Data Visualization

INF552 (2023-2024)

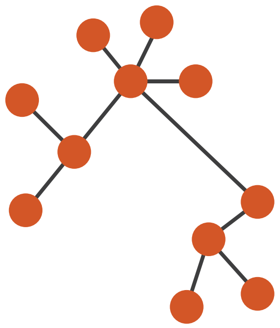
Session 08
Visualization of Hierarchical Structures and Graph Structures (Part II)

emmanuel.pietriga@inria.fr

Visual representation

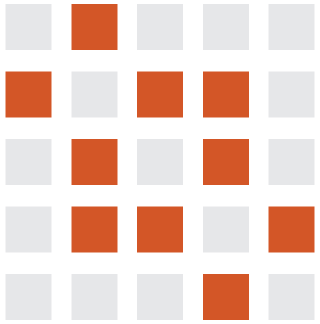
Node–Link Diagrams
Connection Marks

✔ NETWORKS ✔ TREES



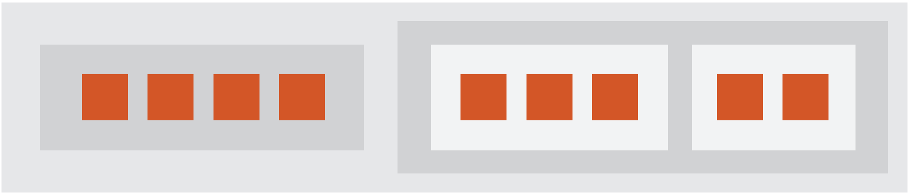
Adjacency Matrix
Derived Table

✔ NETWORKS ✔ TREES



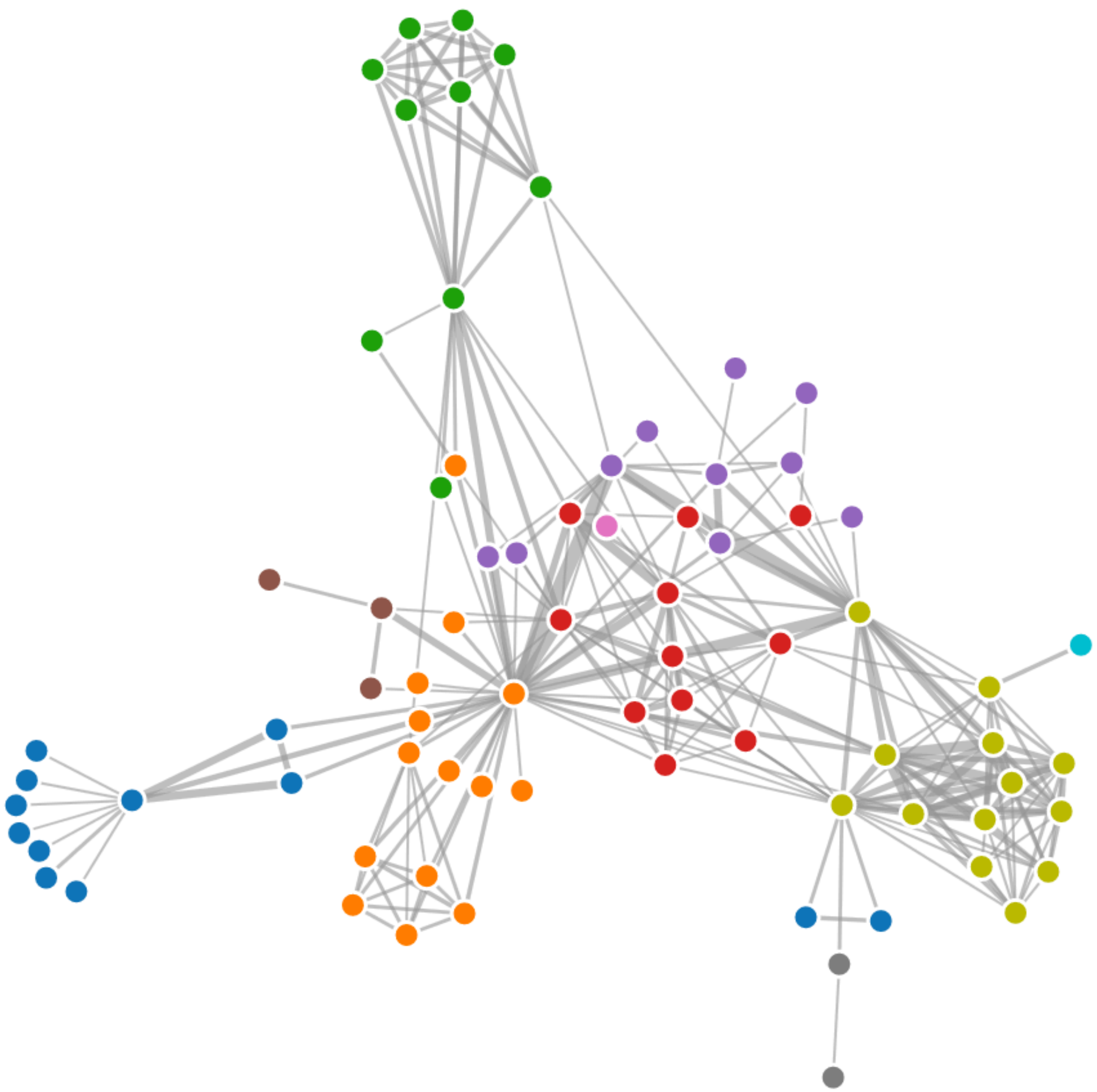
Enclosure
Containment Marks

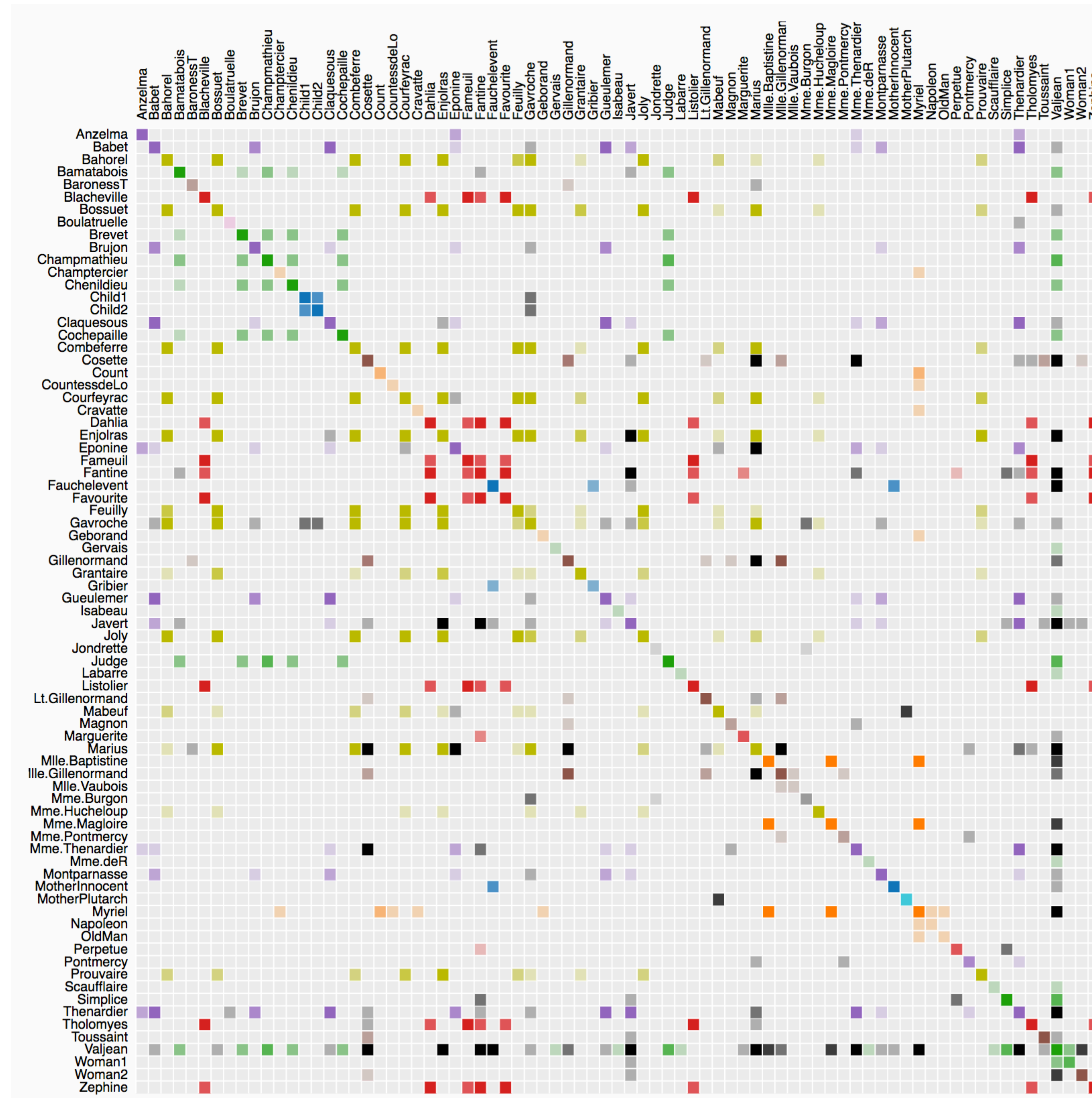
✘ NETWORKS ✔ TREES



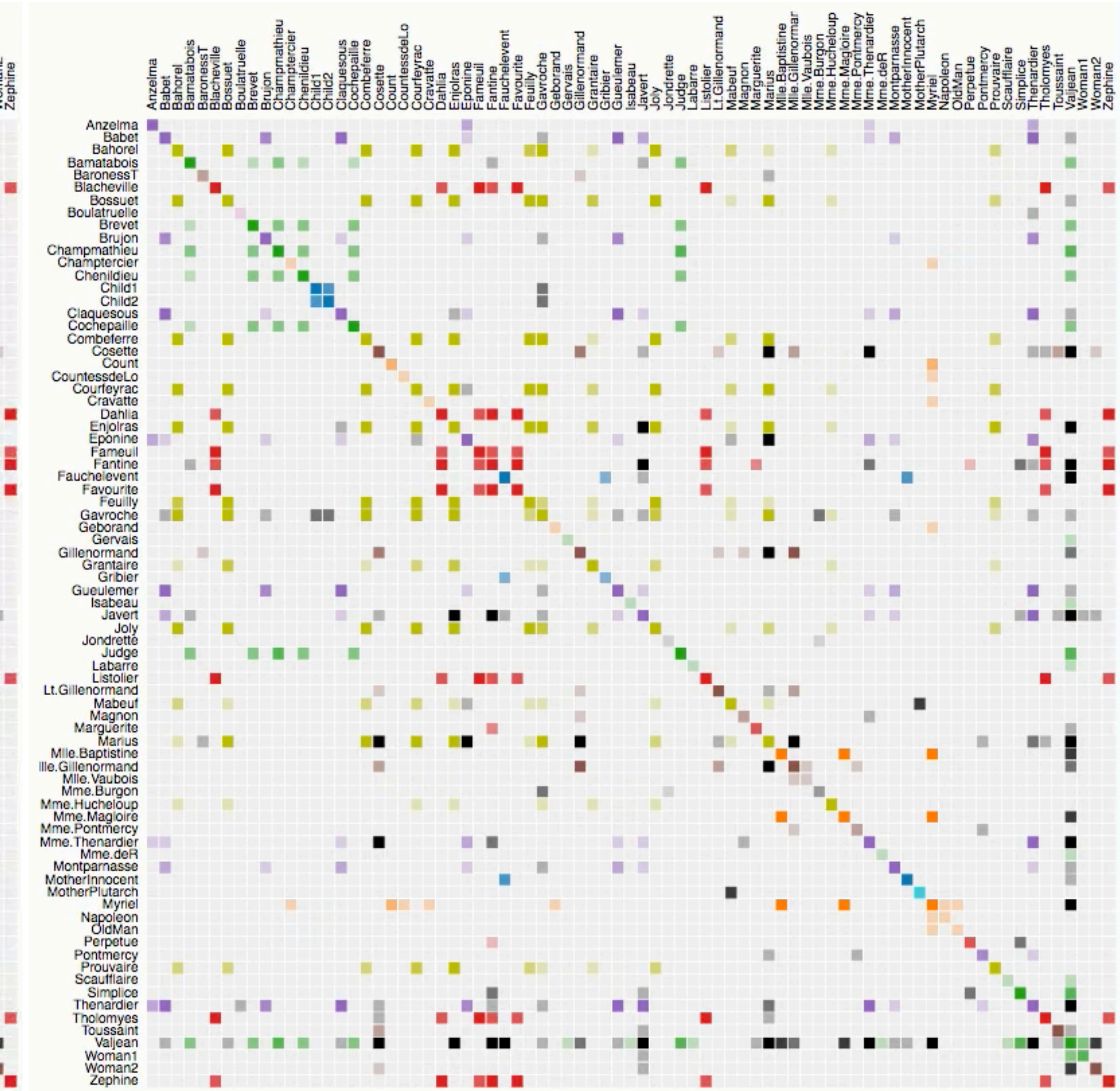
[Image source: Visualization Analysis and Design. Tamara Munzner, with illustrations by Eamonn Maguire. A K Peters Visualization Series, CRC Press, 2014]

Adjacency Matrix



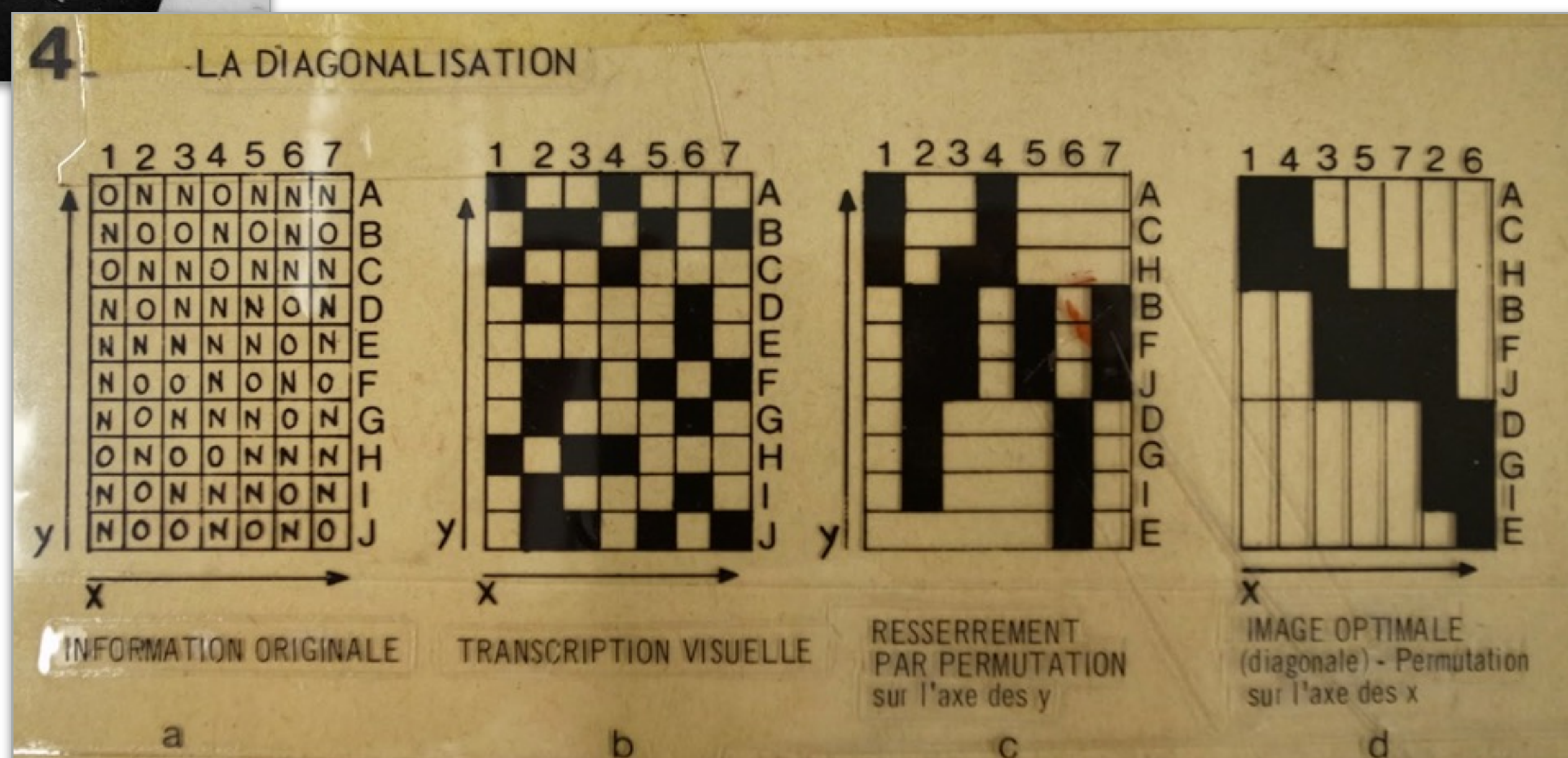


Adjacency Matrix / Reordering

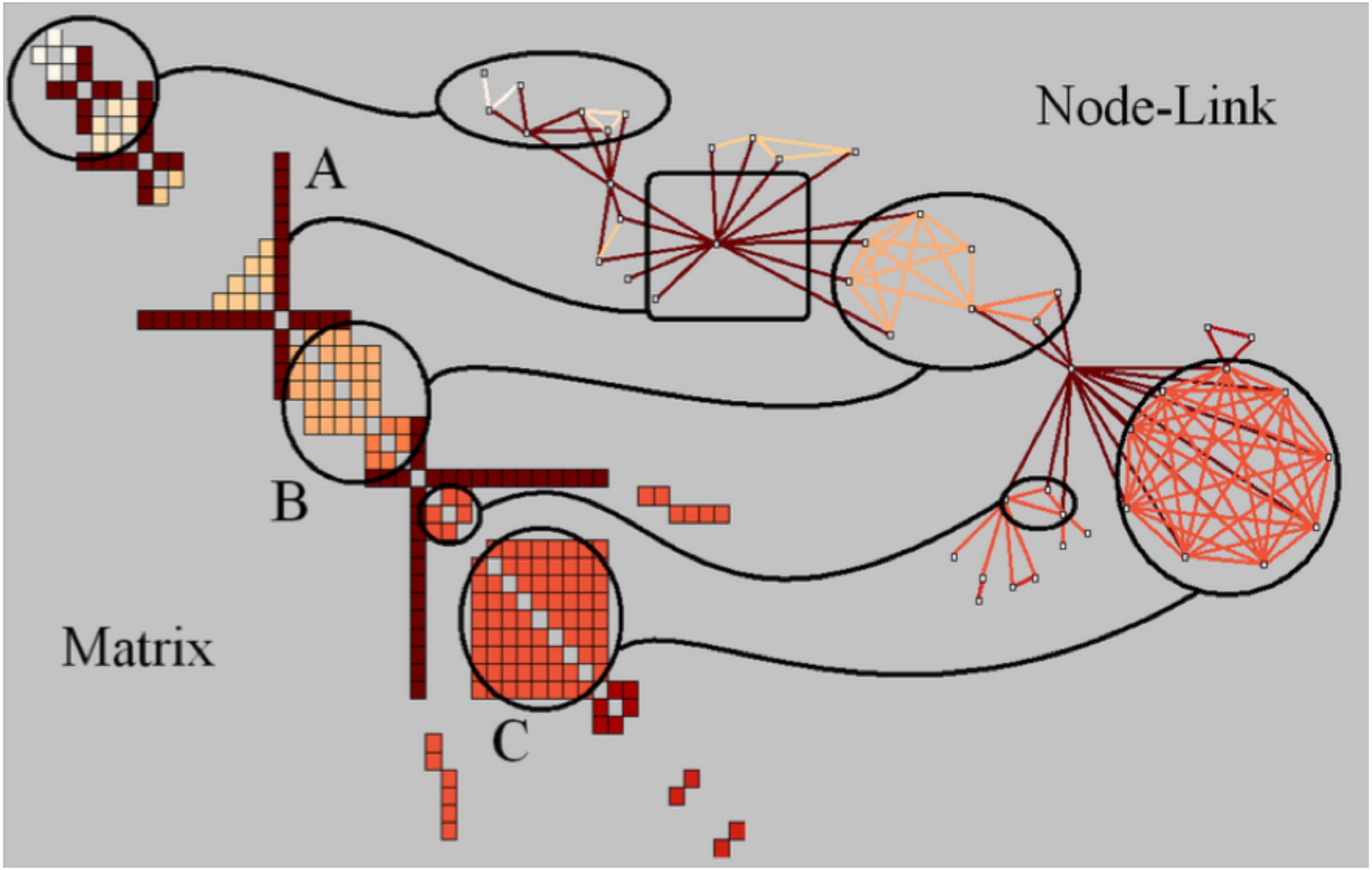


Adjacency Matrix / Reordering

[Archives Nationales]



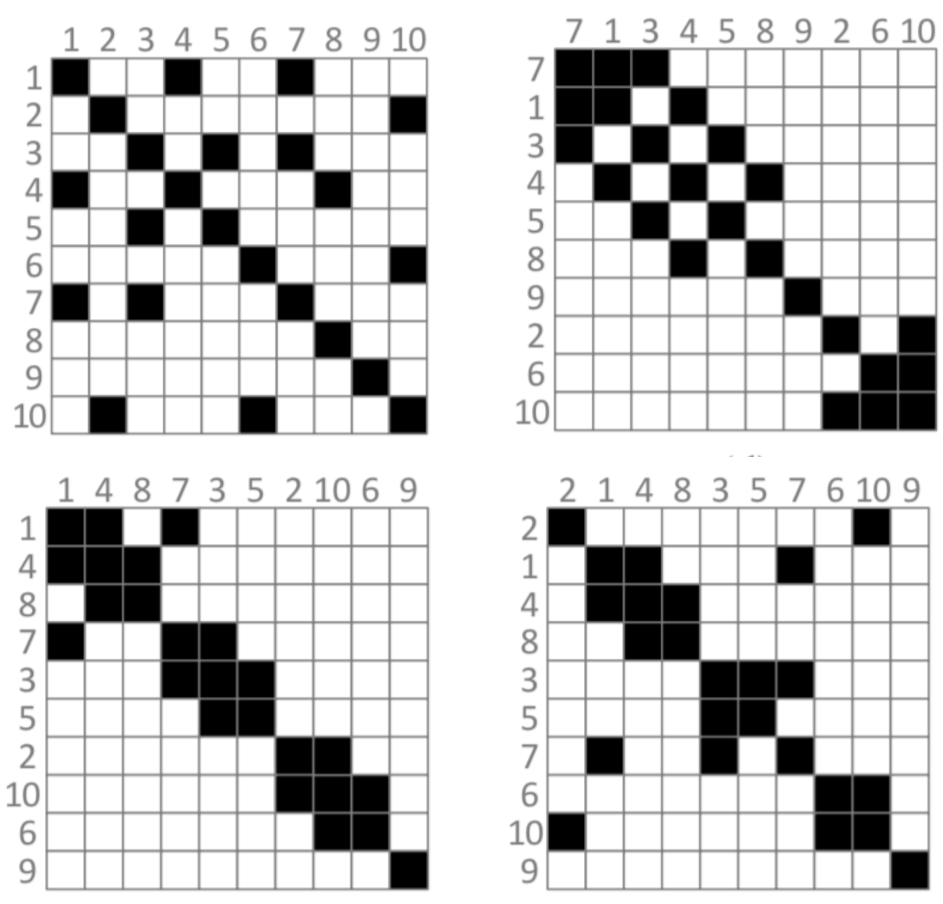
Adjacency Matrix / Motifs

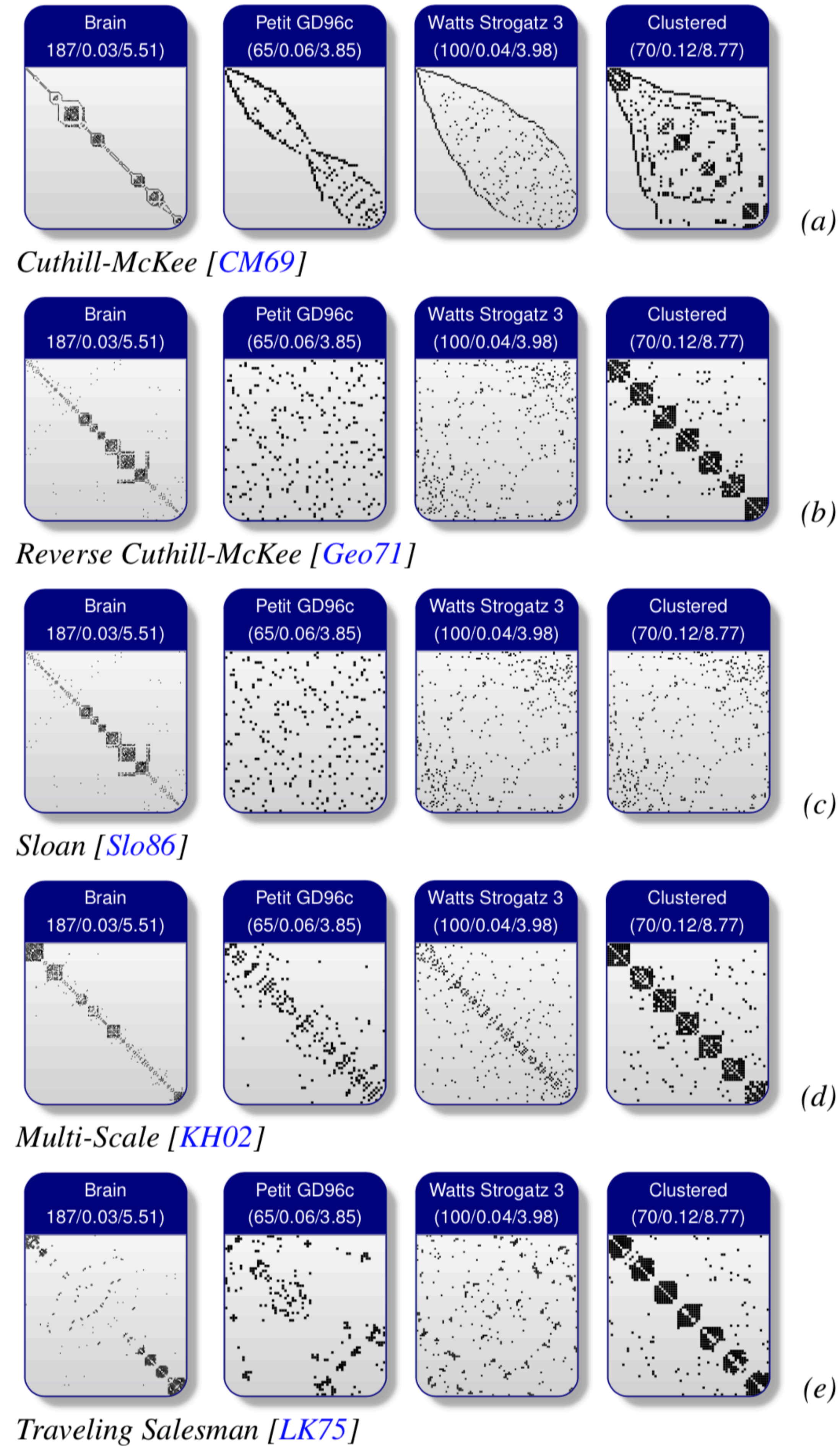


[Henry and Fekete. 2006. MatrixExplorer: a Dual-Representation System to Explore Social Networks. IEEE Transactions on Visualization and Computer Graphics 12, 5, 677-684]

