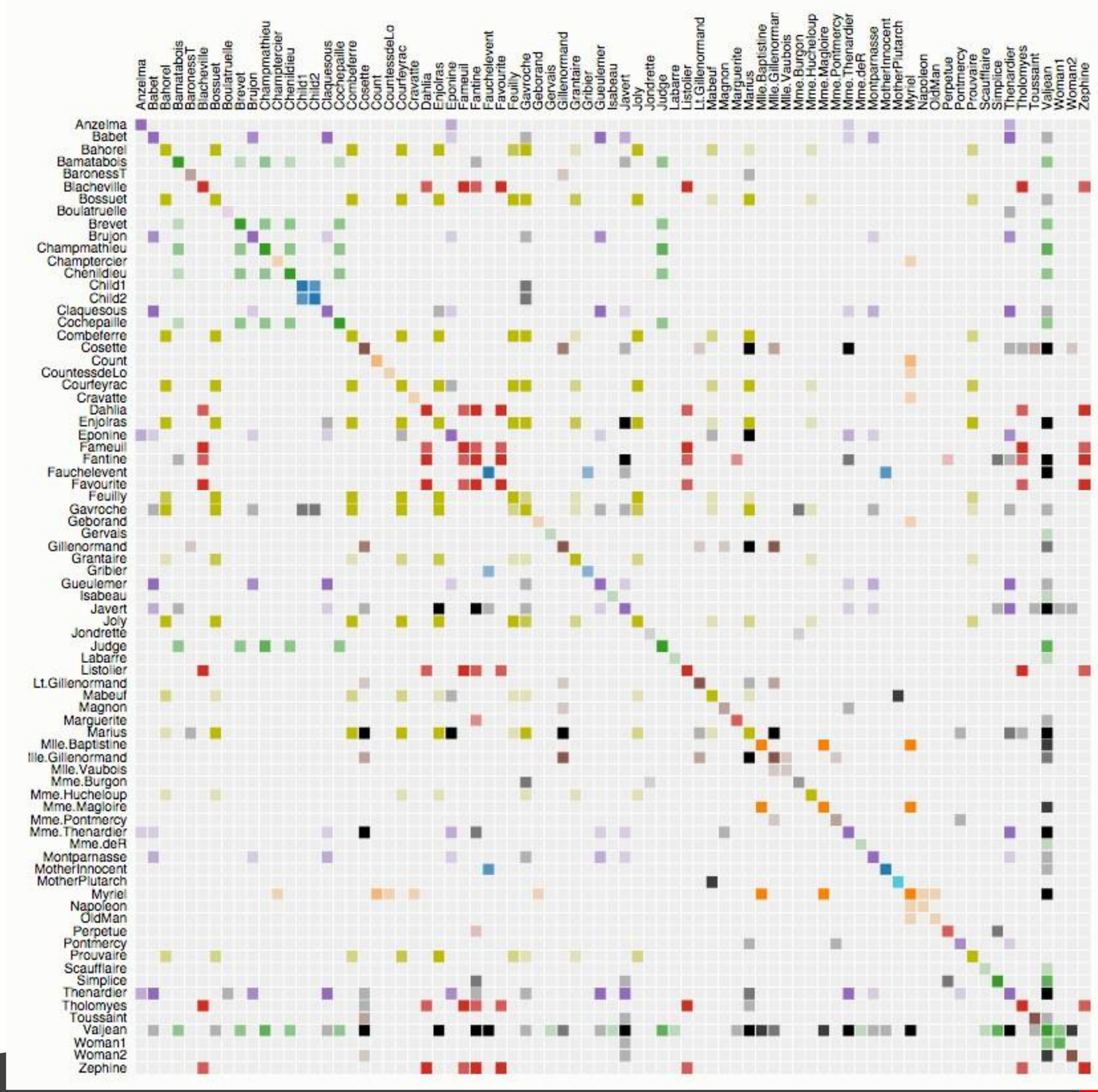
	A	B	C	D	E
A		■	■		
B	■		■	■	
C	■	■			■
D		■			■
E			■	■	

