# VISUALIZING TREES AND GRAPHS

#### adapted from Petra Isenberg



# DATA AND ITS STRUCTURE

### STRUCTURED DATA



0.103	0.176	0.387	0.300	0.379
0.333	0.384	0.564	0.587	0.857
0.421	0.309	0.654	0.729	0.228
0.266	0.750	1.056	0.936	0.911
0.225	0.326	0.643	0.337	0.721
0.187	0.586	0.529	0.340	0.829
0.153	0.485	0.560	0.428	0.628

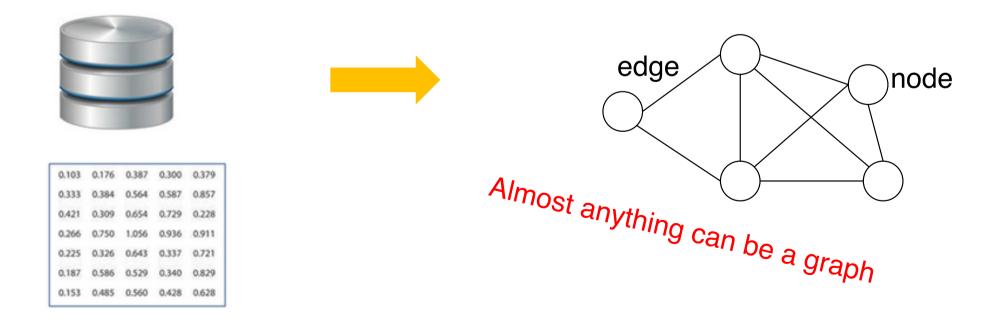