Adjacency Matrix / Reordering

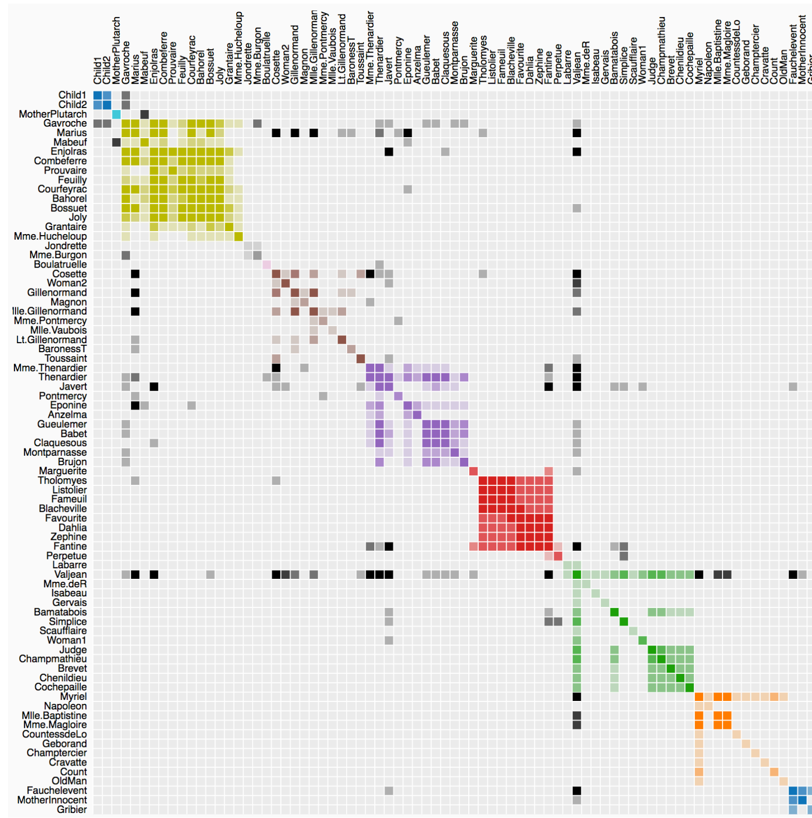
$$\begin{bmatrix} c_{1,1} & c_{1,2} & \cdots & \cdots & \cdots & c_{1,n} \\ c_{2,1} & c_{2,2} & \cdots & \cdots & \cdots & c_{2,n} \\ \cdots & \cdots & \ddots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & c_{i,j} & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \ddots & \cdots \\ c_{m,1} & c_{m,2} & \cdots & \cdots & \cdots & c_{m,n} \end{bmatrix}$$



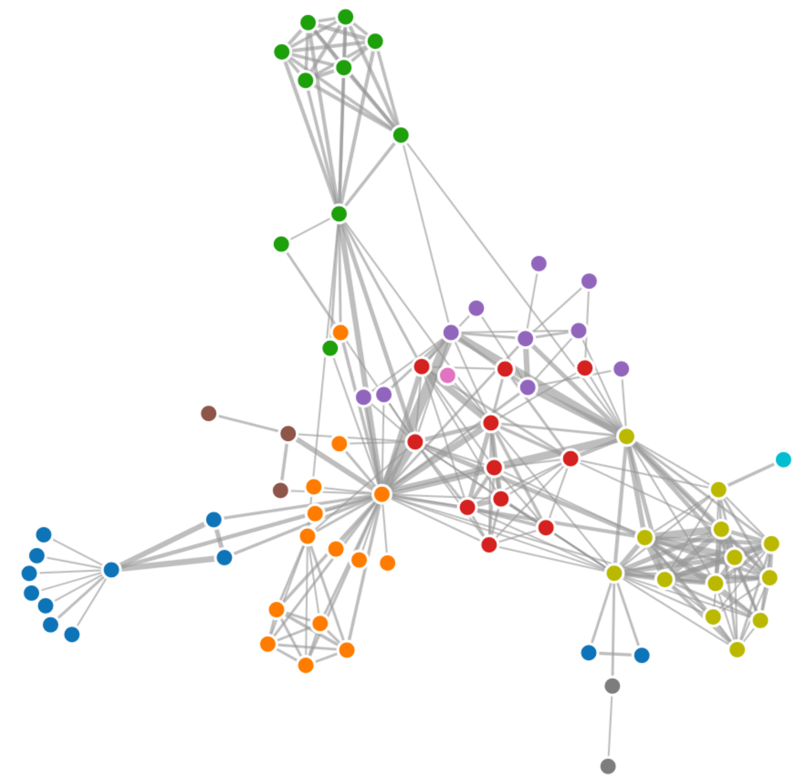


[Behrisch et al. 2016. Matrix Reordering Methods for Table and Network Visualization. Comput. Graph. Forum 35, 3, 693-716.]

Adjacency Matrix vs. Node-link Diagram



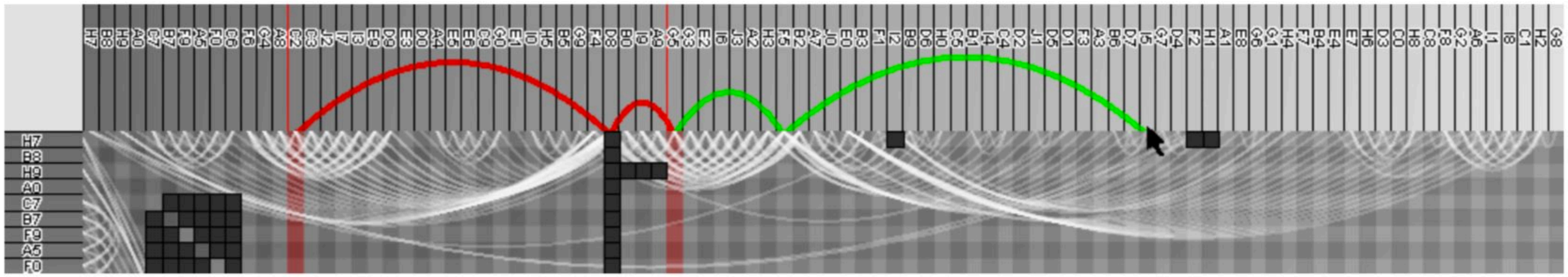
Explore

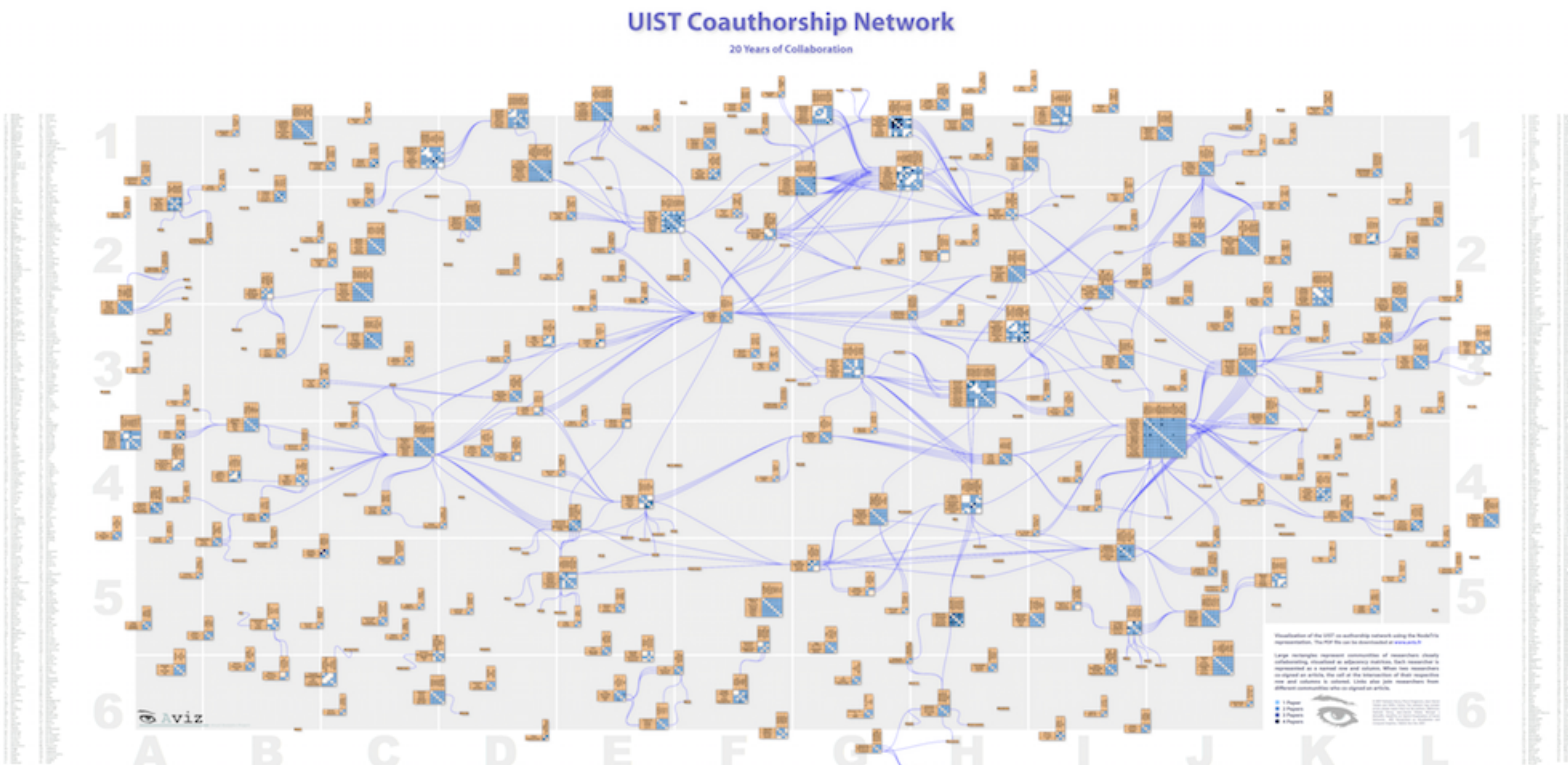


Communicate

	Adjacency Matrix	Node-link Diagram
Node overlapping	never	depends on layout
Link crossing	no link crossing (remains readable for dense graphs)	depends on density and planarity
Screen real-estate use	often poor	often more compact
Familiarity	low	high
Task support	weak for path following	
Graph size	remains readable for dense graphs	works best for small/sparse graphs

Hybrid Approaches



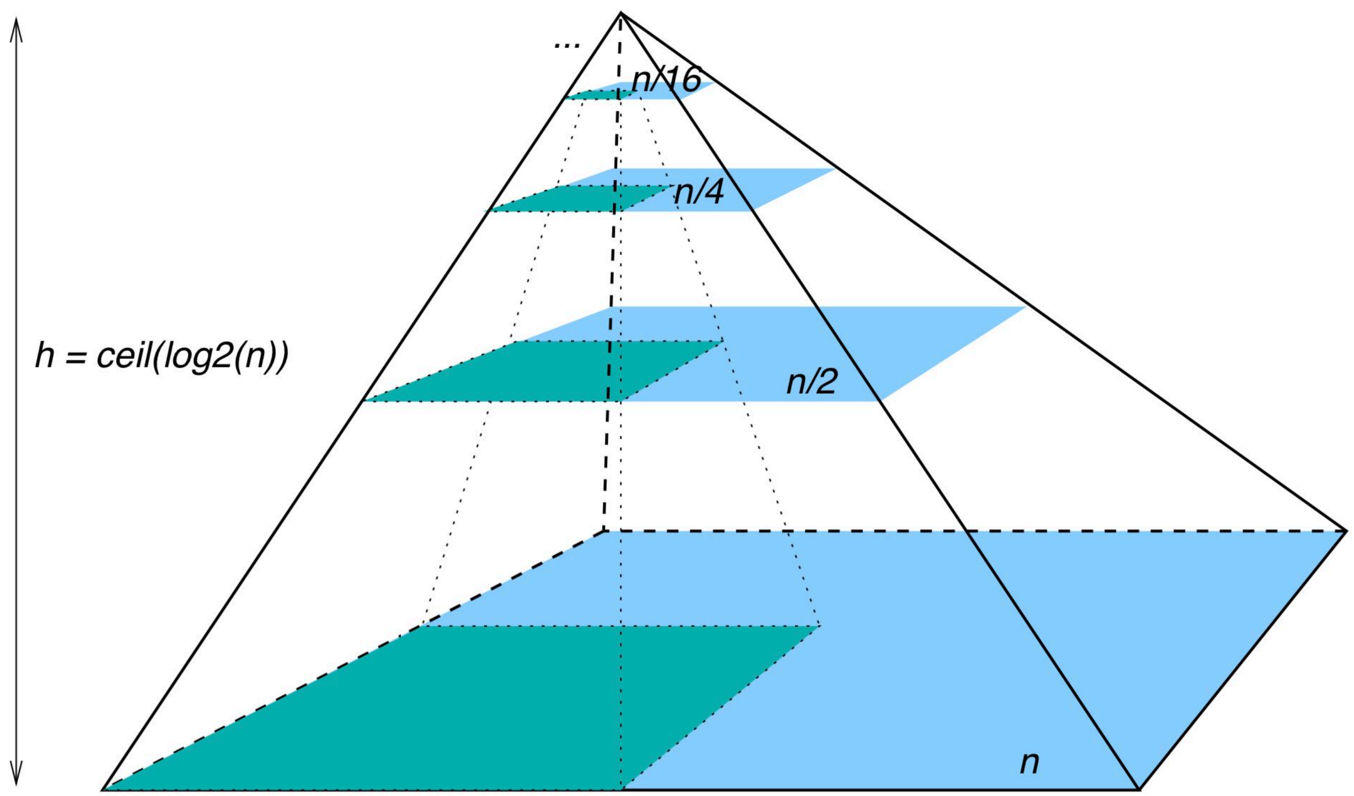


[Henry and Fekete. 2007. MatLink: enhanced matrix visualization for analyzing social networks. In Proceedings of INTERACT'07, Springer, 288-302.]

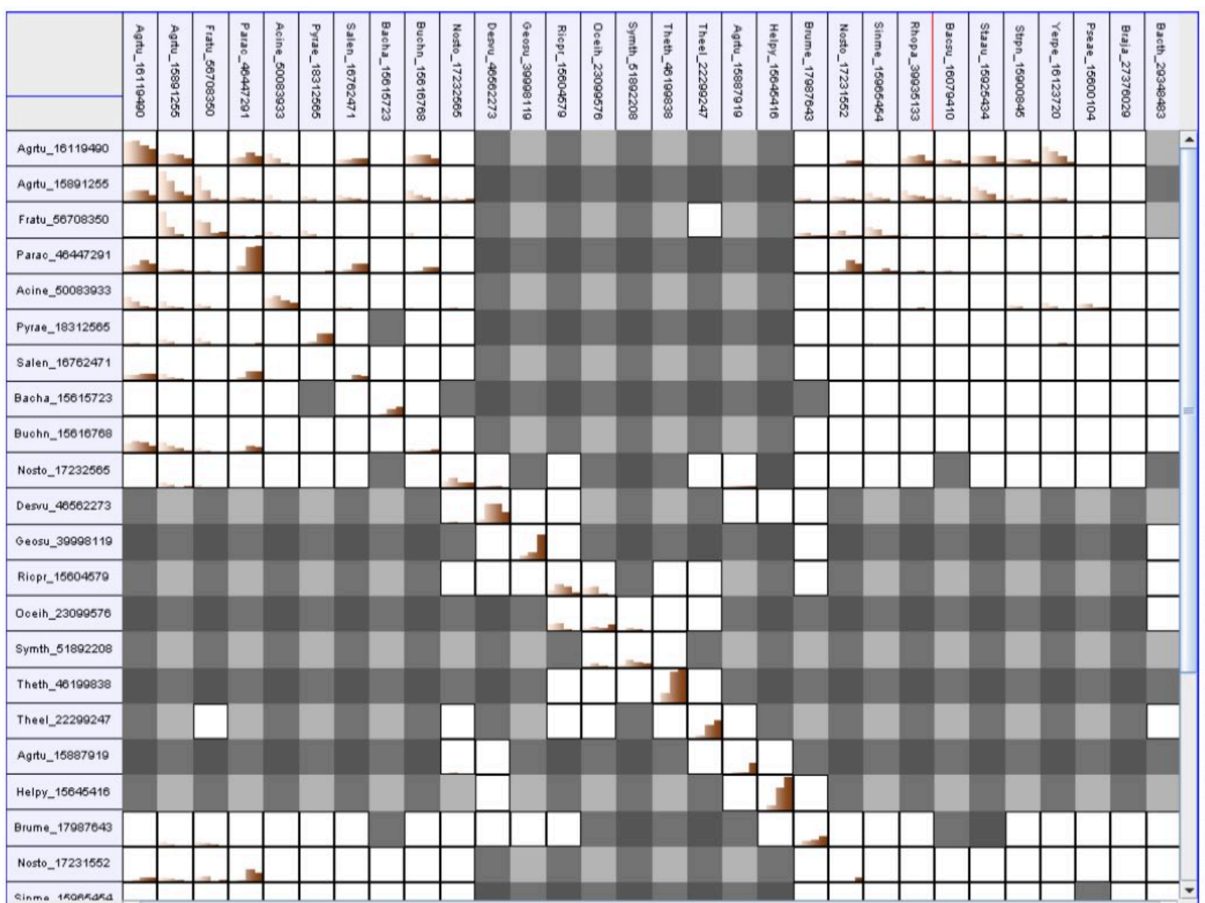
[N. Henry et al. Improving the Readability of Clustered Social Networks using Node Duplication. IEEE Transactions on Visualization and Computer Graphics, 14(6):1317-1324, 2008.]

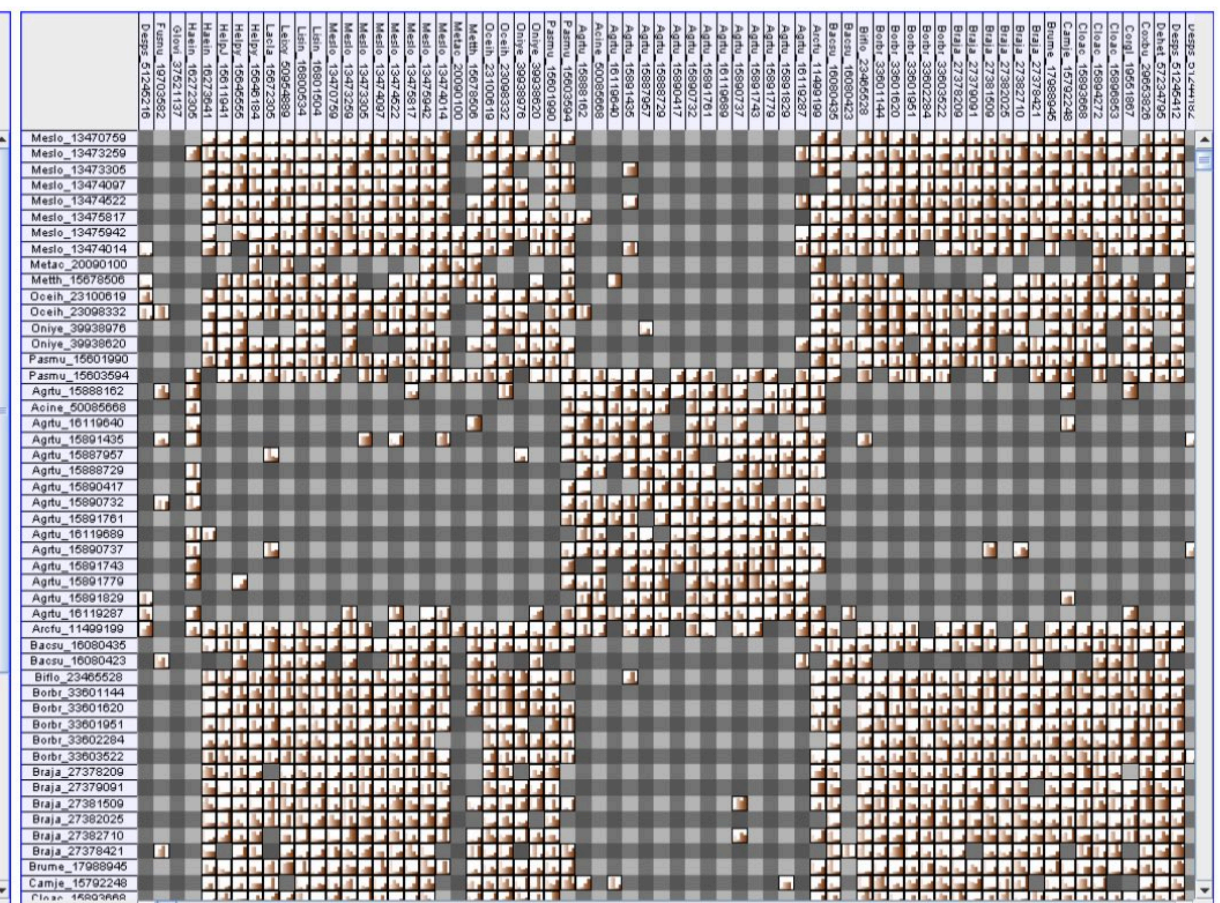
Aggregation / Multiscale Navigation

Zoomable Adjacency Matrix



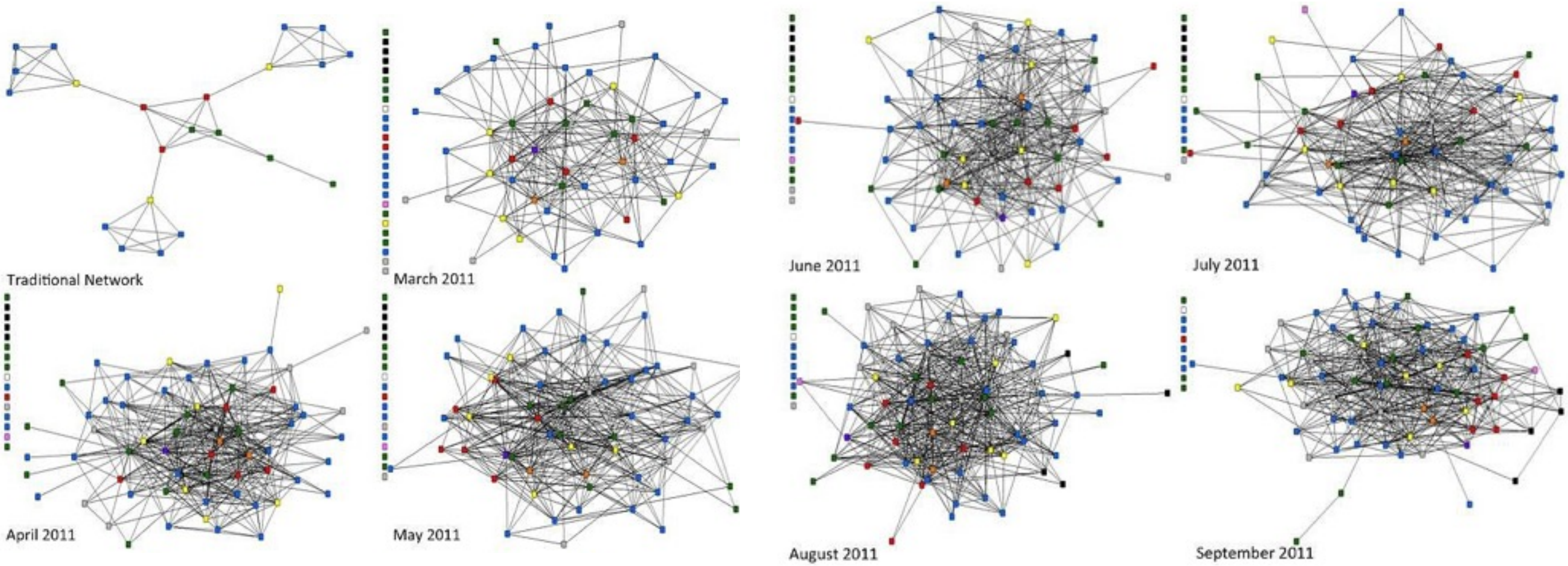
- Single color to show occupancy
- Percentage bar to show average value
- Min/max as a smooth histogram
- Min/max as a band
- Min/max as a tribox
- Tukey box to show average, min and max
- Smooth 4-sample histogram
- Binned (4) histogram