SPOTTING PATTERNS IN MATRICES



Les Misérables

- character co-occurrence

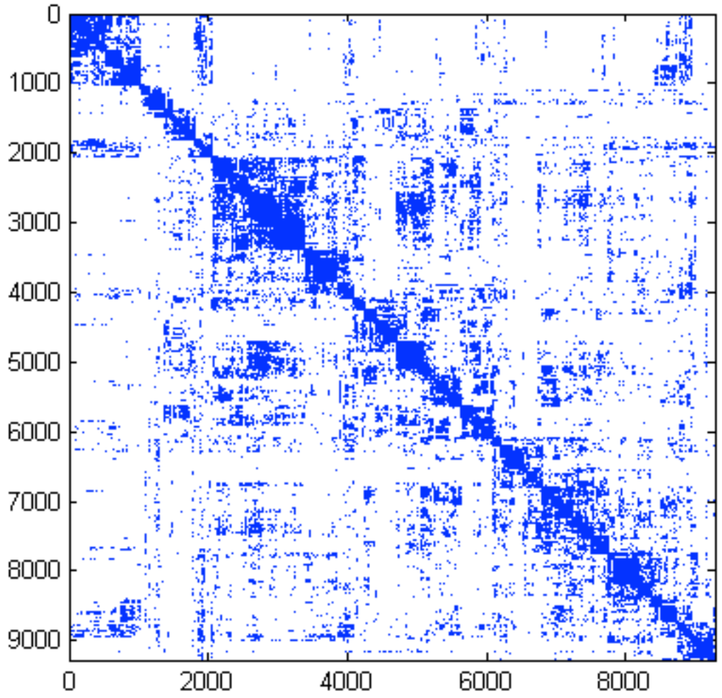


http://bost.ocks.org/mike/miserables/

Adjacency Diagram

- + great for dense graphs
- + visually scalable
- + can spot clusters

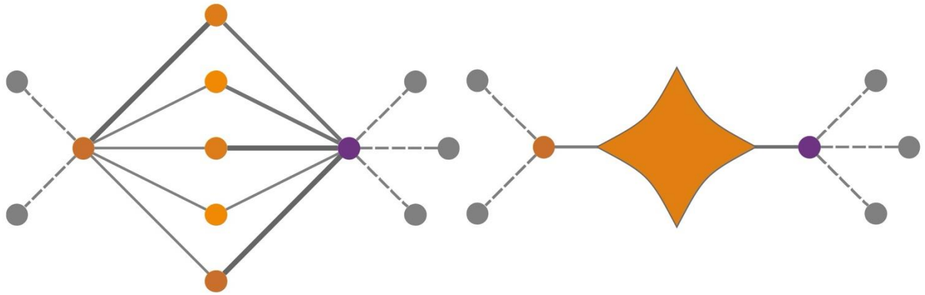
- - row order affects what you can see
- - abstract visualization
- - hard to follow paths