### UNSTRUCTURED DATA

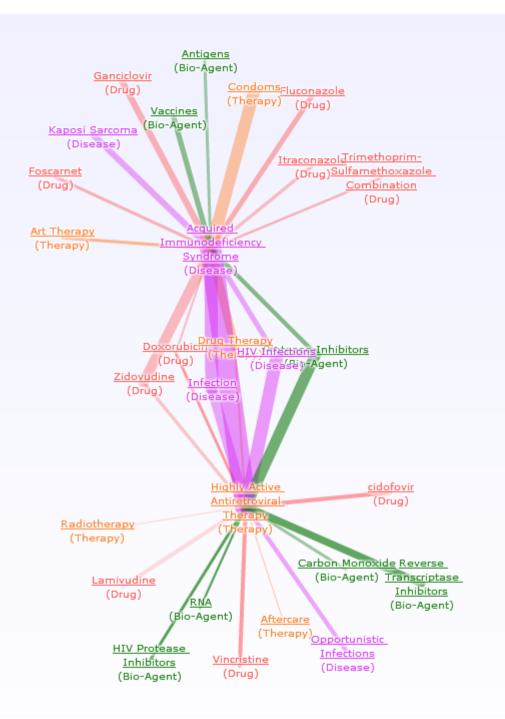




# STRUCTURED DATA

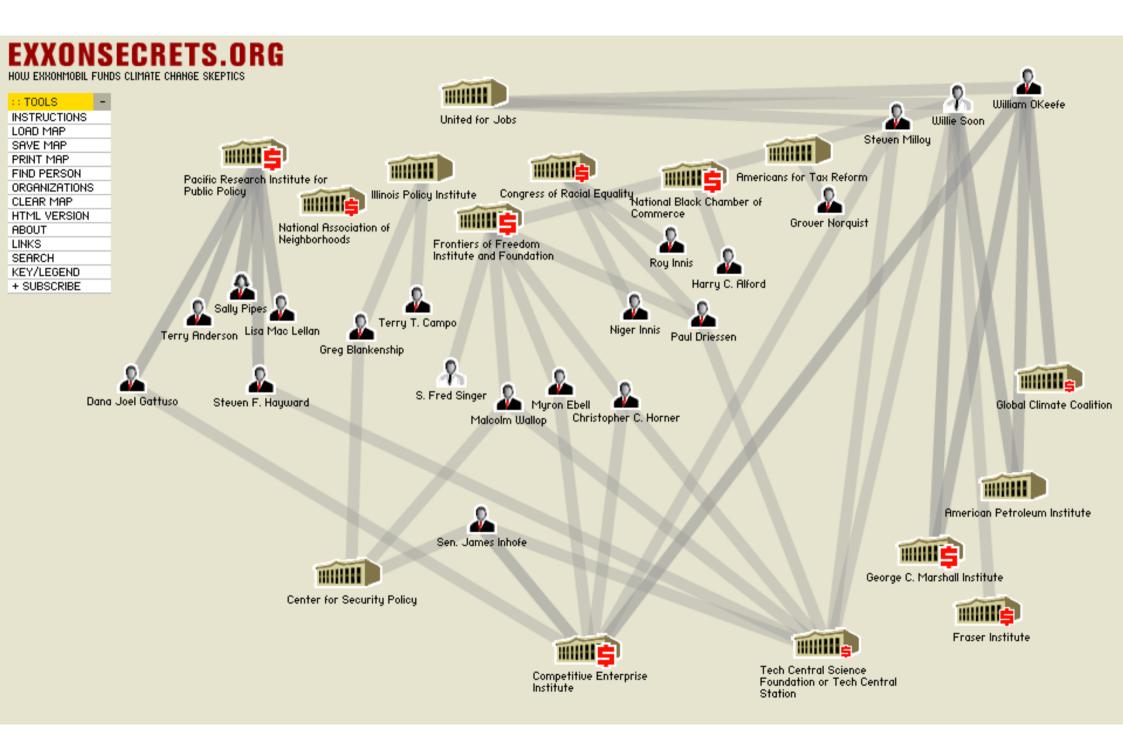
- there are relationships between the data items
- you can use a graph representation



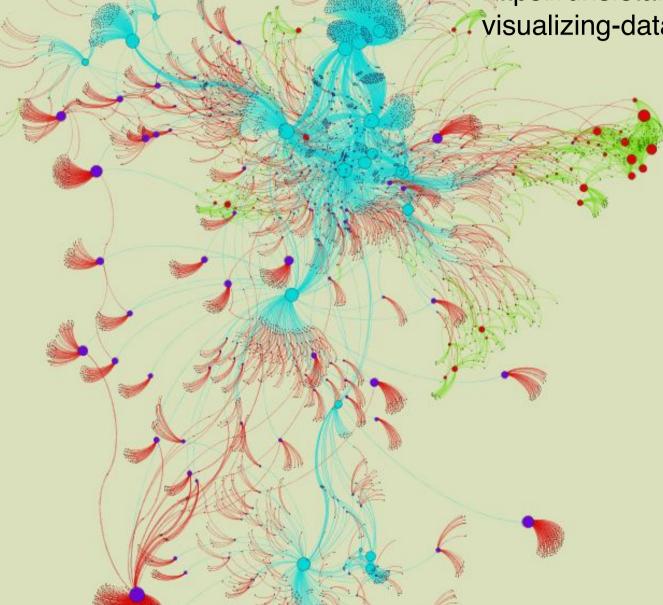


#### http://www.curehunter.com

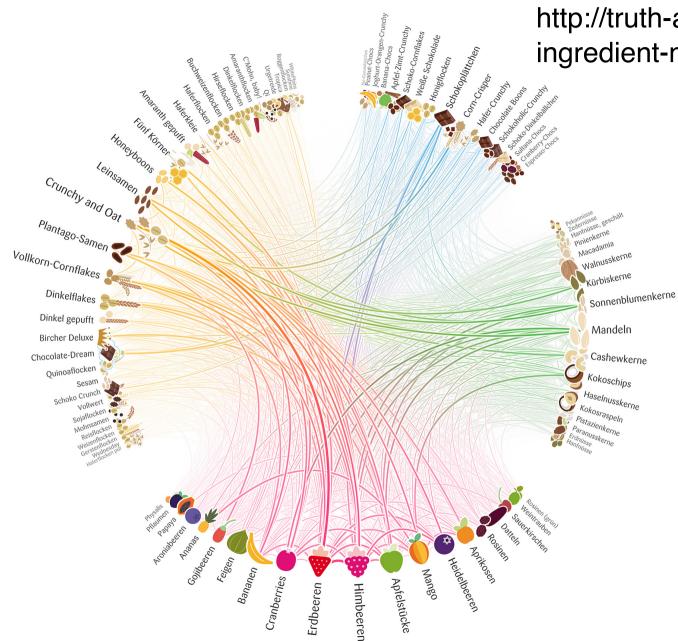
visual dictionary of drugs, diseases and therapies