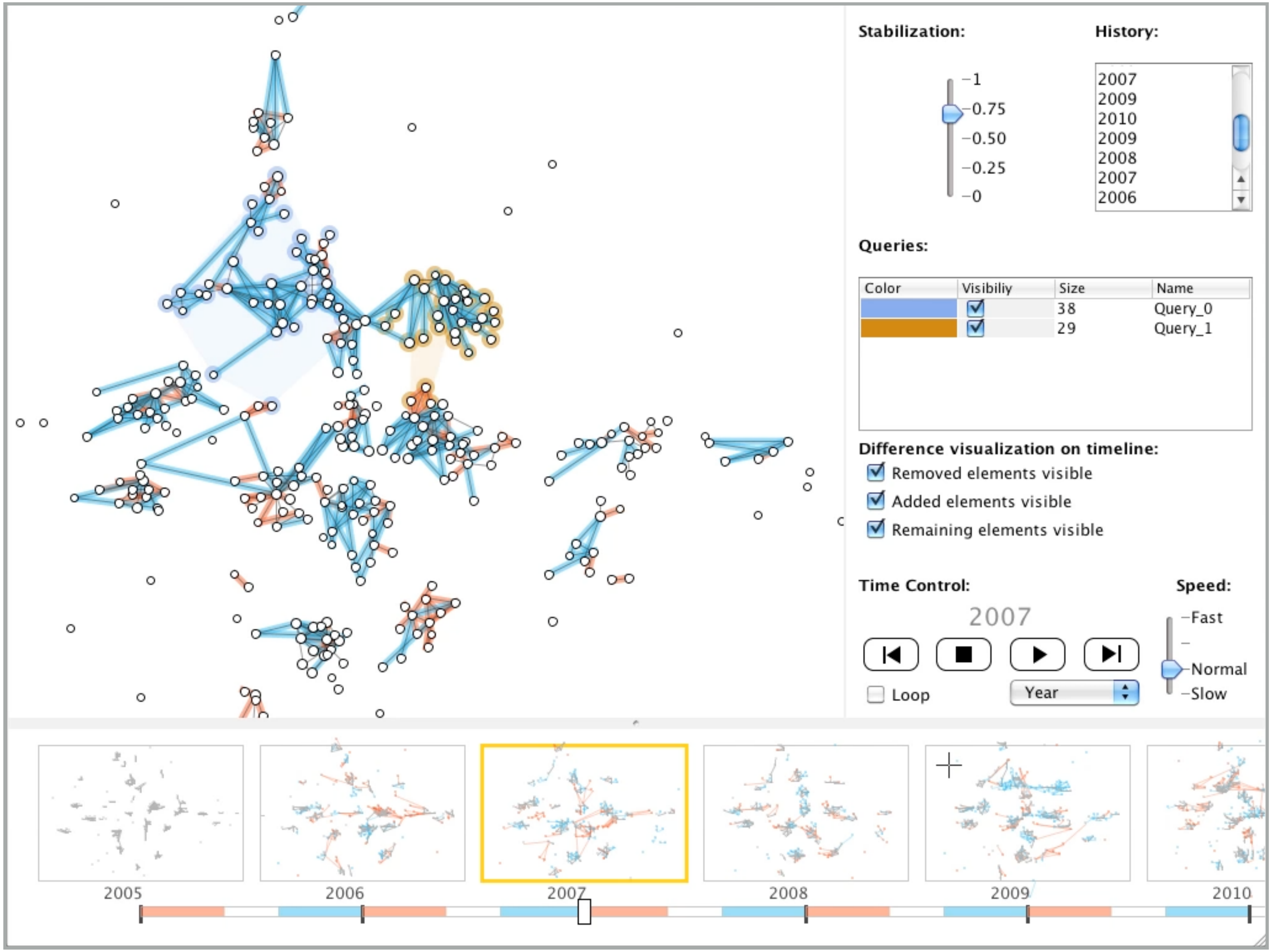


[N. Elmqvist et al.. ZAME: Interactive Large-Scale Graph Visualization. In Proceedings of the IEEE Pacific Visualization Symposium, pages 215-222, March 2008.]

Temporal Navigation in Dynamic Networks



Dynamic Networks / Animation

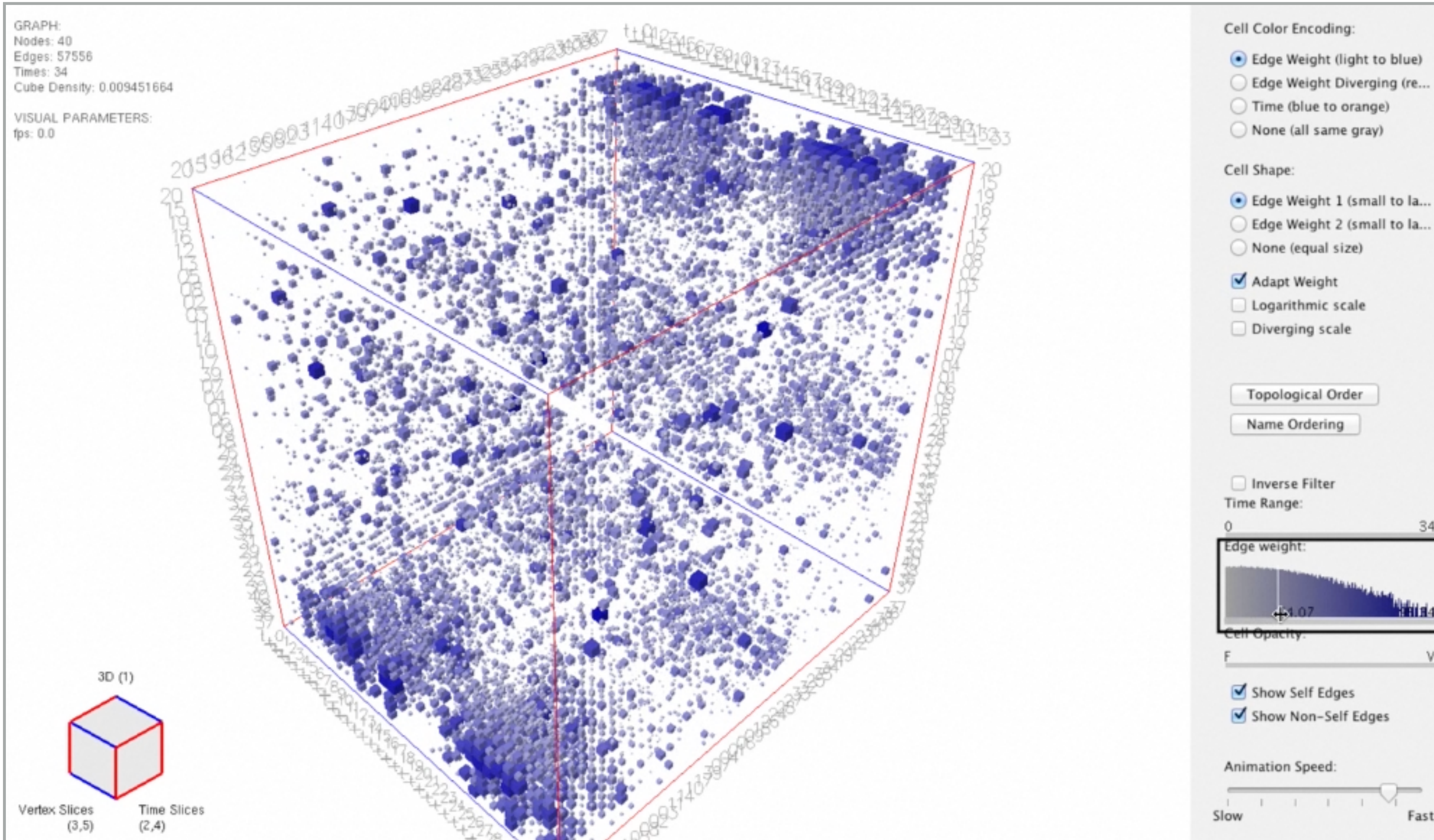


graph_diaries.mov

- Highlight changes
- Track entities
- Stabilize layout

[B. Bach et al., GraphDiaries: Animated Transitions and Temporal Navigation for Dynamic Networks, IEEE Transactions on Visualization and Computer Graphics (TVCG), Volume 20, Issue 5, pages 740-754, May 2014]

Dynamic Networks / Animated Transitions in Node-Link Diagrams



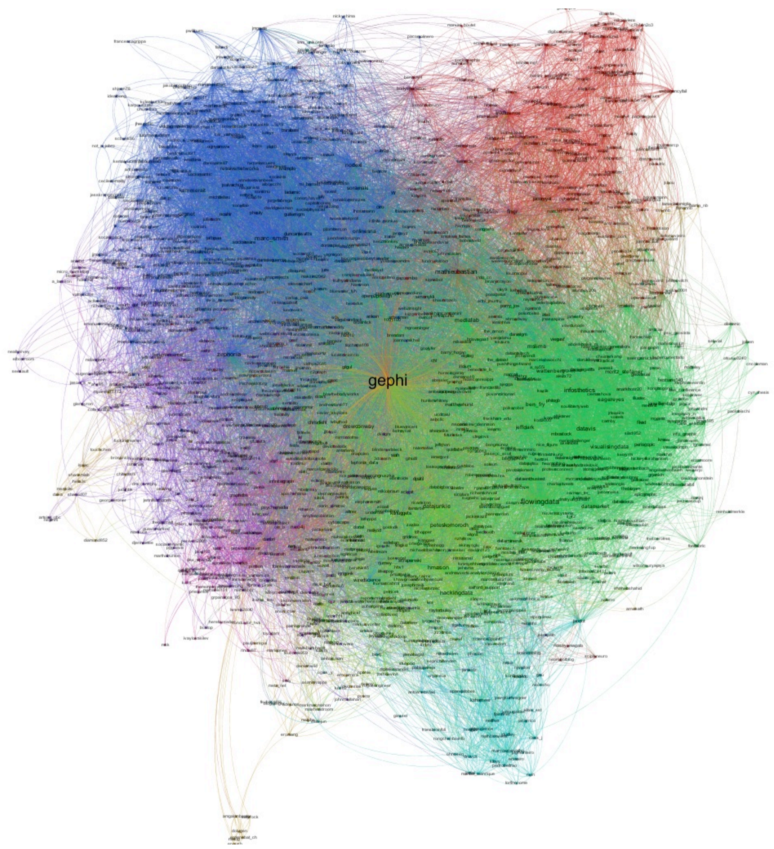
cubix.m4v

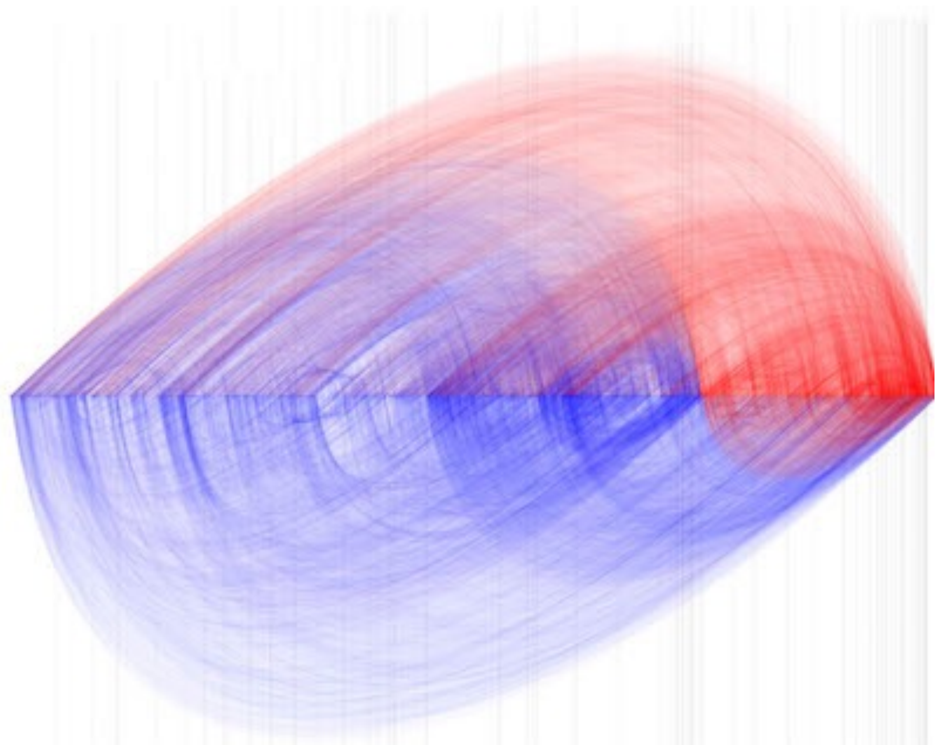
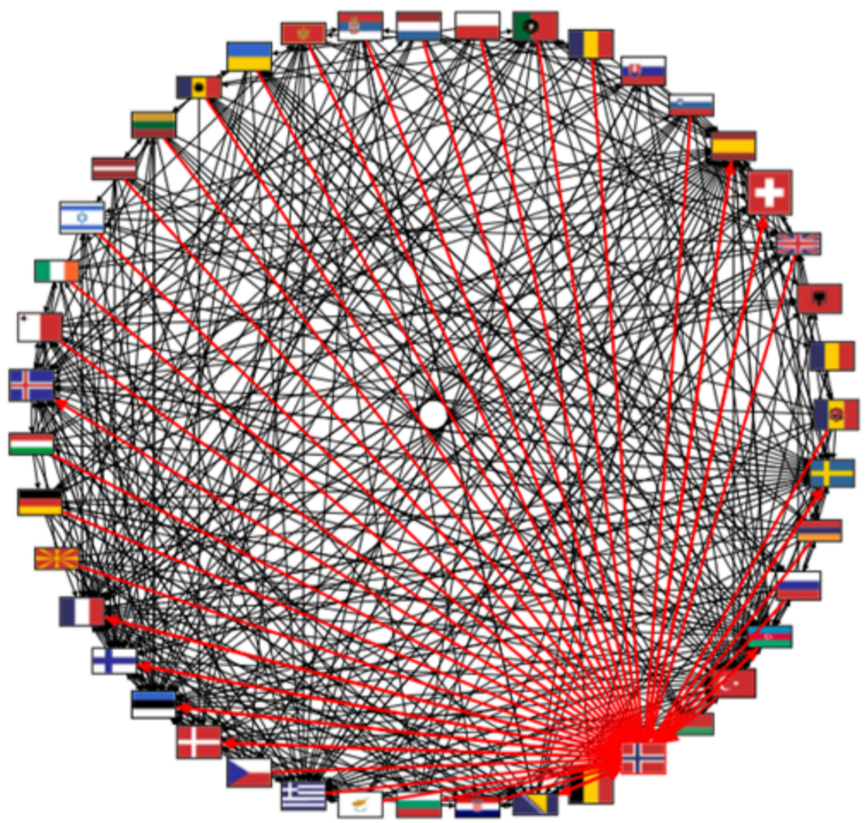
[B. Bach et al., Visualizing Dynamic Networks with Matrix Cubes, CHI '14: Proceedings of the 32nd SIGCHI conference on Human Factors in computing systems, pages 877-886, April 2014, Toronto, Canada]

Dealing with density / Interaction

The hairball hides many things:

- difficult to follow individual links
- difficult to identify clusters



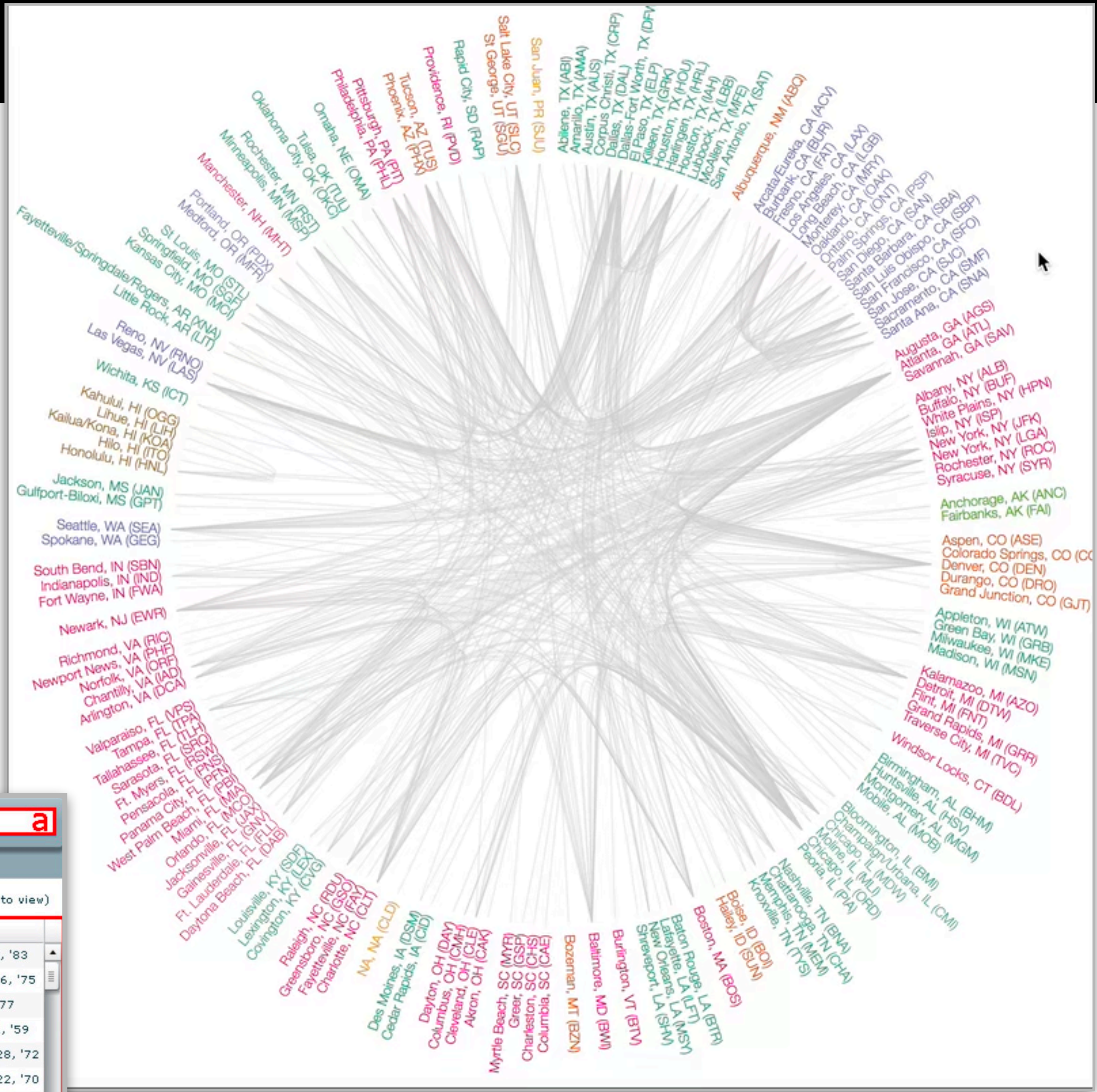



Strategies:

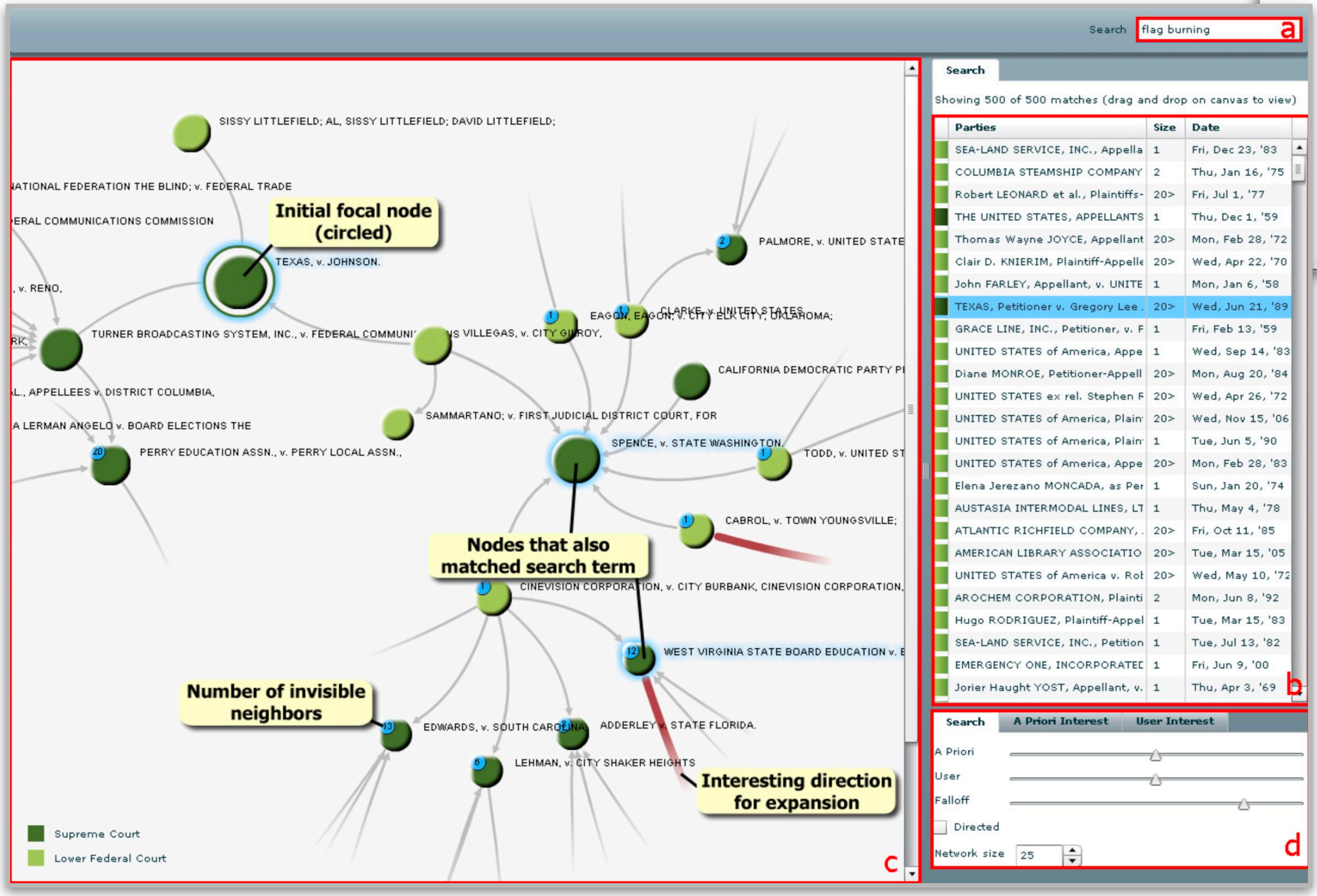
- layout & ordering
- filtering, bundling
- use color

add interaction

Interaction / Filtering & Highlighting



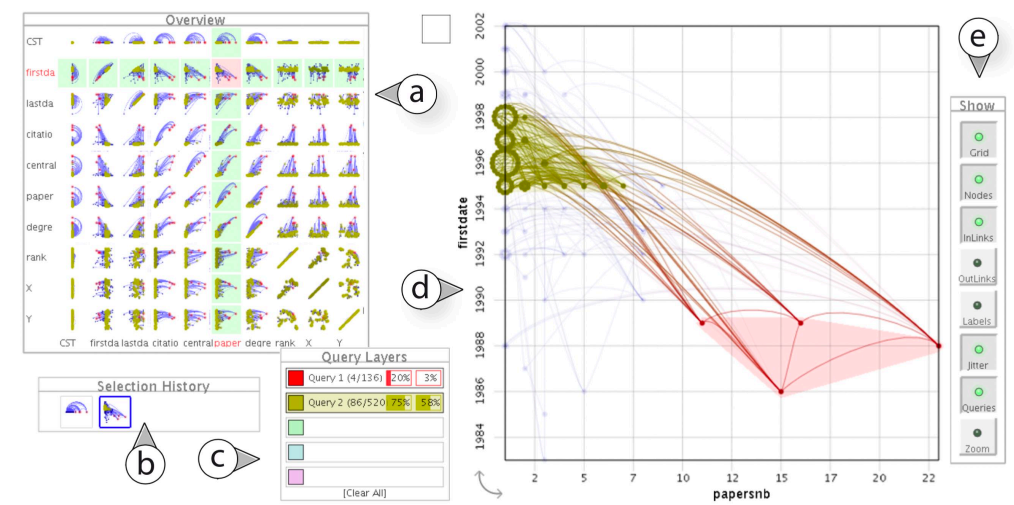
- Highlight neighborhood (possibly recursively):
- Add/remove nodes and links based on attribute values using dynamic queries (possibly using a DOI function):



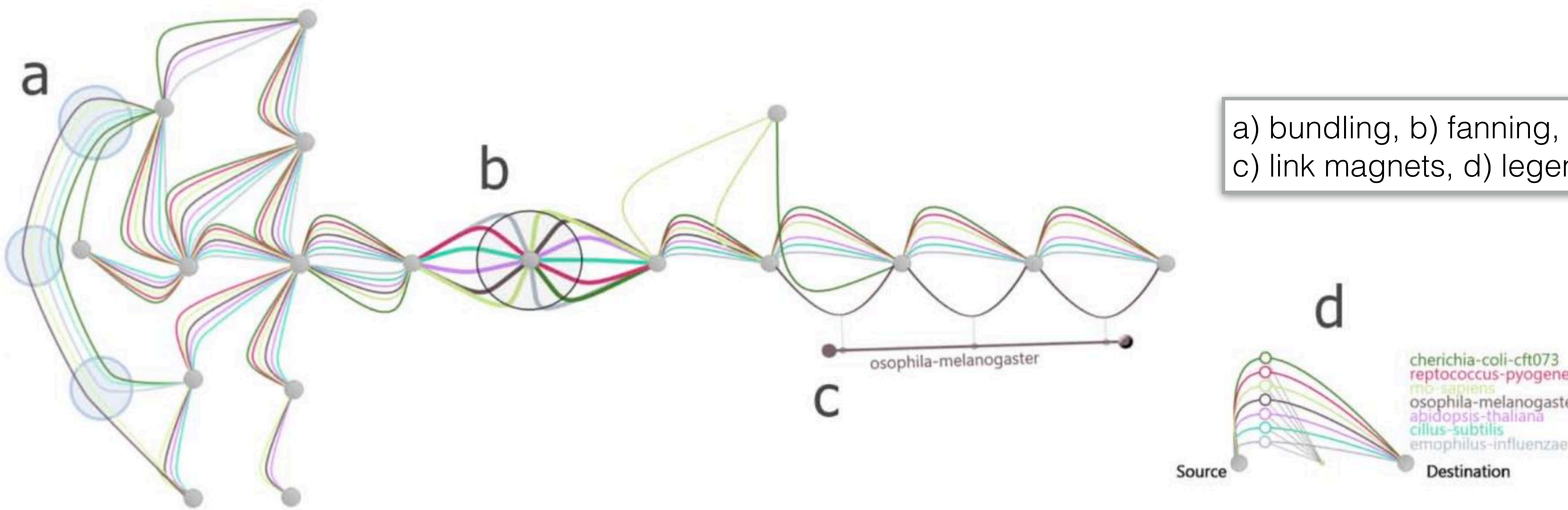
[Frank van Ham and Adam Perer. 2009. "Search, Show Context, Expand on Demand": Supporting Large Graph Exploration with Degree-of-Interest. IEEE Transactions on Visualization and Computer Graphics 15, 6, 953-960. DOI=http://dx.doi.org/10.1109/TVCG.2009.108]

Interaction / Layout & Ordering, Bundling, *etc.*

- Interactive layout manipulation
  - Dragging nodes
  - Reordering / mapping attribute to node position



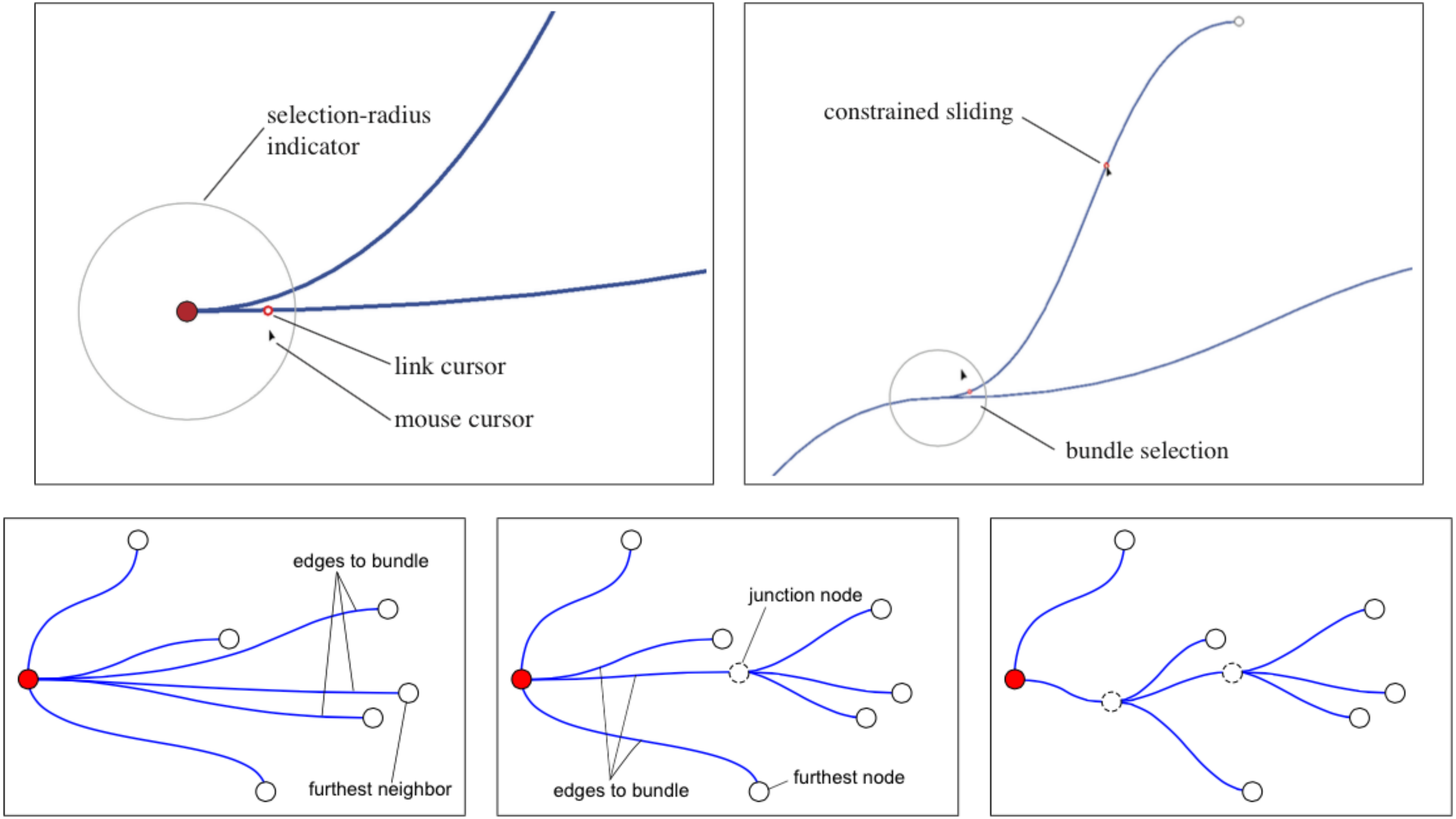
- Interactive bundling and fanning



a) bundling, b) fanning,
c) link magnets, d) legends

[Henry Riche et al. 2012. Exploring the design space of interactive link curvature in network diagrams. In Proceedings of the International Working Conference on Advanced Visual Interfaces (AVI '12), ACM, New York, NY, USA, 506-513.]

Interaction / Topology-aware Navigation



toponav.mov

[Tomer Moscovich et al. 2009. Topology-aware navigation in large networks. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09). ACM, New York, NY, USA, 2319-2328.]

Item Reduction Strategies

- Aggregate: merging items.

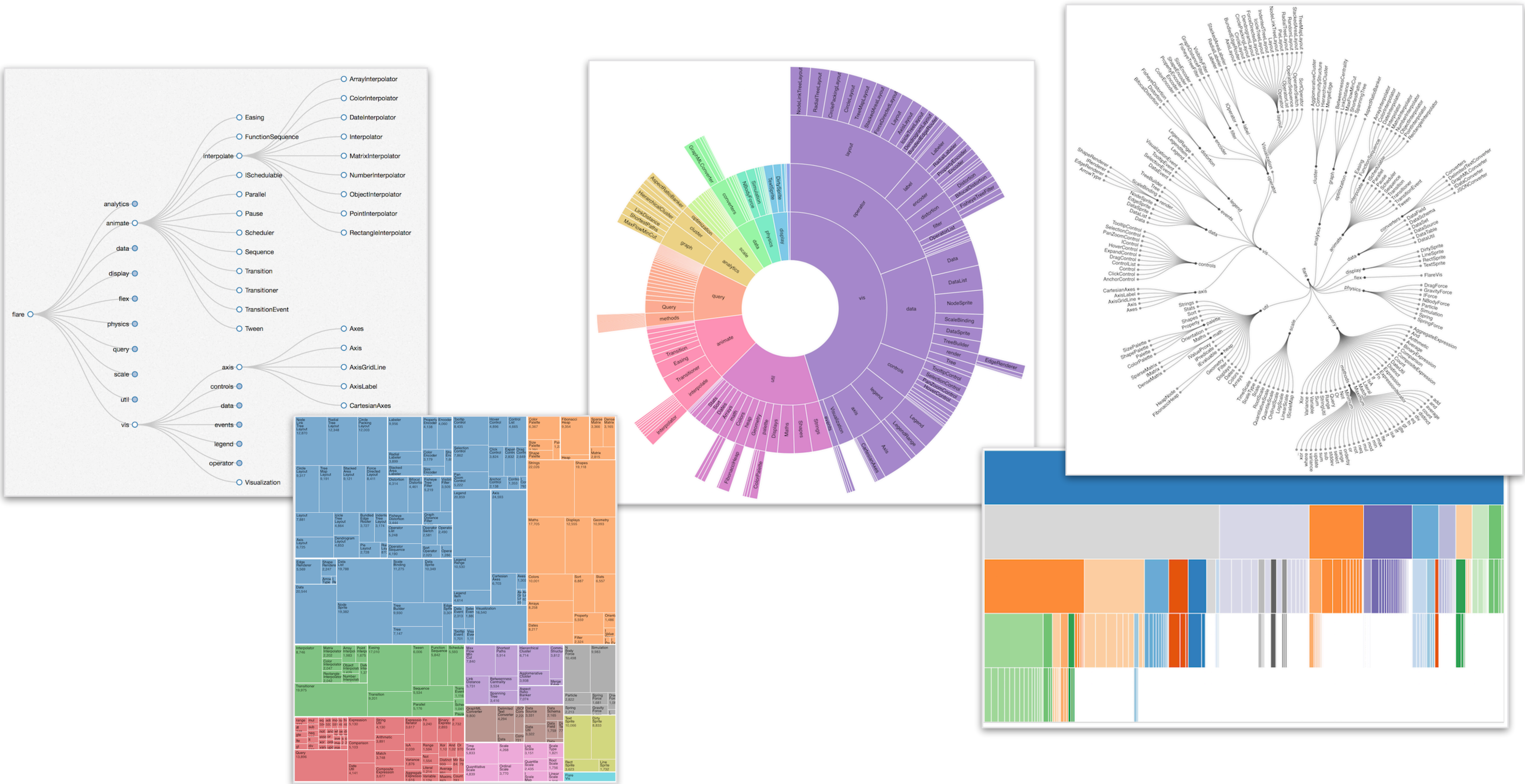
- Filter: removing items.

Multi-scale navigation, later in this session

- Navigate: removing items, but in a different way.
  Can be seen as a way of filtering by moving the viewpoint.

[Illustrated using Gephi snapshots]

Trees


flare
analytics
animate
data
display
flex
physics
query
scale
util
vis
Easing
FunctionSequence
interpolate
ISchedulable
Parallel
Pause
Scheduler
Sequence
Transition
Transitioner
TransitionEvent
Tween
ArrayInterpolator
ColorInterpolator
DateInterpolator
Interpolator
MatrixInterpolator
NumberInterpolator
ObjectInterpolator
PointInterpolator
RectangleInterpolator
axis
controls
data
events
legend
operator
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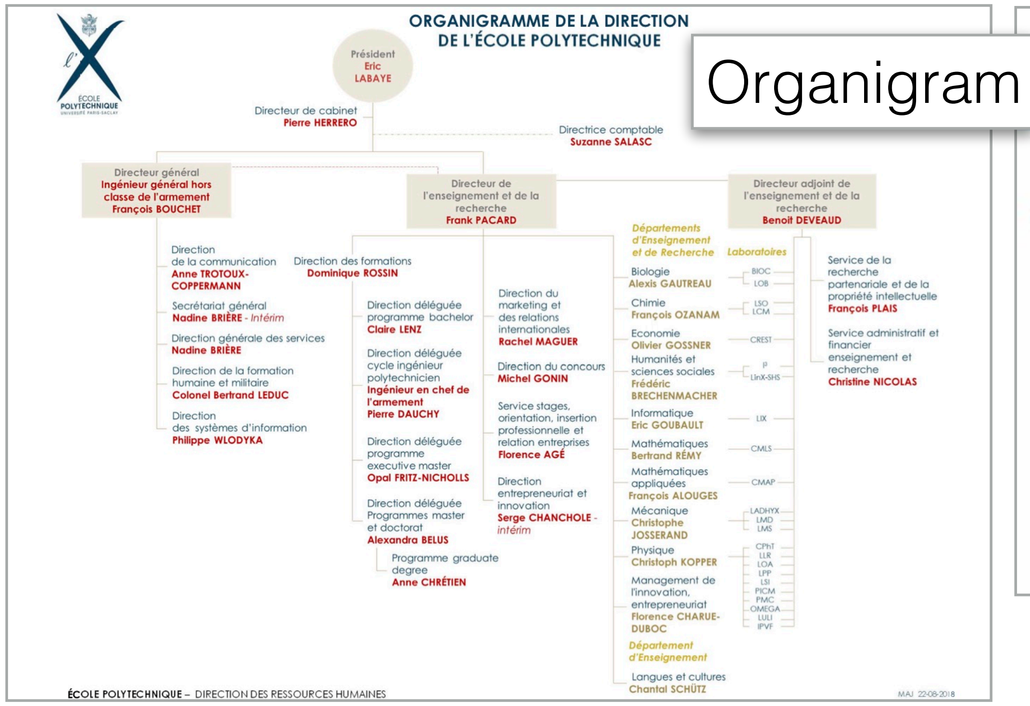
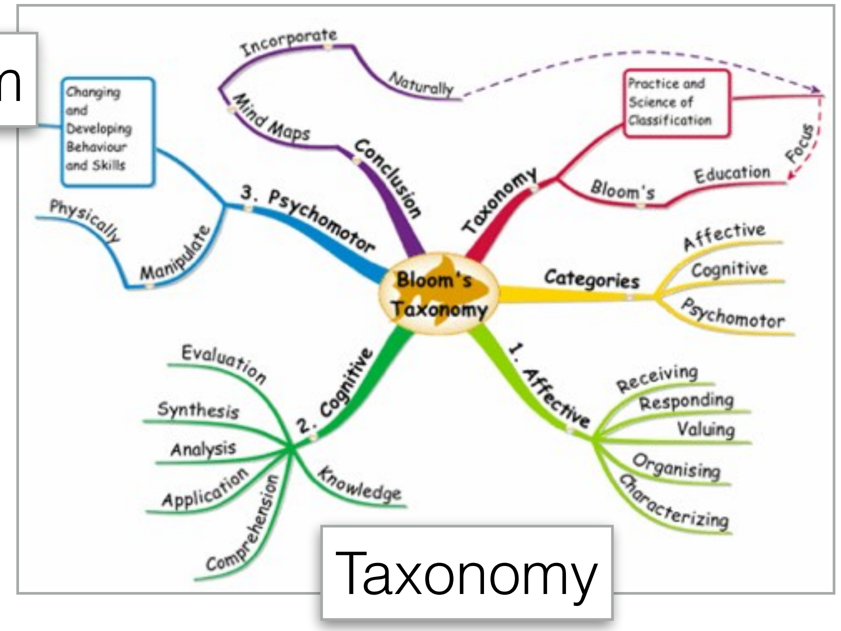
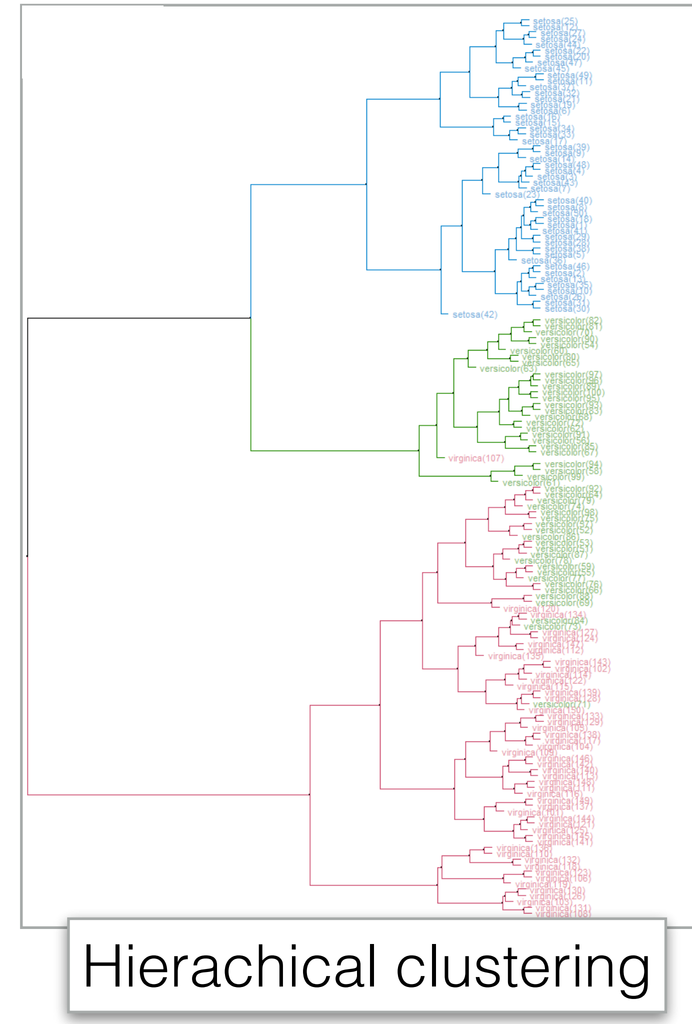
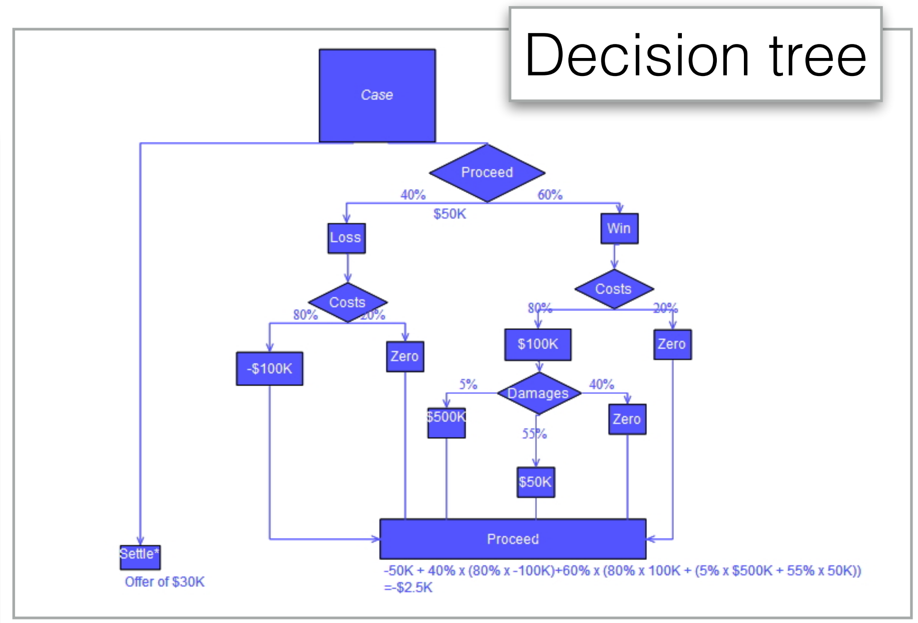
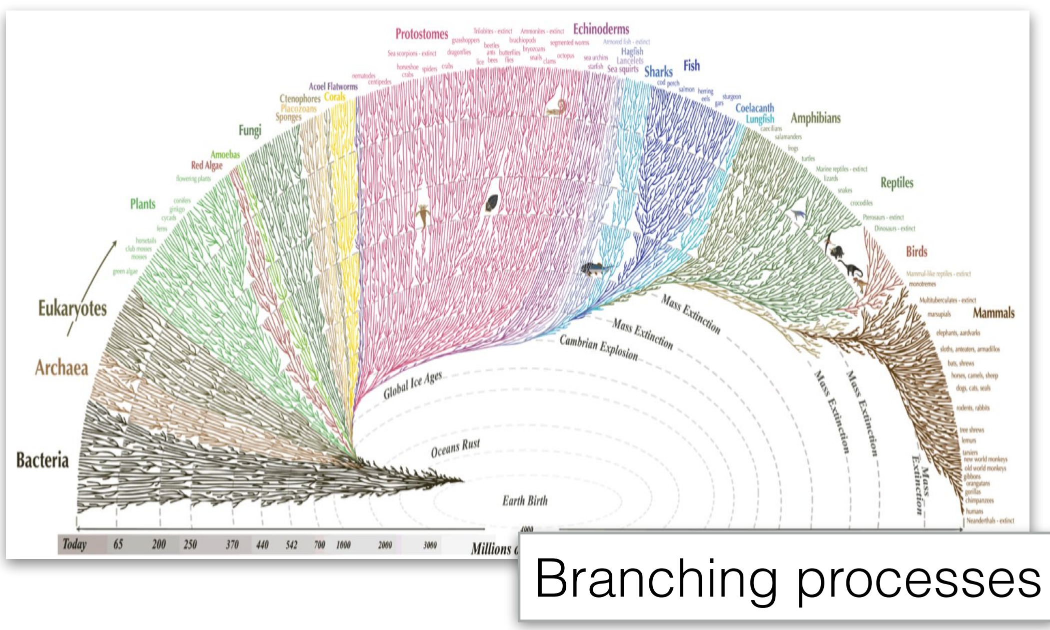
Axes
Axis
AxisGridLine
AxisLabel
CartesianAxes