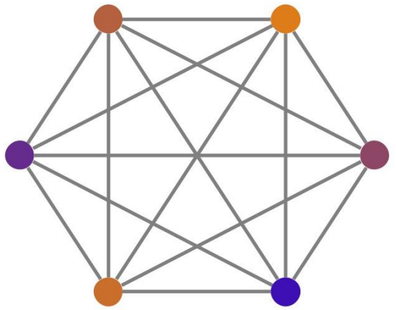
AGGREGATE VIEWS

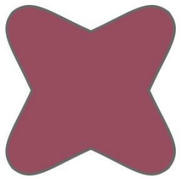
MOTIF GLYPHS

Connector

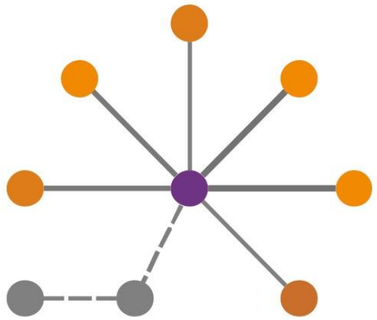


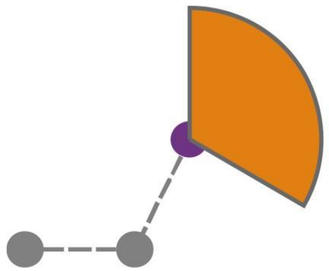
Clique





Fan





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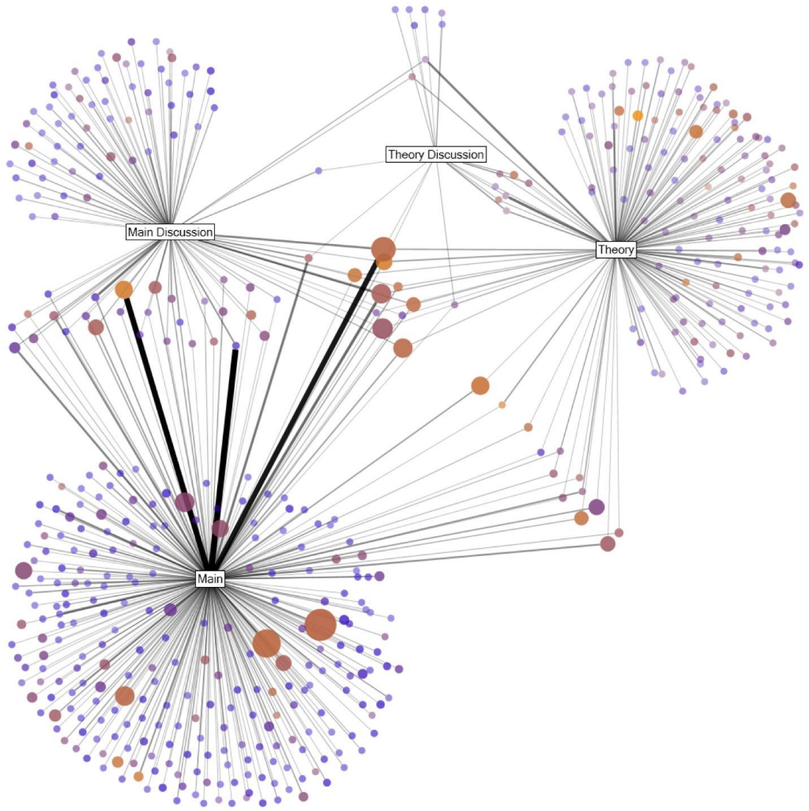