#### https://dhs.stanford.edu/spatial-humanities/ visualizing-databases/



Top Contributors to the Catalogue of Life and their associated species, references and databases

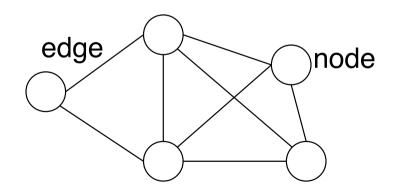


#### http://truth-and-beauty.net/projects/muesliingredient-network

# GRAPHS

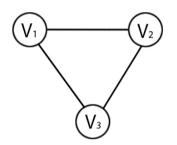
### Graphs

- Describe relations among data items
- Using nodes and edges





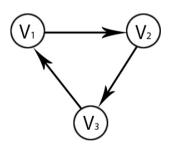
**Undirected Graph** 



undirected graph: edges have no orientation

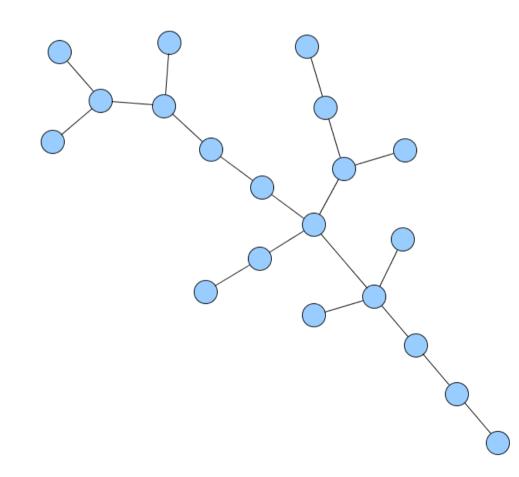
**Directed Graph** 

directed graph (digraph): edges have orientation





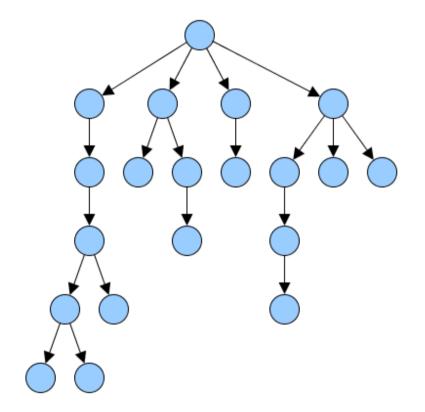
#### a tree is a connected graph with no cycles



# DEFINITIONS

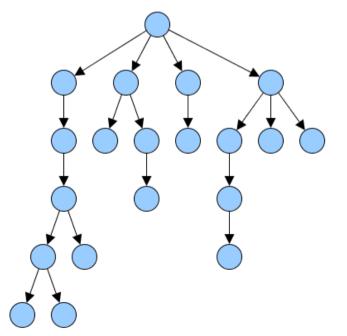
a directed tree is a digraph (directed graph) whose underlying graph is a tree

- a directed tree consists of a number of **nodes** and parent-child relationships
- every node has just one parent and any number of children
- directed trees are the most common form in computer science

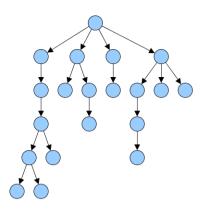




- the number of children of a node is called its degree
- leaf nodes are nodes without children



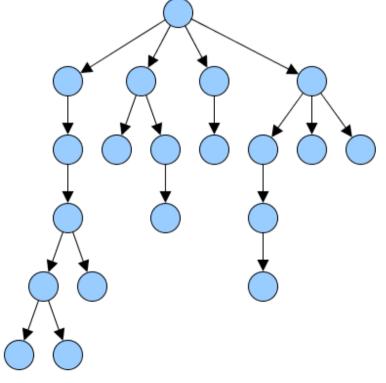




- a rooted tree is a directed tree with a distinguished vertex r, called the root, such that for every other vertex v there is directed path from r to v
- the root node is the only node with no parent
- any node may act as a root in undirected trees