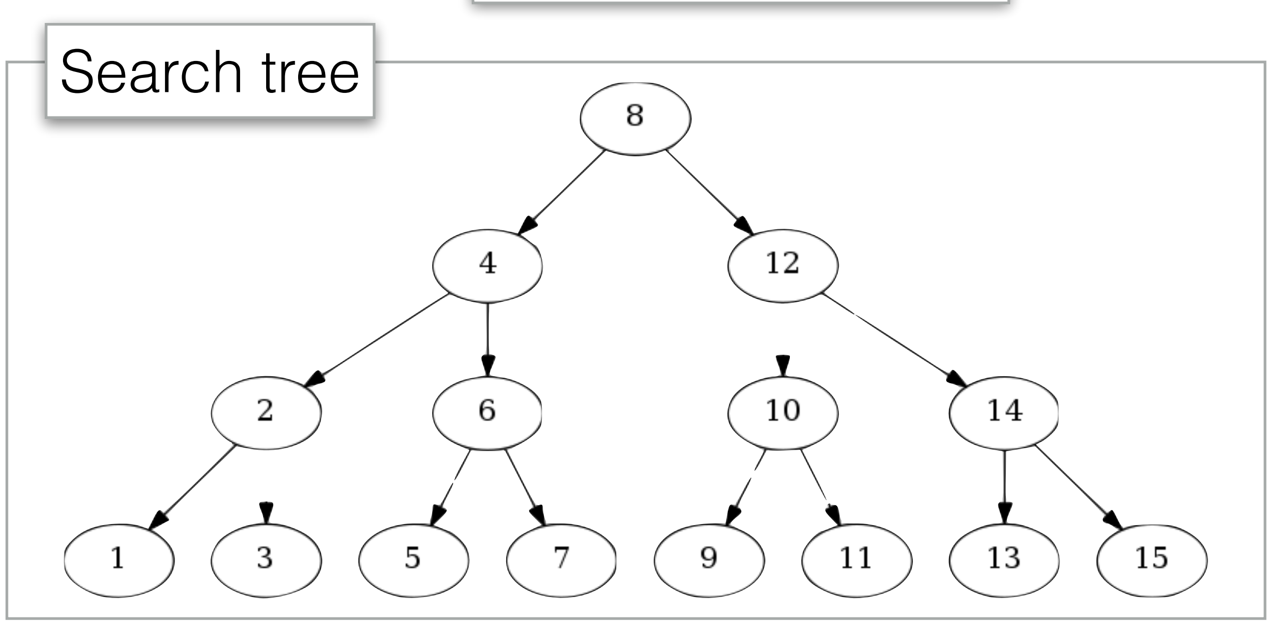

ORGANIGRAMME DE LA DIRECTION
DE L'ÉCOLE POLYTECHNIQUE
Organigram
ÉCOLE POLYTECHNIQUE – DIRECTION DES RESSOURCES HUMAINES

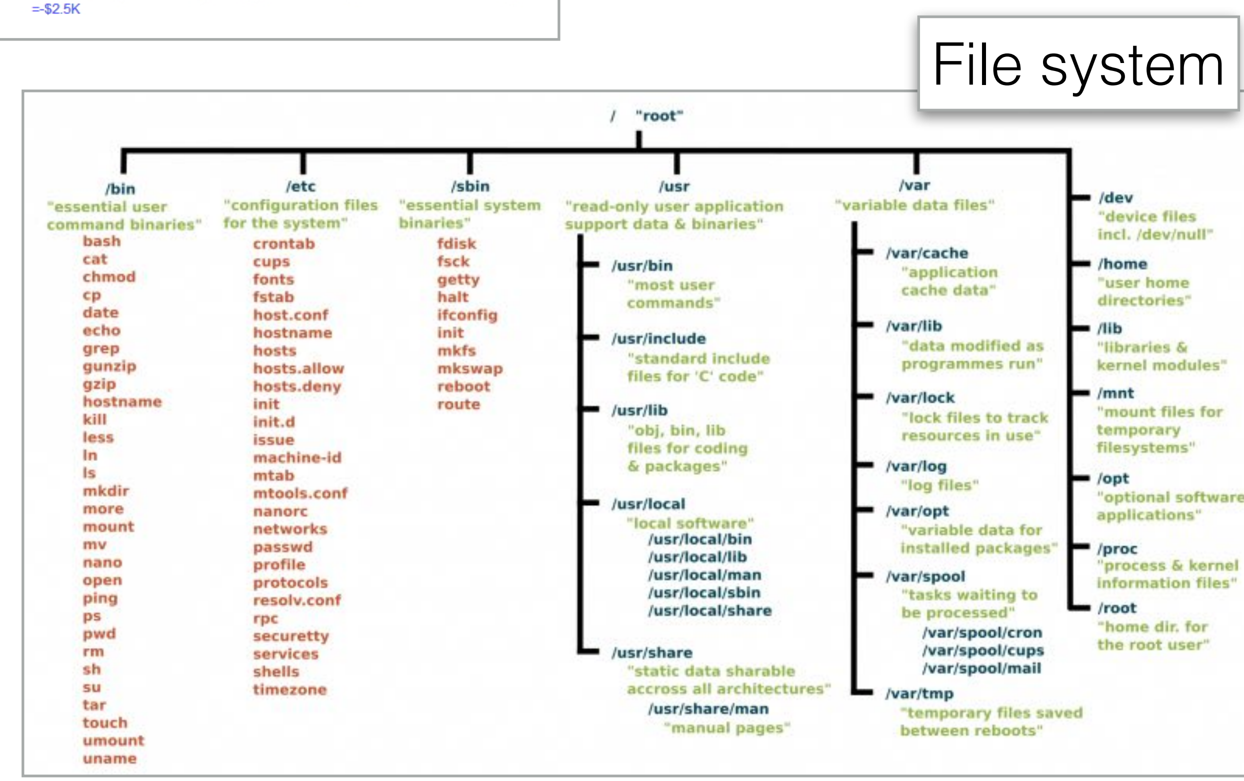

Bloom's Taxonomy
Taxonomy
Incorporate
Naturally
Mind Maps
Conclusion
Practice and Science of Classification
Bloom's
Education
Focus
Changing and Developing Behaviour and Skills
3. Psychomotor
Physically
Manipulate
Categories
Affective
Cognitive
Psychomotor
Evaluation
Synthesis
Analysis
Application
Comprehension
2. Cognitive
Knowledge
1. Affective
Receiving
Responding
Valuing
Organising
Characterizing


Hierachical clustering


Decision tree
Case
Proceed
40%
60%
$50K
Loss
Win
Costs
Costs
80%
20%
80%
20%
-$100K
Zero
$100K
Zero
5%
Damages
40%
$500K
55%
Zero
$50K
Proceed
Settle*
Offer of $30K
-50K + 40% x (80% x -100K)+60% x (80% x 100K + (5% x $500K + 55% x 50K))
=-$2.5K

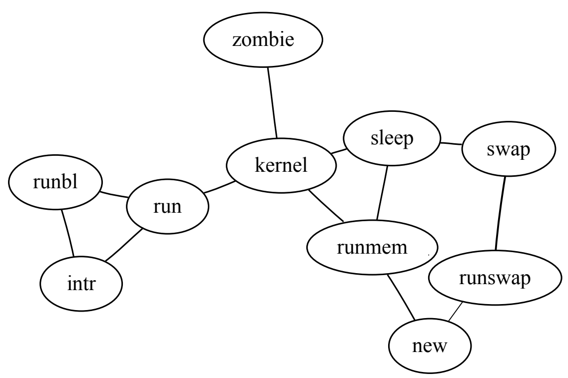

Branching processes
Protostomes
Echinoderms
Sharks
Fish
Amphibians
Reptiles
Birds
Mammals
Plants
Fungi
Eukaryotes
Archaea
Bacteria
Cambrian Explosion
Mass Extinction
Global Ice Ages
Oceans Rust
Earth Birth
Today
Millions

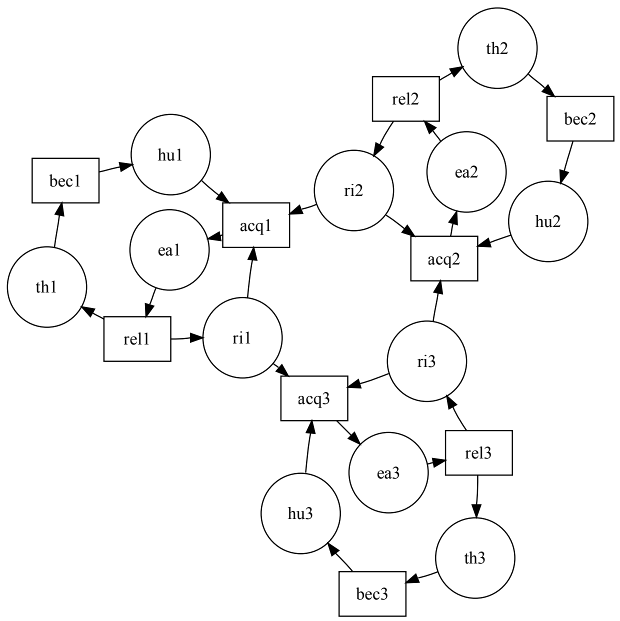

Search tree
8
4
12
2
6
10
14
1
3
5
7
9
11
13
15


File system
/ "root"
/bin
"essential user command binaries"
/etc
"configuration files for the system"
/sbin
"essential system binaries"
/usr
"read-only user application support data & binaries"
/var
"variable data files"
/dev
"device files incl. /dev/null"
/home
"user home directories"
/lib
"libraries & kernel modules"
/mnt
"mount files for temporary filesystems"
/opt
"optional software applications"
/proc
"process & kernel information files"
/root
"home dir. for the root user"
/usr/bin
"most user commands"
/usr/include
"standard include files for 'C' code"
/usr/lib
"obj, bin, lib files for coding & packages"
/usr/local
"local software"
/usr/share
"static data sharable accross all architectures"
/var/cache
"application cache data"
/var/lib
"data modified as programmes run"
/var/lock
"lock files to track resources in use"
/var/log
"log files"
/var/opt
"variable data for installed packages"
/var/spool
"tasks waiting to be processed"
/var/tmp
"temporary files saved between reboots"

Definitions: graphs (reminder)

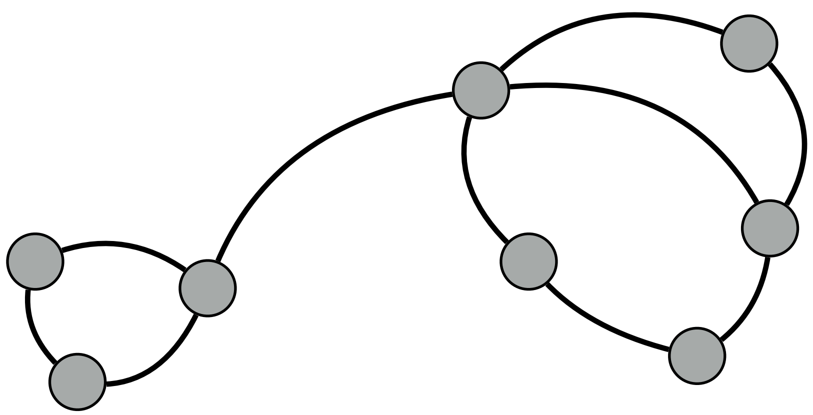
Directed *vs.* undirected



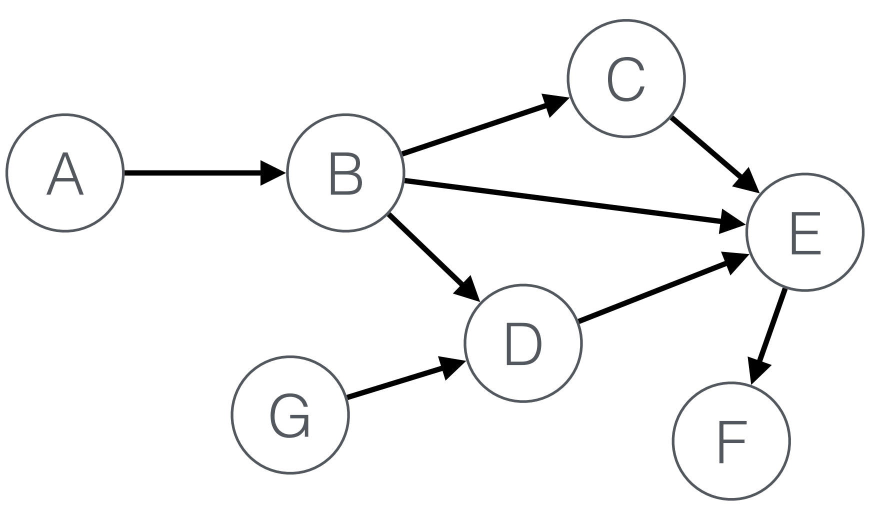


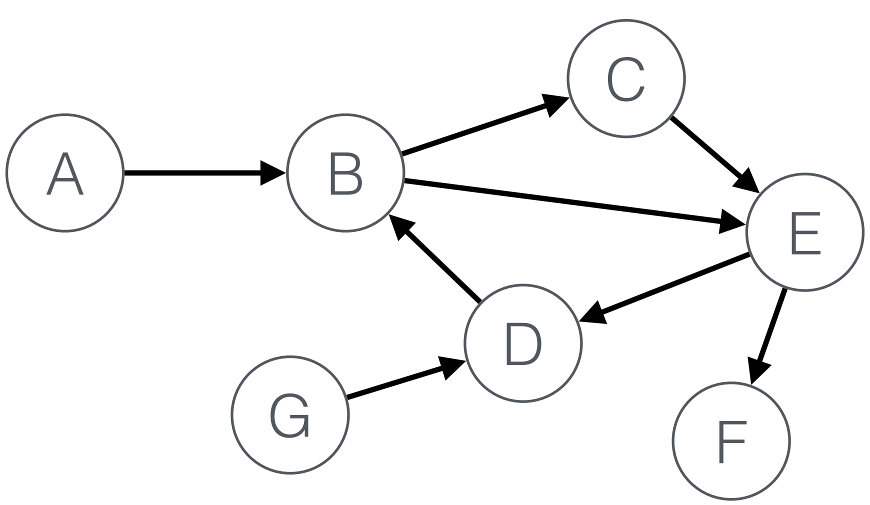
$v_i v_j$ $\overrightarrow{v_i v_j}$

Connected *vs.* disconnected



Acyclic *vs.* cyclic

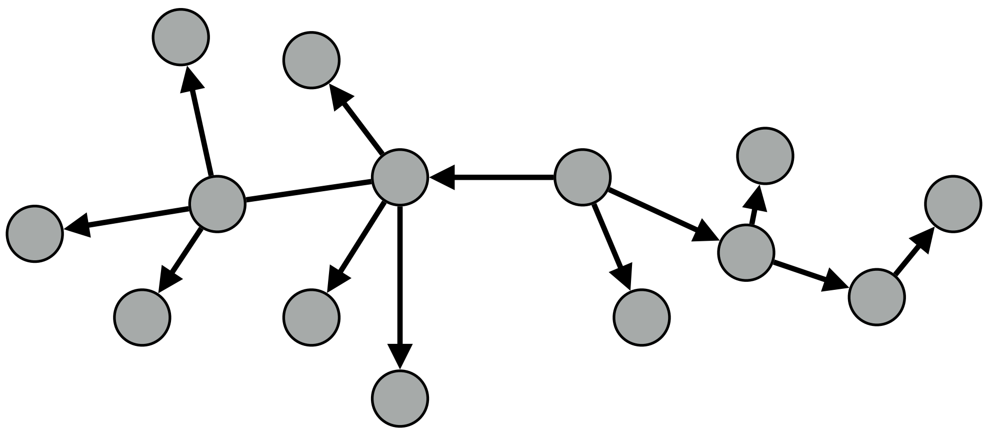




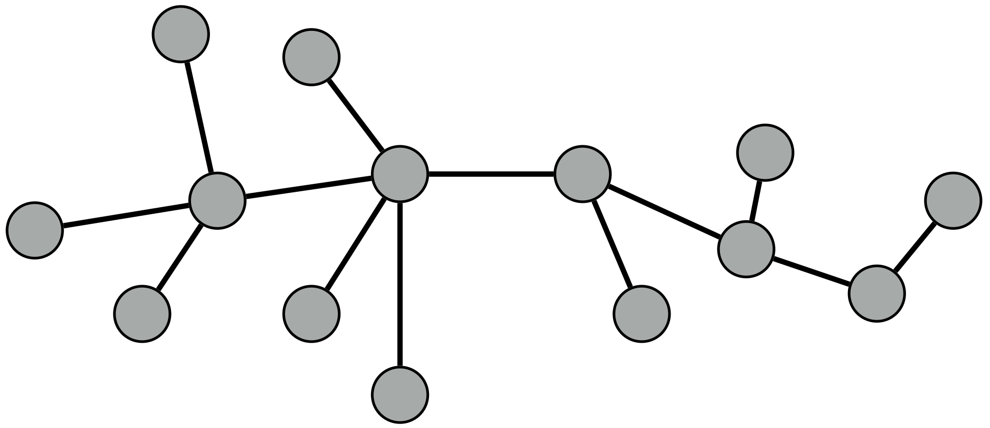
[Examples from http://graphviz.org/gallery/]

Definitions: trees

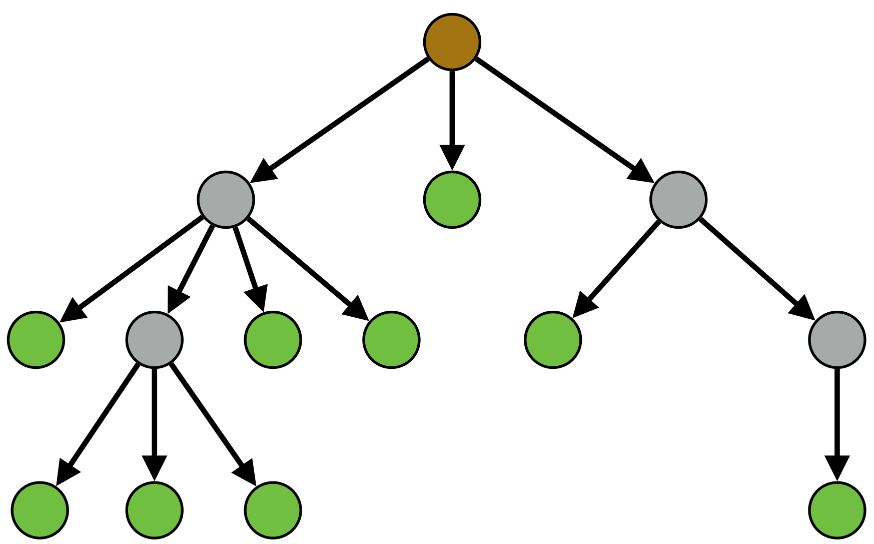
- A tree is a directed, connected, acyclic graph



- An undirected tree is an undirected, connected, acyclic graph

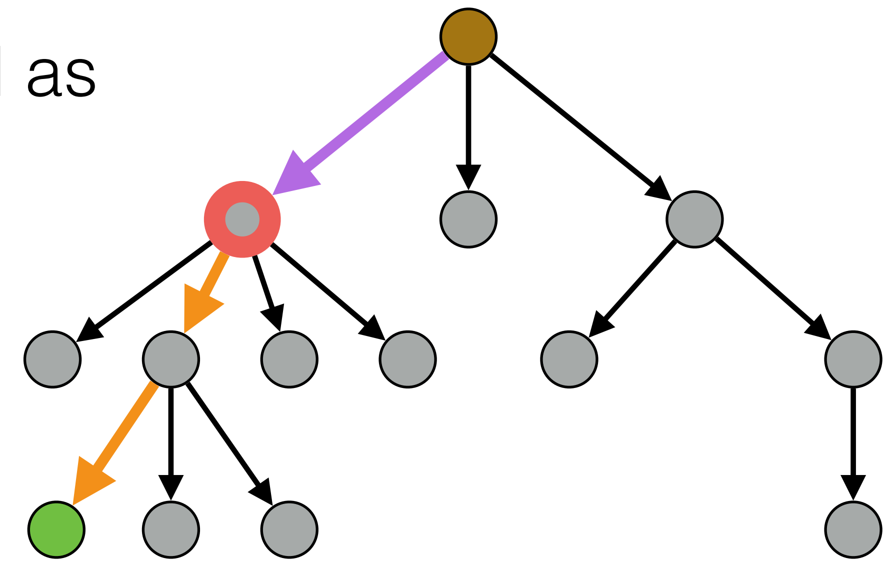


- Trees only define parent-child relations

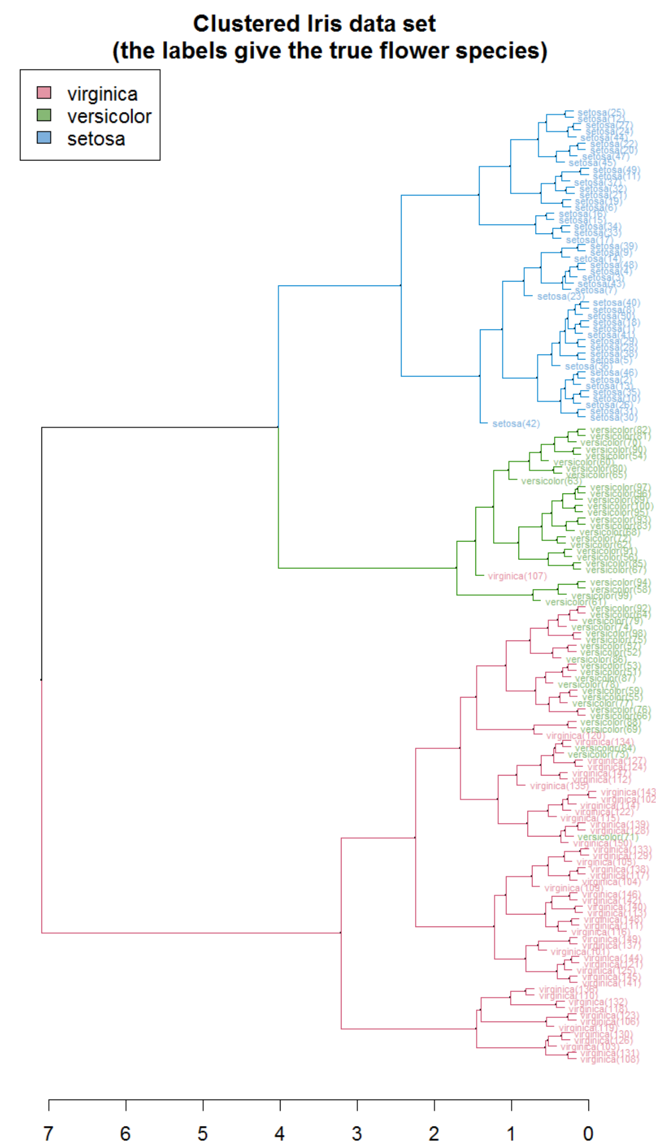


- Trees have one **root** node, and multiple **leaf** nodes
- A tree with *n* vertices has *n-1* edges.