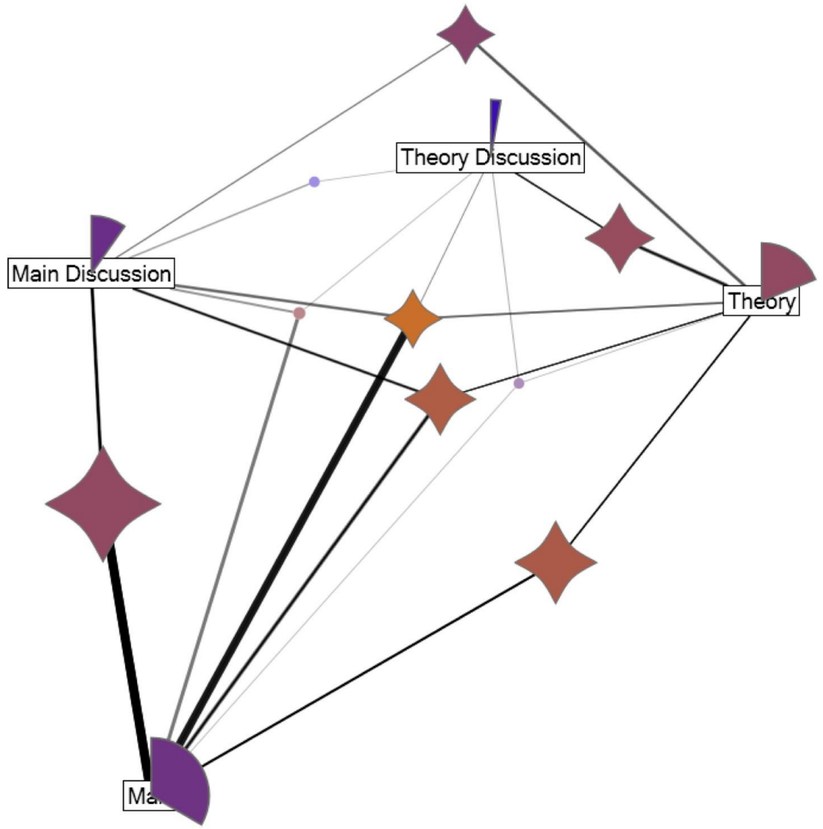

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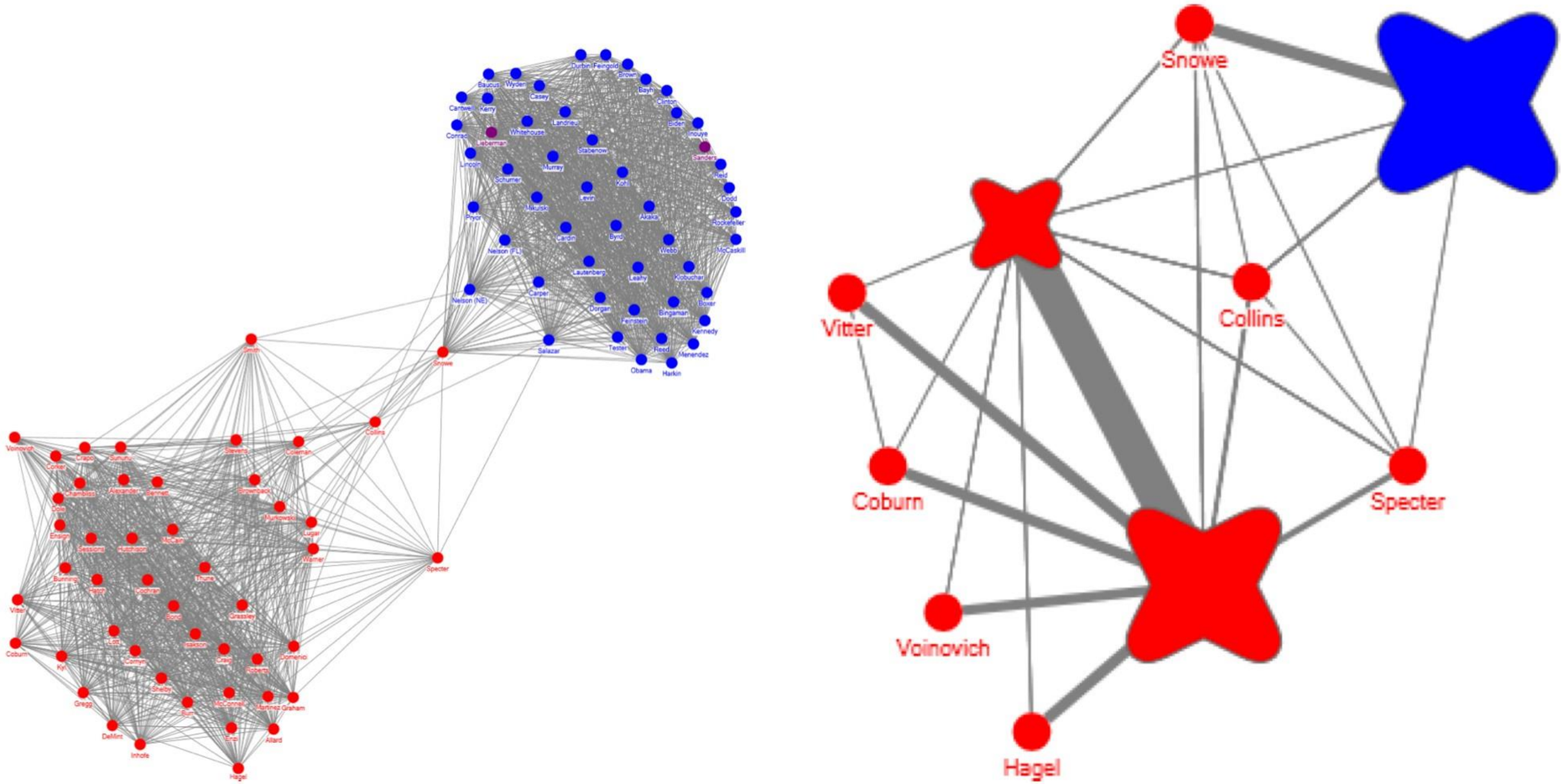

RECAP

TREES

- indentation
  - simple, effective for small trees
- node link and layered
  - looks good but needs exponential space
- enclosure (treemaps)
  - great for size related tasks but suffer in structure related tasks

GRAPHS

- node link
  - familiar, but problematic for large or dense graphs
- adjacency matrices
  - abstract, hard to follow paths
- aggregation can help
  - not always possible, not always appropriate
- extracting structure can help
  - unclear how crosscutting it will be

TAKE HOME MESSAGE
No best solution!