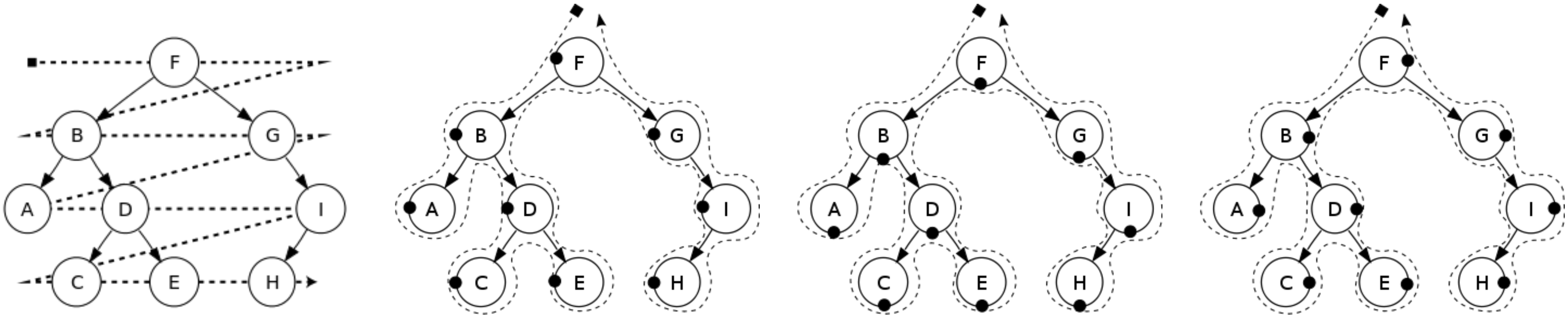
Definitions



- Rooted *vs.* free tree: one vertex has been designated as the root
- Height *vs.* depth of a vertex:
  - h = length of **longest downward path to a leaf**
  - d = length of **path to root**
- Forest: disconnected direct graphs, all connected components are trees
- Polytree: DAG whose underlying undirected graph is a tree
- *k*-ary tree: each vertex has at most *k* children
  binary tree, ternary tree, …
  - dendogram
    similarity-based clustering



Definitions: tree traversal



F B G A D I C E H F B A D C E G I H A B C D E F G H I A C E D B H I G F

(illustrated on a binary tree)

- Breadth-first: level order

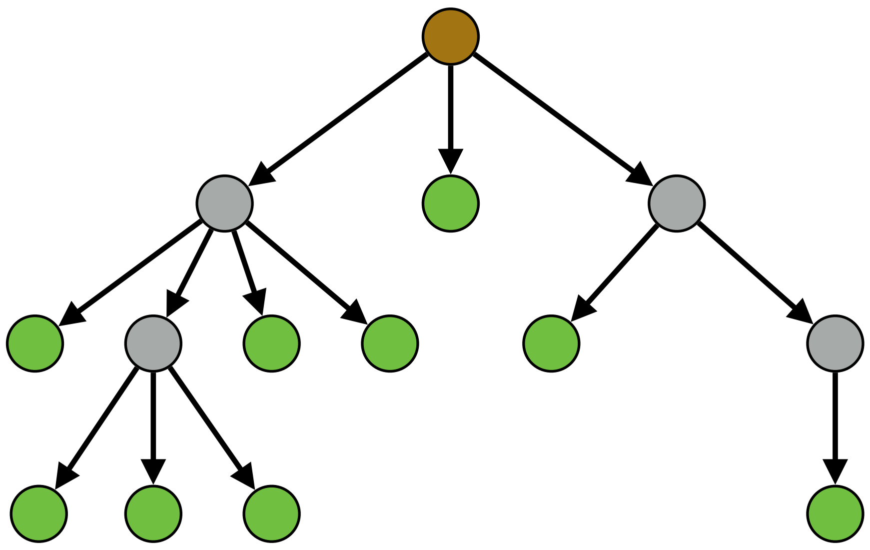
- Depth-first:
  - pre-order: process current, traverse left branch, traverse right branch
  - in-order: traverse left branch, process current, traverse right branch
  - post-order: traverse left branch, traverse right branch, process current

[Image source: https://en.wikipedia.org/wiki/Tree_traversal]

Tree Visualization - Tasks

graphs

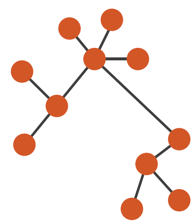
trees

Low-level tasks	**Higher-level tasks**	
tend to involve few elements; tend to involve little human judgment.	tend to involve more elements; tend to involve more human judgment.	
Examples		
How many neighbors does v_i have?	Which nodes are important?	Which branch is deepest?
Are v_i and v_j connected?	Are there clusters? Where are they? Other interesting patterns?	How wide is the tree?
How are they connected? (type, strength, distance)	How are they connected? (correlate attributes and topology)	How long is the path between n_i and n_j ?
How dense is the graph?	How does the network evolve over time?	Which node has the most leaves?

Not only about the topology, can also involve attributes

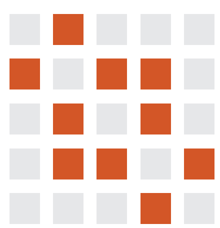
Node–Link Diagrams
Connection Marks

✔ NETWORKS ✔ TREES



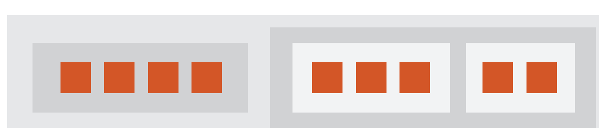
Adjacency Matrix
Derived Table

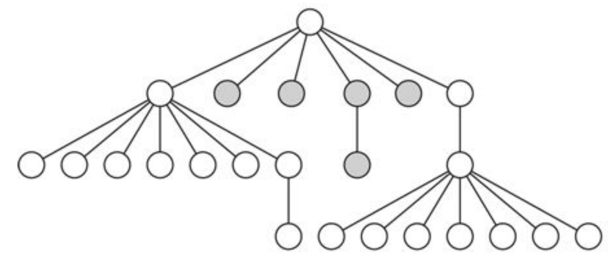
✔ NETWORKS ✔ TREES

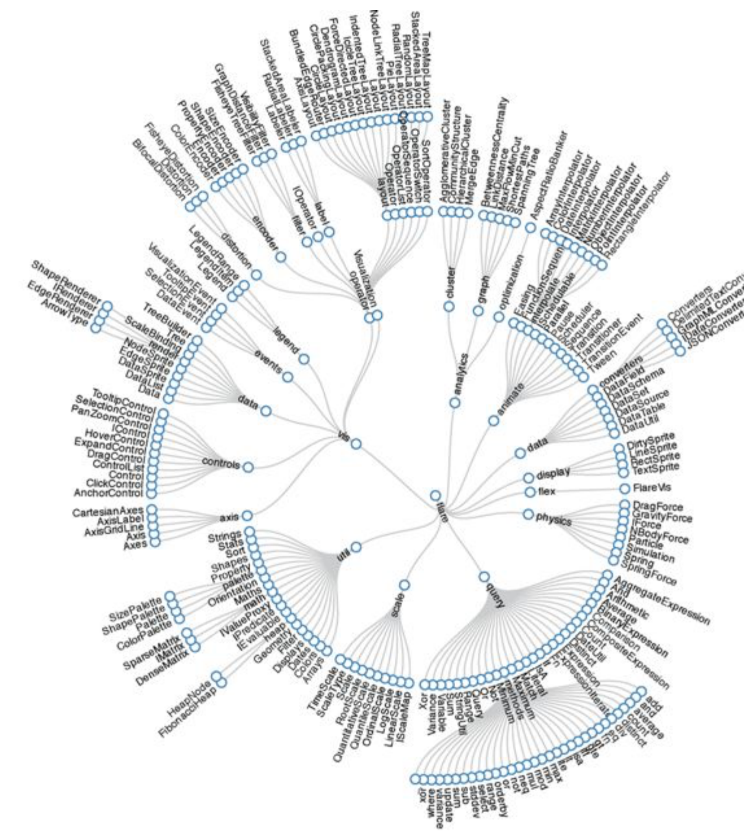


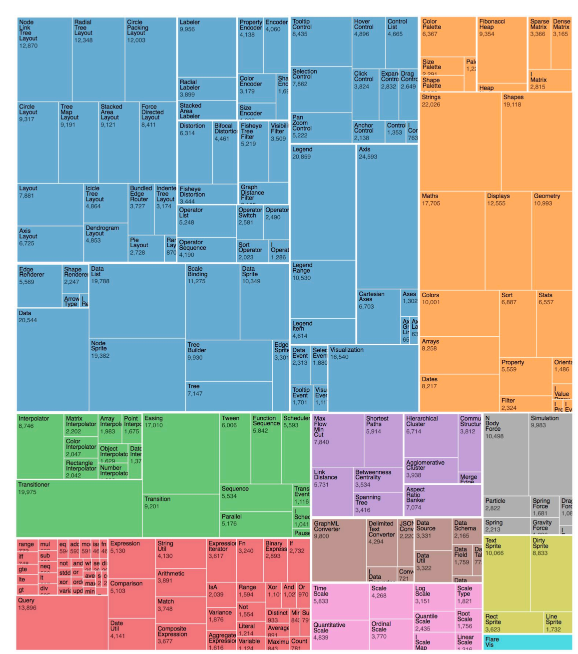
Enclosure
Containment Marks

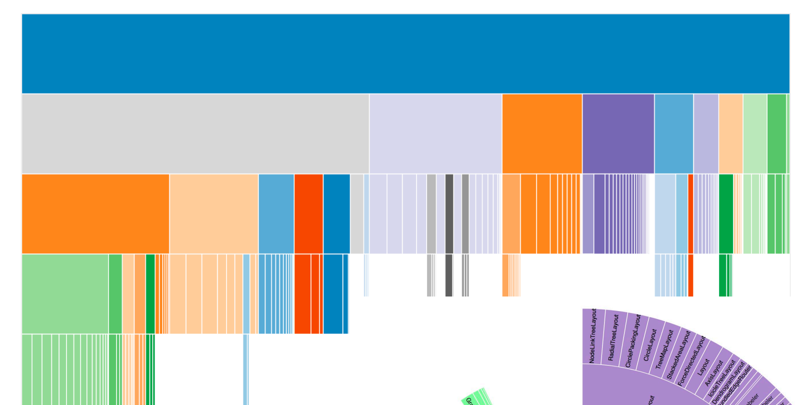
✘ NETWORKS ✔ TREES

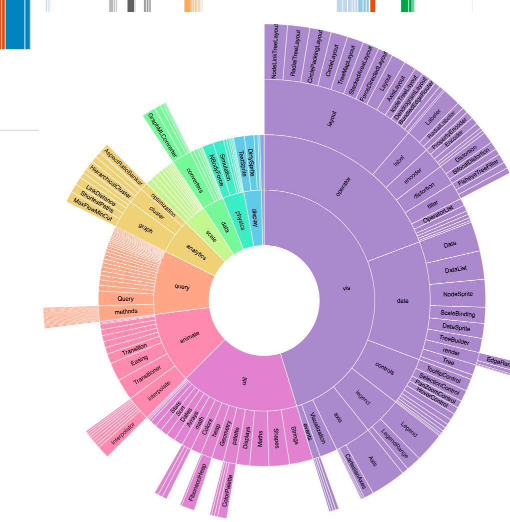












[Image source: Visualization Analysis and Design. Tamara Munzner, with illustrations by Eamonn Maguire. A K Peters Visualization Series, CRC Press, 2014]

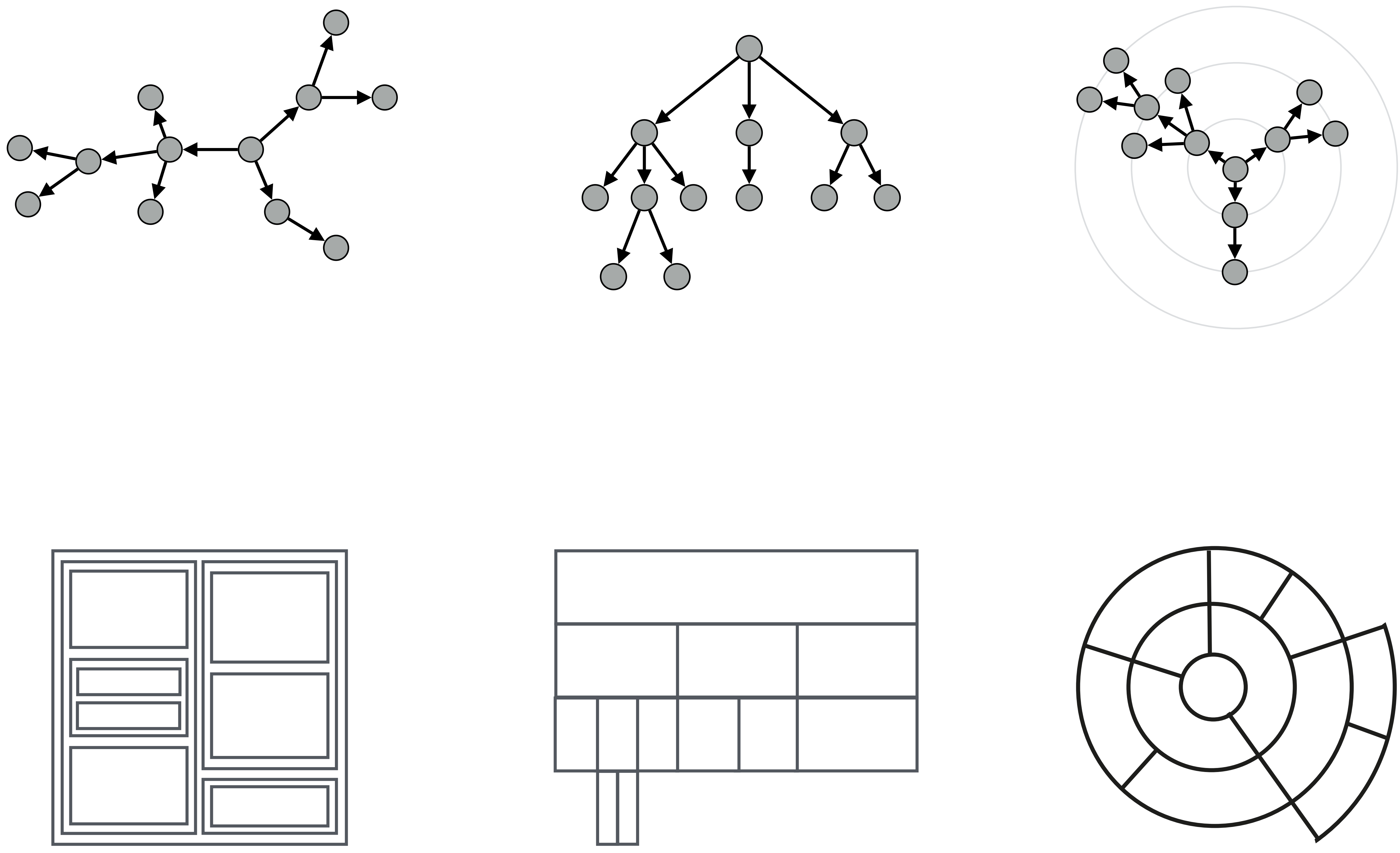
[Image source: d3js.org]

Tree Visualization - Layout

Free | Axis-parallel | Radial

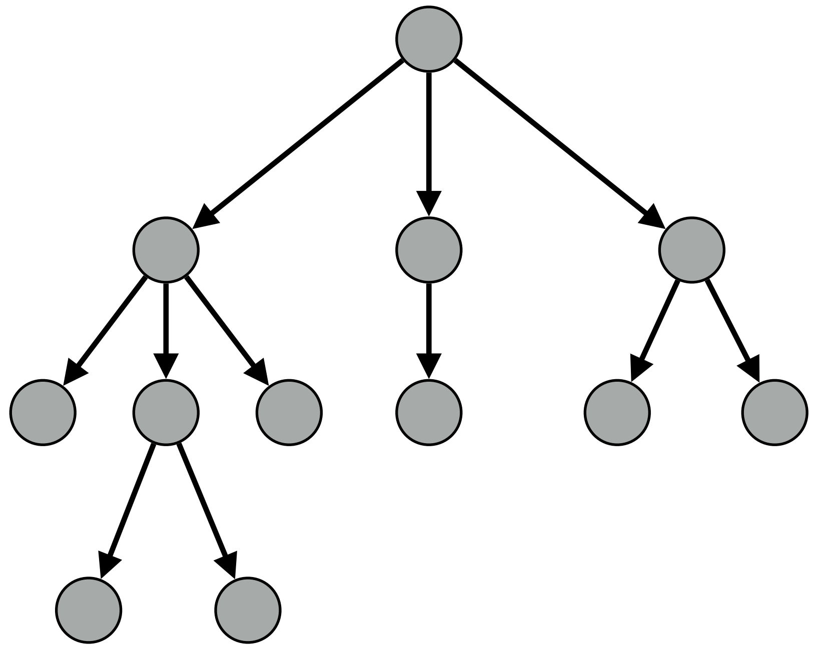
Node-link diagram

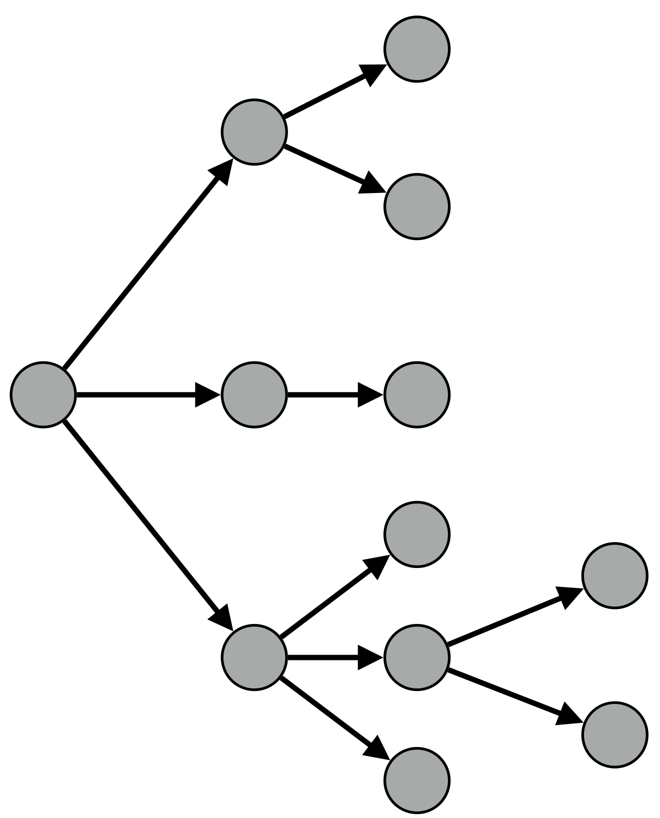
Space-filling (containment)



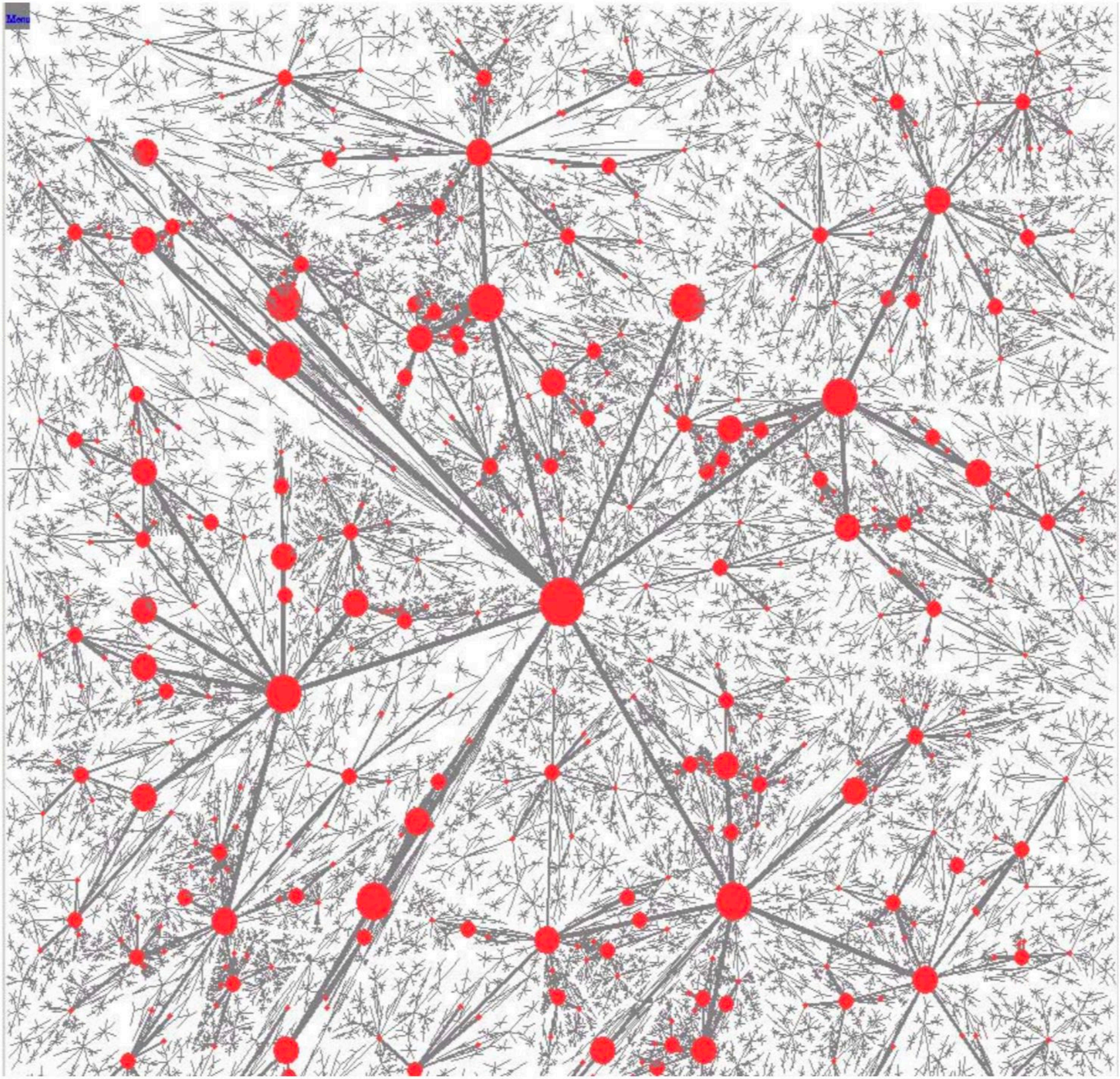
Node-link / Axis-parallel

- Familiar
- Clear layers
- Easy to answer questions related to:
    - vertex depth
    - layers
    - paths
- Consumes much screen real-estate





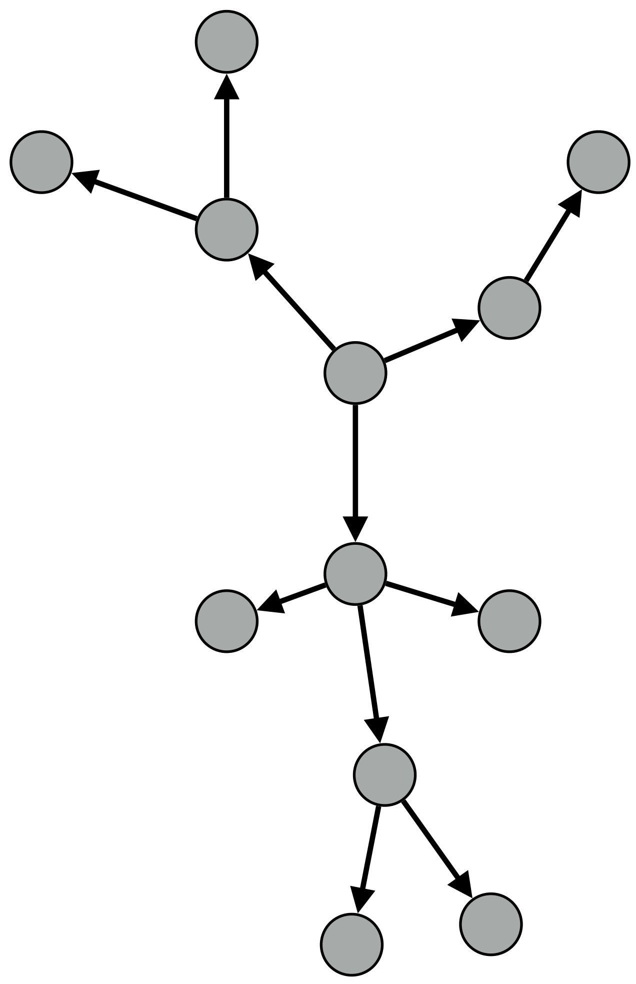
Node-link / Free



[Nguyen and Huang. 2002. A Space-Optimized Tree Visualization. In Proceedings of the IEEE Symposium on Information Visualization (InfoVis'02). IEEE Computer Society]

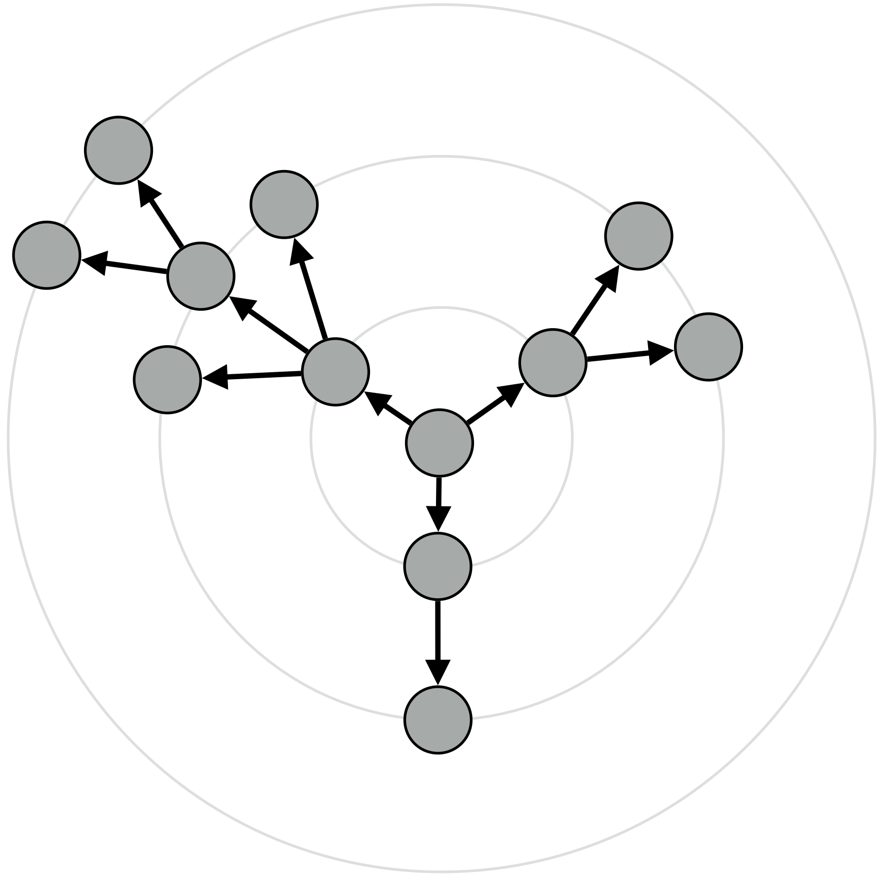
Node-link / Free

- Can be more compact,
- but difficult to:
  - find the root
  - see layers
  - answer questions related to depth

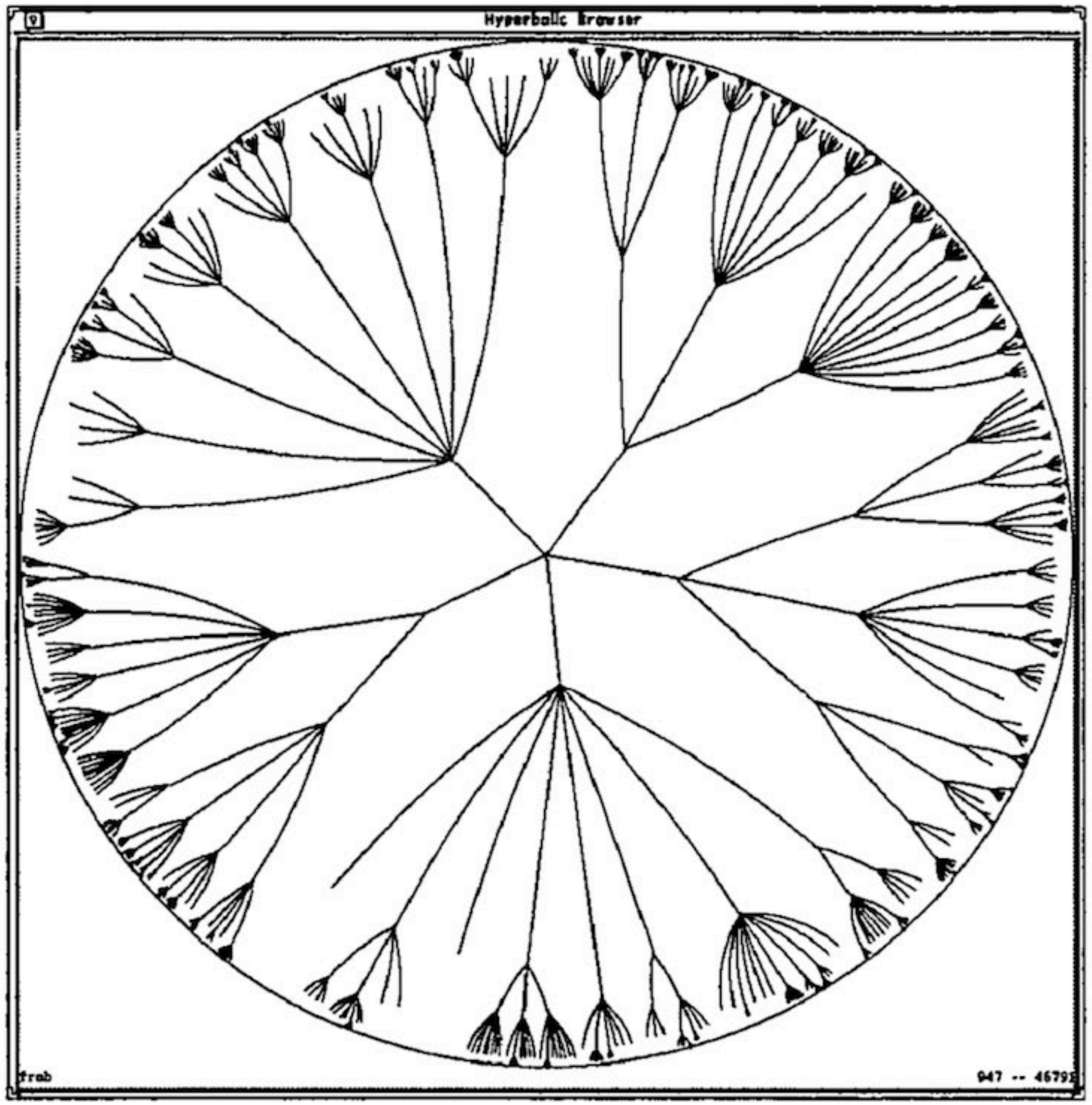


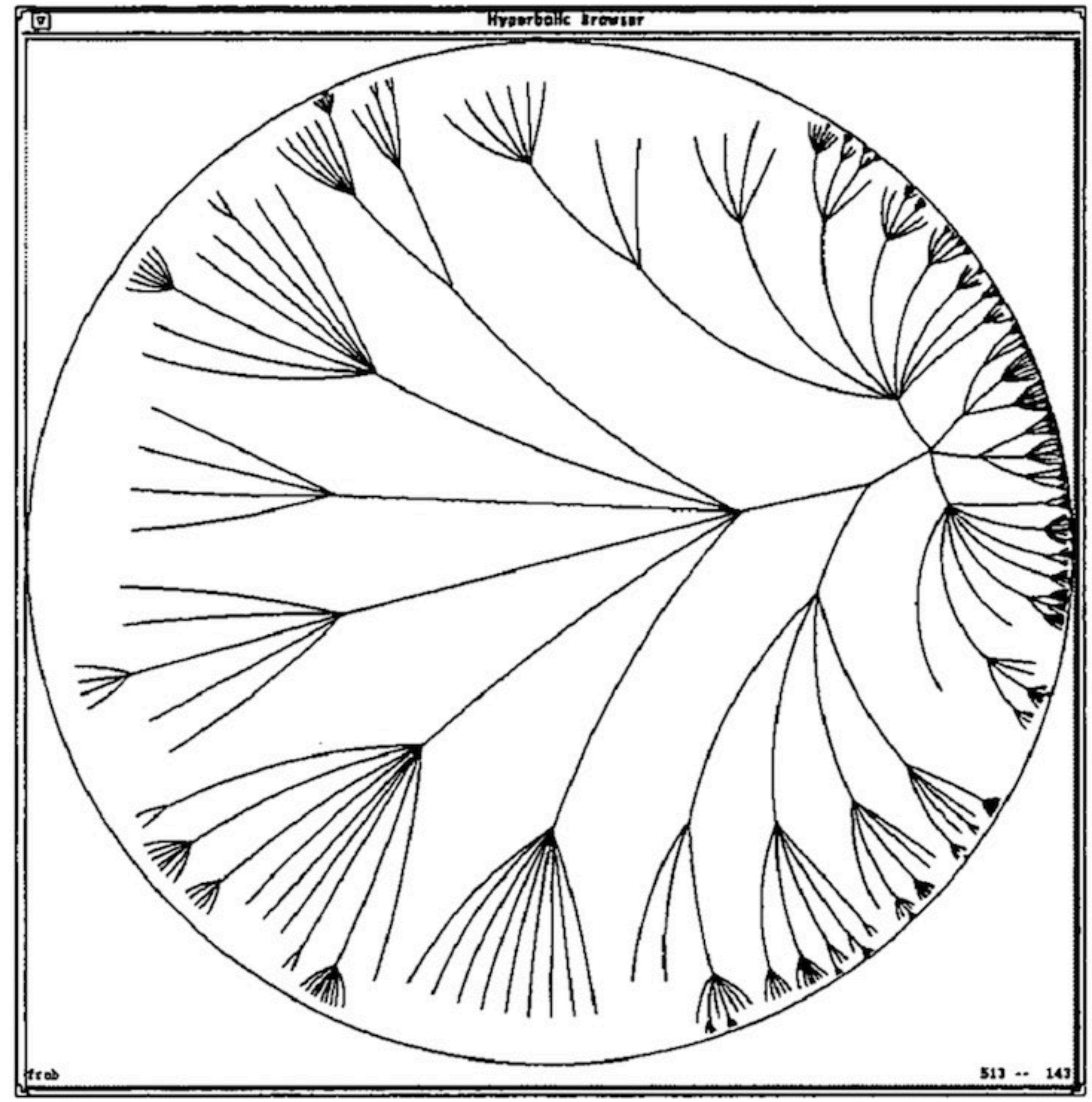
Node-link / Radial

- Alternative to axis-parallel
- More or less the same properties in terms of legibility and task support
- Choose one or the other depending on topology (breadth, depth, balancing), aesthetics criteria



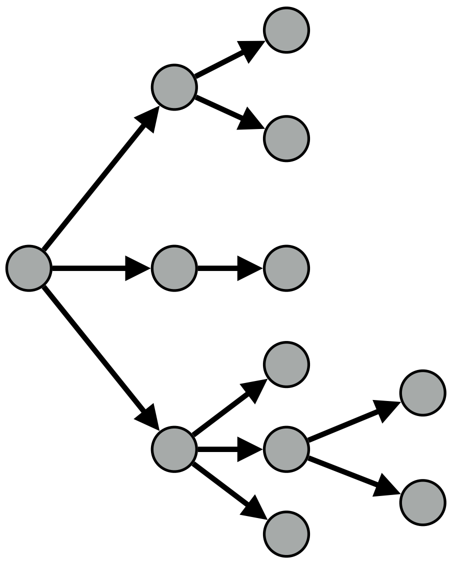
Node-link / Radial

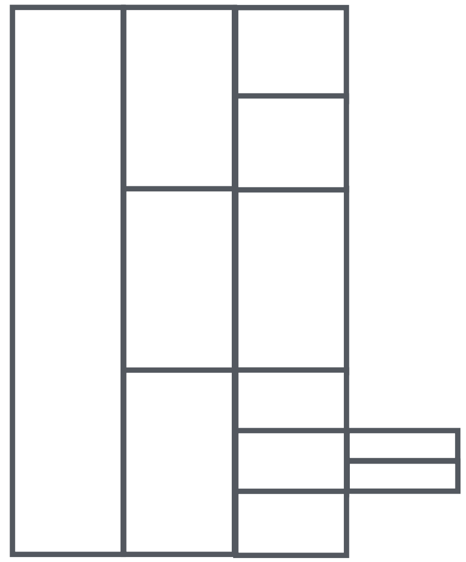


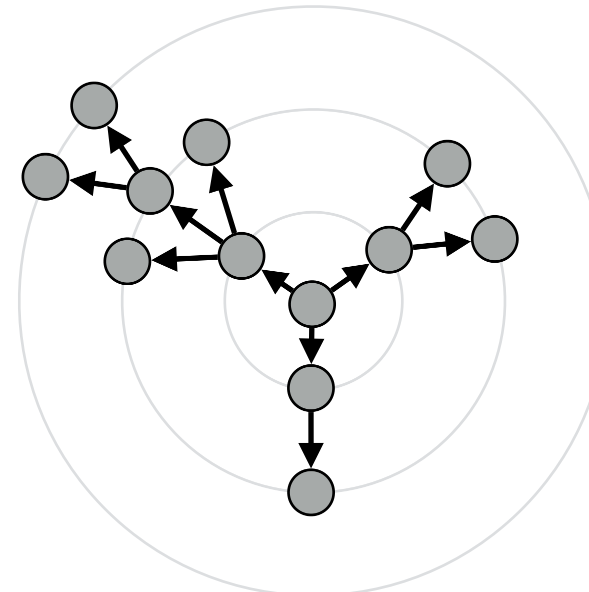


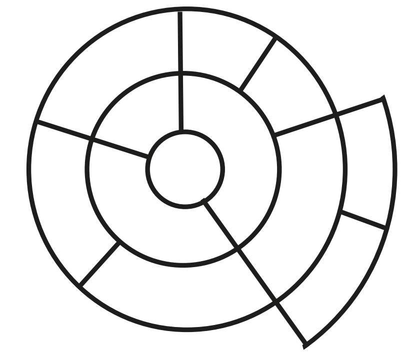
[Lamping et al. 1995. A focus+context technique based on hyperbolic geometry for visualizing large hierarchies. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '95),ACM, 401-408]

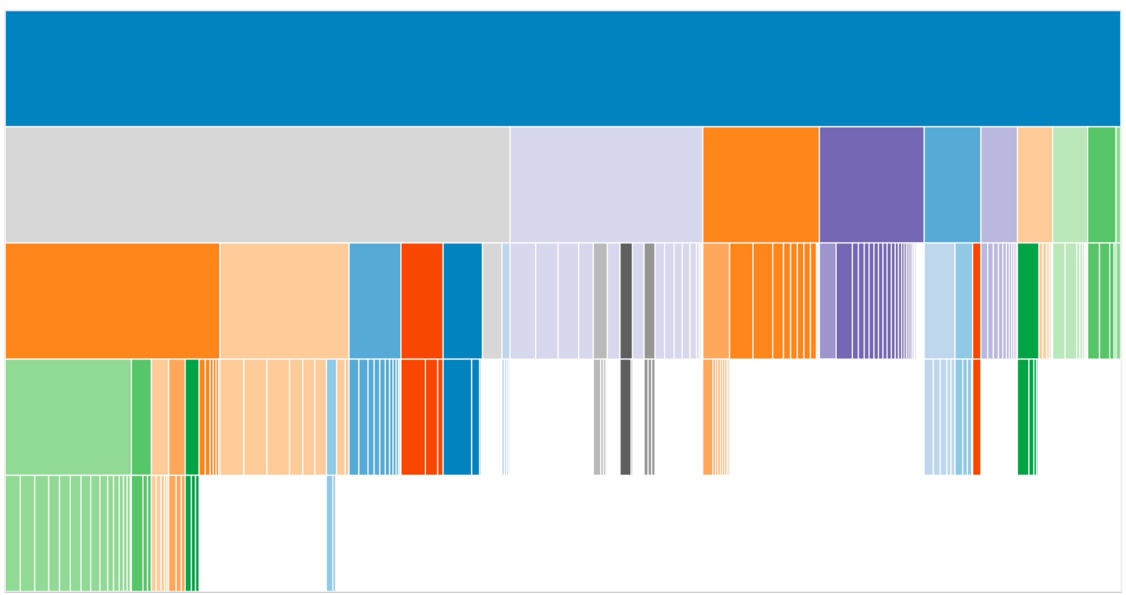
Space-filling / Axis-parallel & Radial







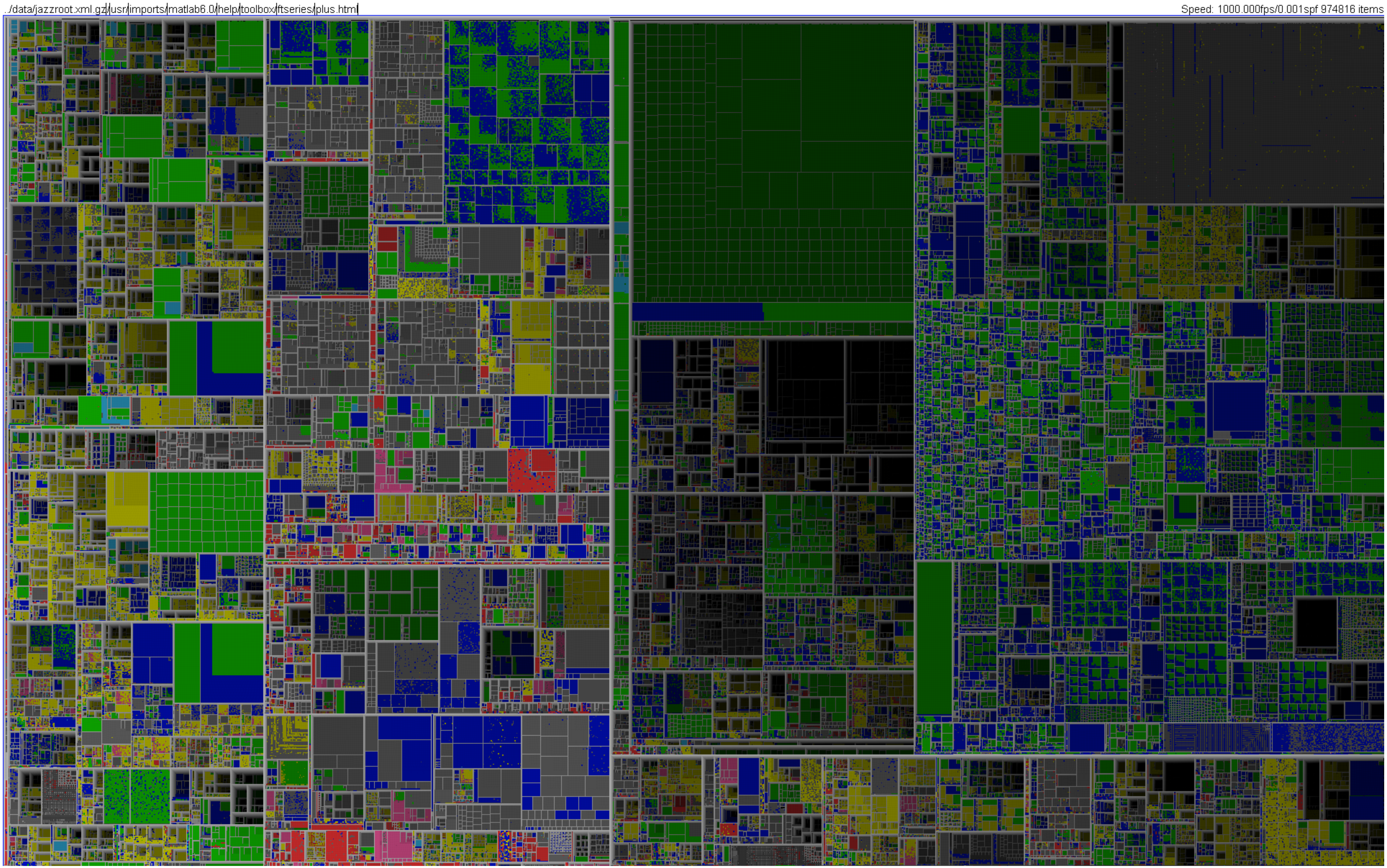




- Helps identify long branches, large branches
- Not particularly space-efficient

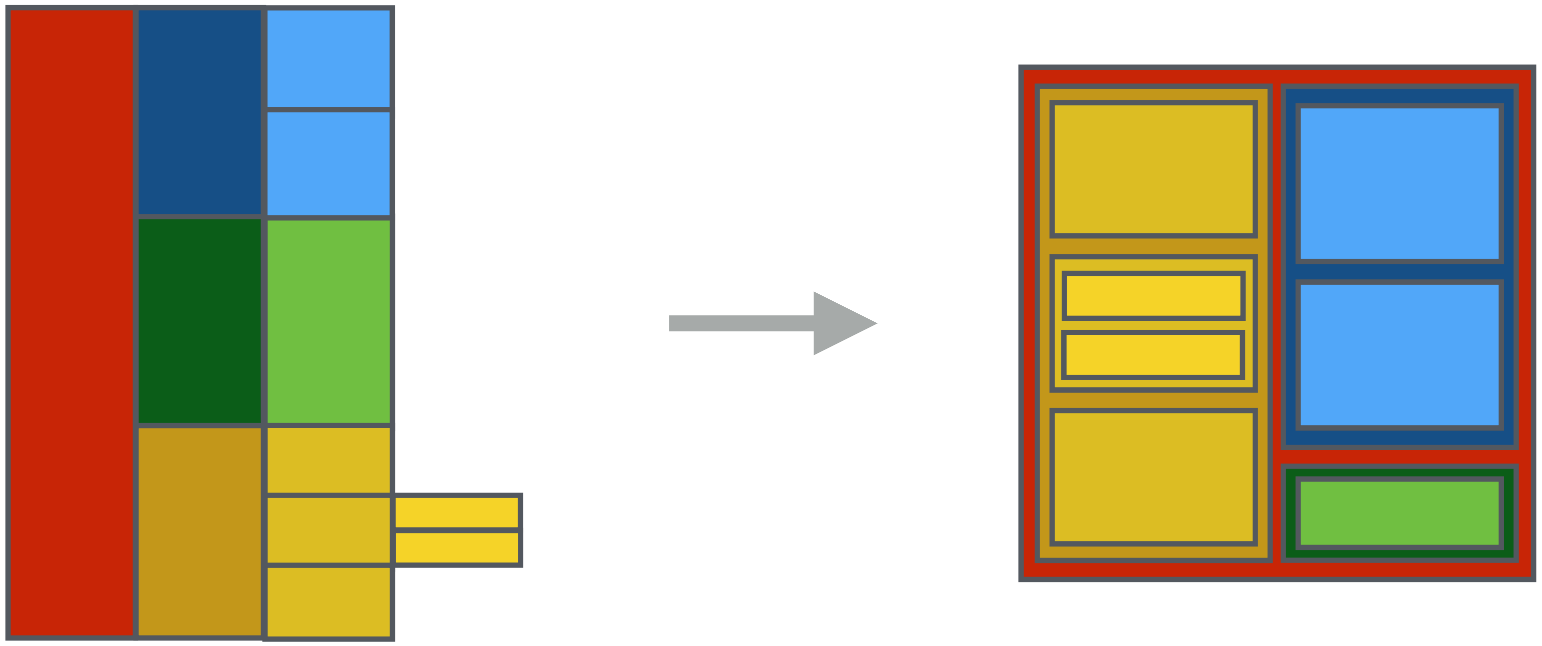
- More or less the same
- Choice is a question of topology and aesthetics

Space-filling / Free: Treemap



[Fekete and Plaisant. Interactive Information Visualization of a Million Items. In Proceedings of the Symposium on Information Visualization (InfoVis'02). IEEE Computer Society]

Space-filling / Free: Treemap



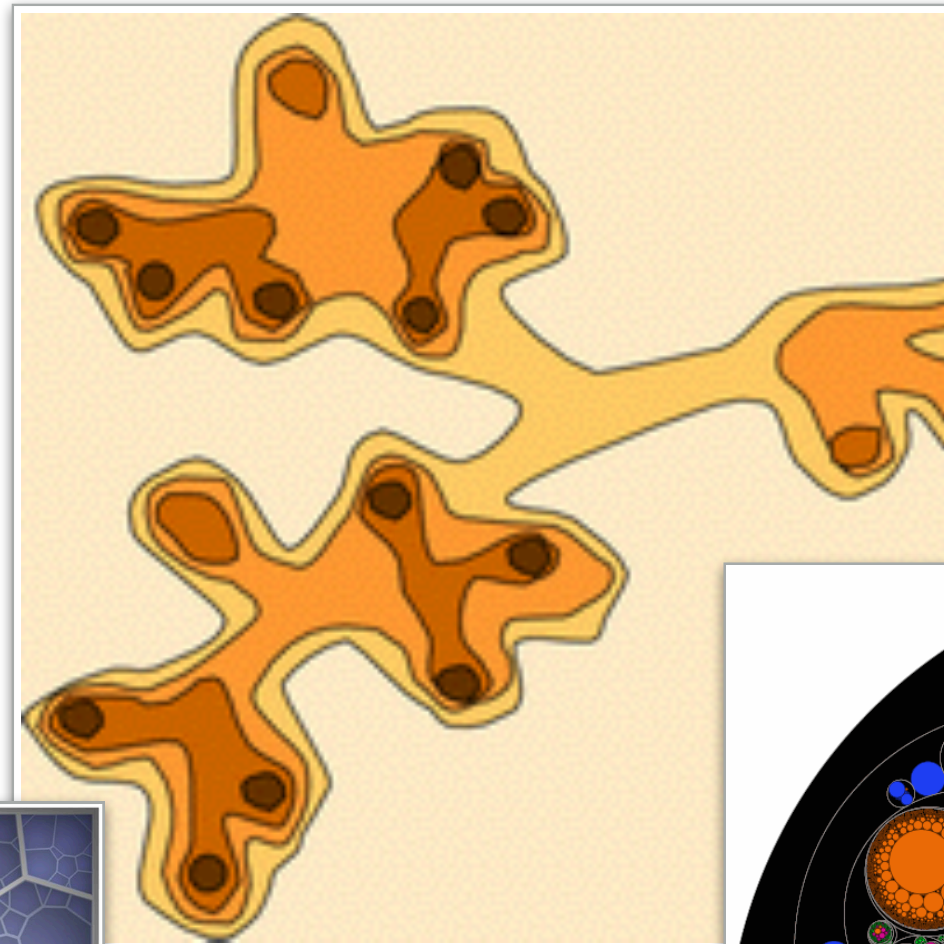
- Most compact one
- Some topology-related tasks become difficult:
  - Which branch is deepest?
  - How wide is the tree?
  - How deep is the tree?
  - How long is the path between n_i and n_j?

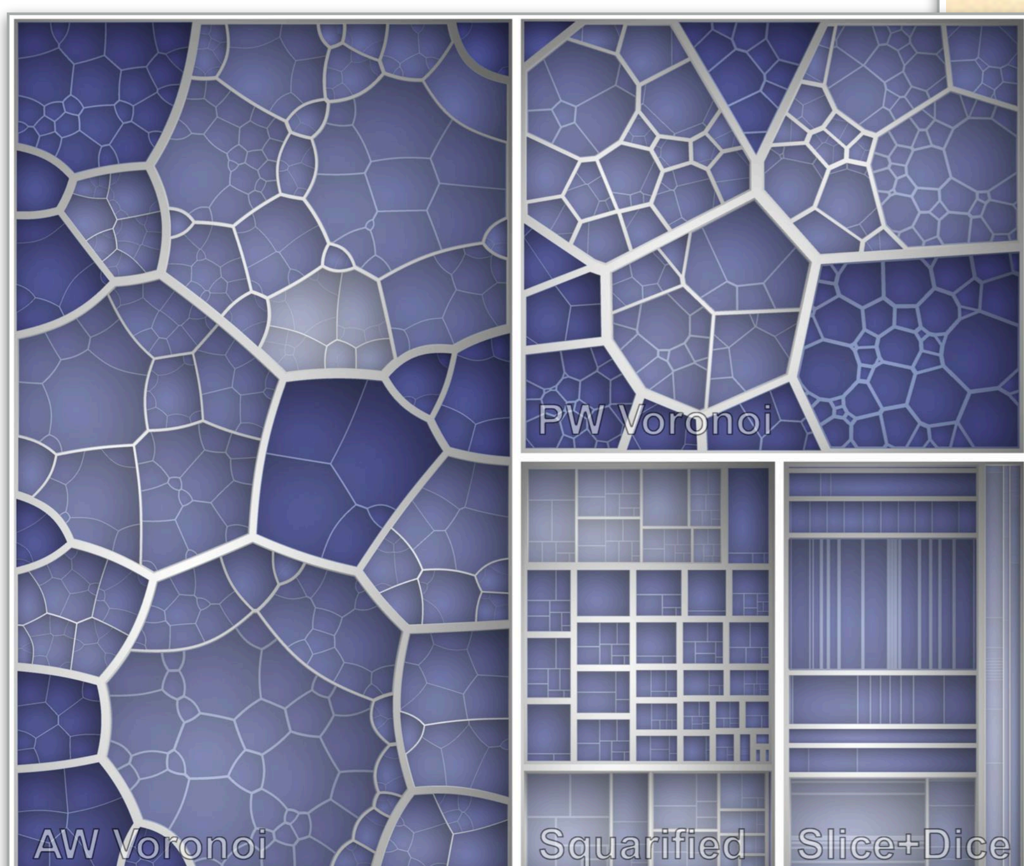
Space-filling / Free: Treemap

https://finviz.com

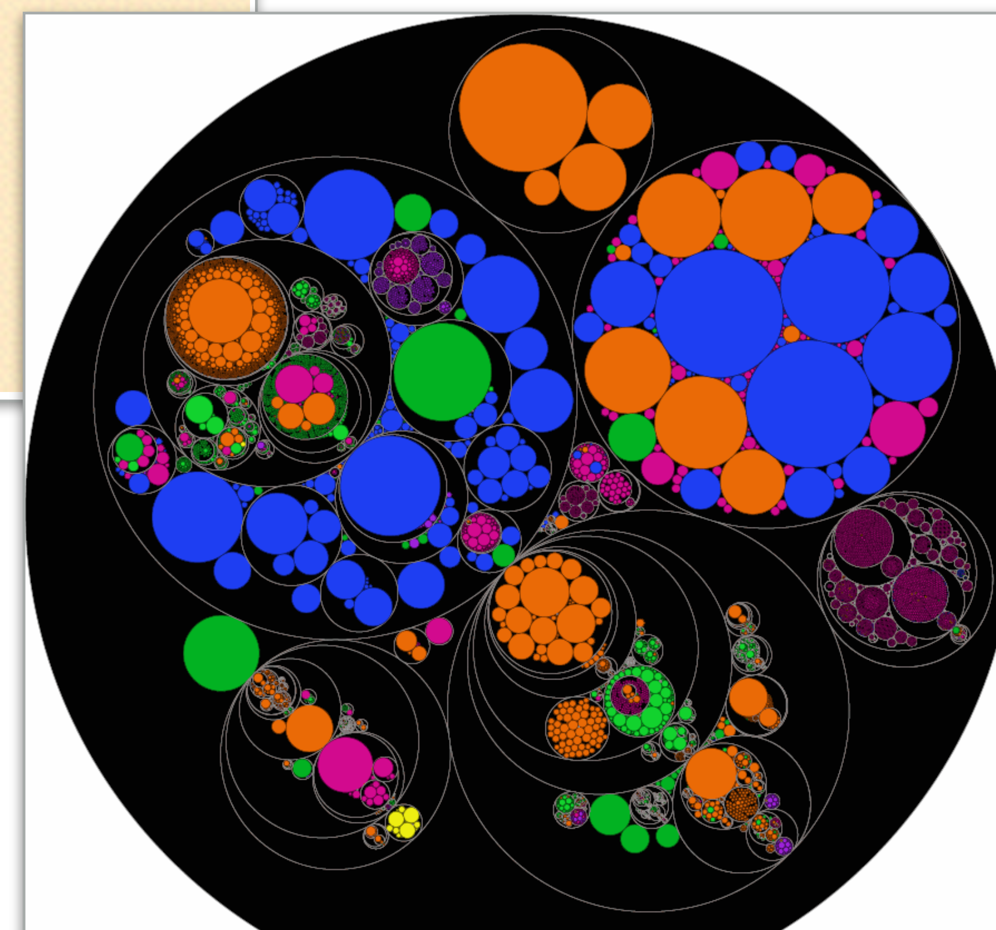
Space-filling / Free: Alternatives

[Hidekazu Kubota et al. 2006. Visualization of contents archive by contour map representation. In Proceedings of the 20th annual conference on New frontiers in artificial intelligence (JSAI'06), Springer, 19-32.]





[Michael Balzer and Oliver Deussen. 2005. Voronoi Treemaps. In Proceedings of the Proceedings of the Symposium on Information Visualization (INFOVIS '05). IEEE Computer Society]



[Image source: Linux Interface Project GUI musings]

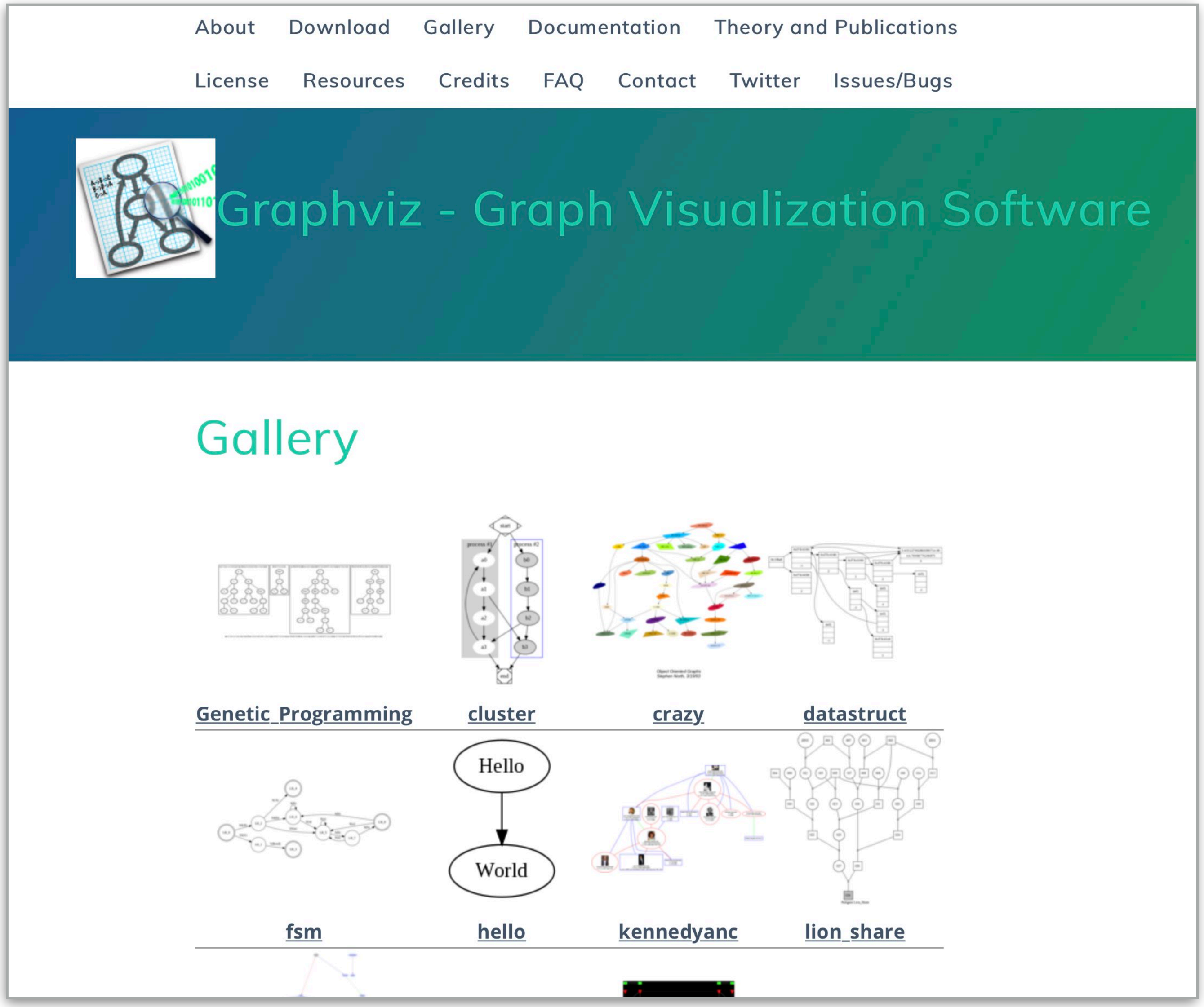
[Weixin Wang et al. Visualization of large hierarchical data by circle packing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '06), ACM, 517-520]

Interactive Network Visualization Systems

Some Examples

Systems

- GraphViz `http://graphviz.org`
  - Suite of C++, command line programs
  - Take DOT files as input
  - Export decorated DOT, as well as bitmap and vector graphics formats
  - Essentially a black box

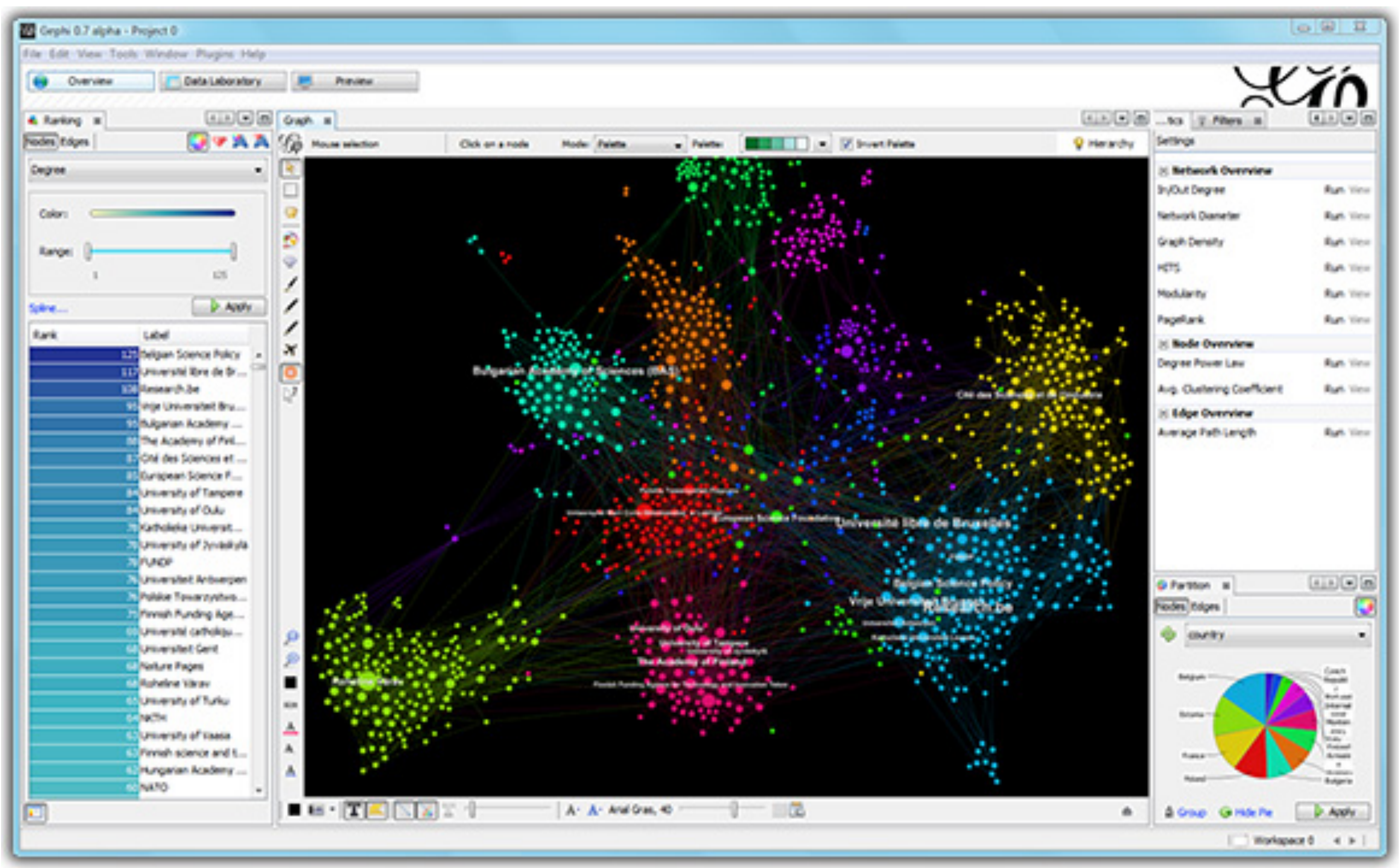


Systems

- Gephi   https://gephi.org

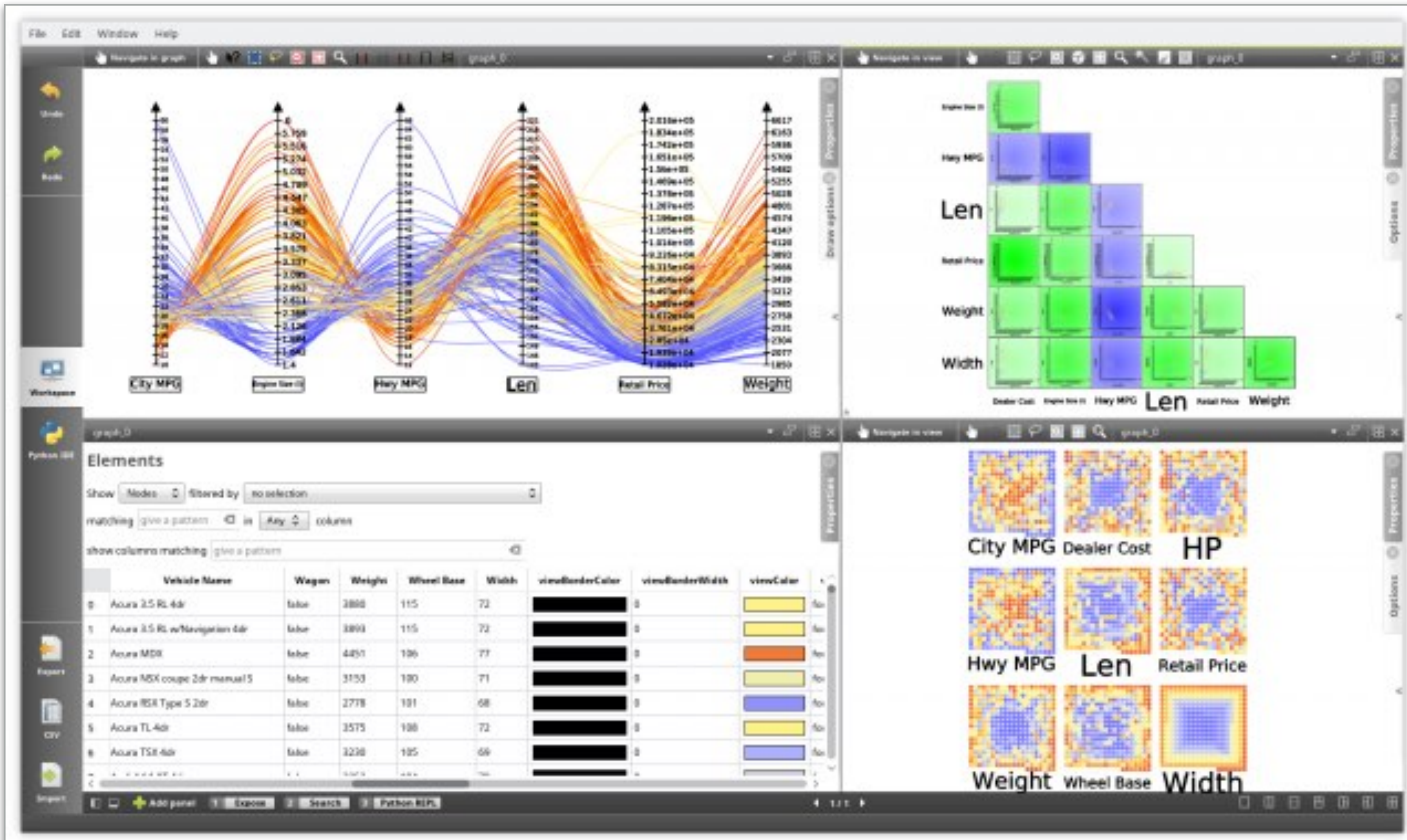
gephi.mp4

  - Full-fledged Application
  - Exploratory Data Analysis
  - Manipulation
  - Layout
  - Measures
  - Dynamic networks



Systems

- Tulip http://tulip.labri.fr/TulipDrupal/
  - full-fledged Application tulip.mp4
  - less centered on node-link diagrams than Gephi

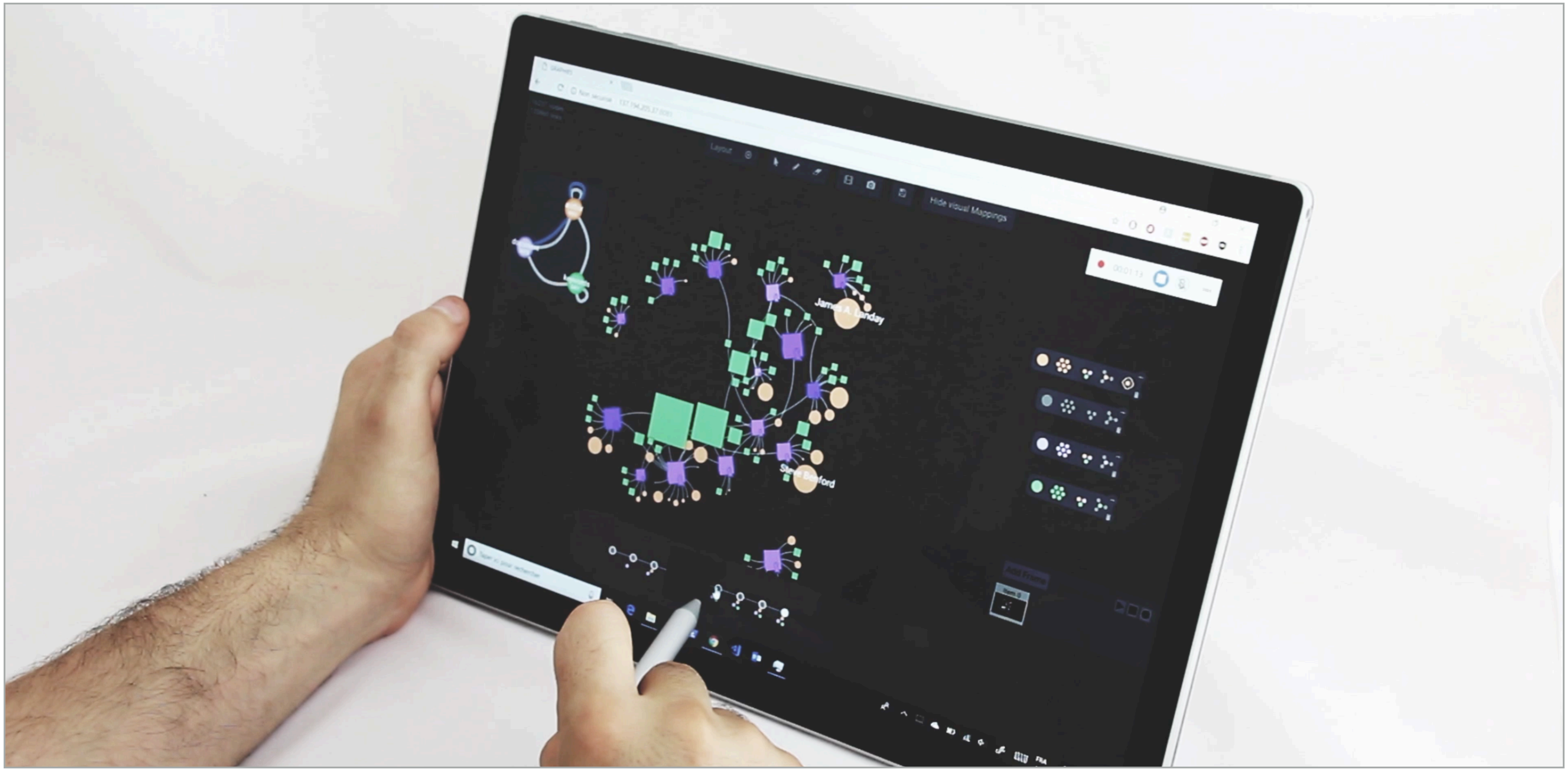


Systems

- Graphies

Demo

  - Direct manipulation
  - Flexible workflow favoring iterative design
  - Rich visual mappings



[H. Romat et al., Expressive Authoring of Node-Link Diagrams with Graphies, IEEE Transactions on Visualization and Computer Graphics (TVCG), 12 pages, early access, November 2019, doi: https://doi.org/10.1109/TVCG.2019.2950932]