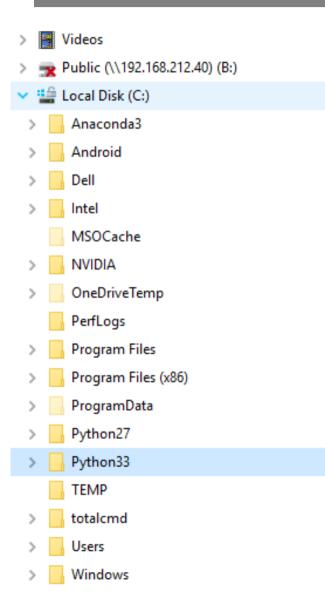


# the connection between parent and child nodes is called an **edge**



### **EXAMPLES OF TREES**

# HIERARCHIES



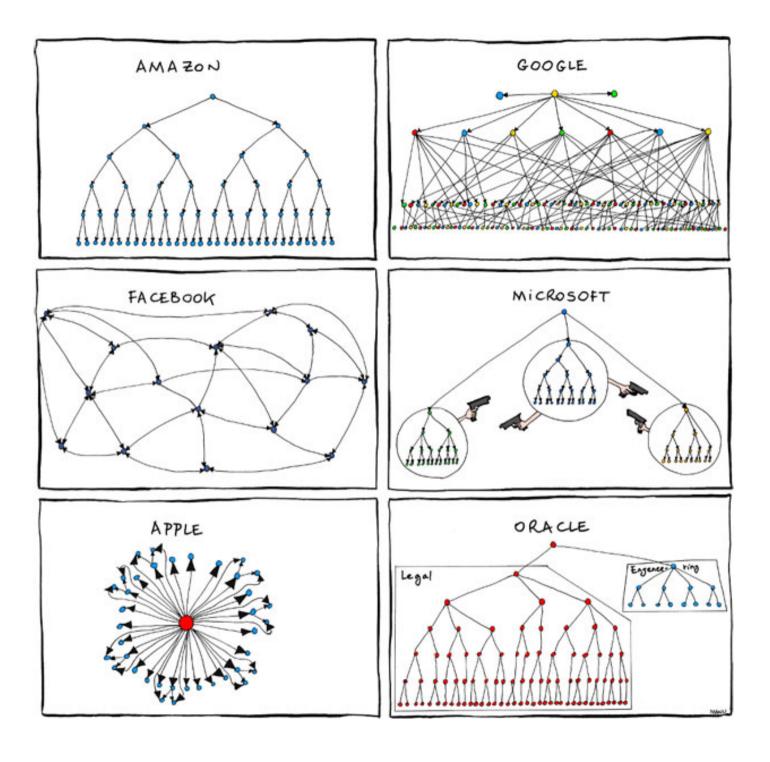
^	Name	Date modified	Туре	Size
	DLLs	23-Mar-16 13:39	File folder	
	Doc	23-Mar-16 13:39	File folder	
	include	23-Mar-16 13:39	File folder	
	Lib	23-Mar-16 13:39	File folder	
	libs	23-Mar-16 13:39	File folder	
	Scripts	23-Mar-16 15:20	File folder	
	📊 tcl	23-Mar-16 13:39	File folder	
	Tools	23-Mar-16 13:39	File folder	
	🔁 ez_setup.py	23-Mar-16 13:42	Python File	12 KB
	📔 LICENSE.txt	09-Mar-14 10:37	TXT File	31 KB
	📔 NEWS.txt	09-Mar-14 10:27	TXT File	258 KB
	🛃 python.exe	09-Mar-14 10:35	Application	40 KB
	🛃 pythonw.exe	09-Mar-14 10:35	Application	40 KB
	📔 README.txt	09-Mar-14 10:27	TXT File	7 KB
	📳 setuptools-20.3.1.zip	23-Mar-16 13:43	Compressed (zipp	706 KB

# HIERARCHIES

### OrgOrgChart

Autodesk Research

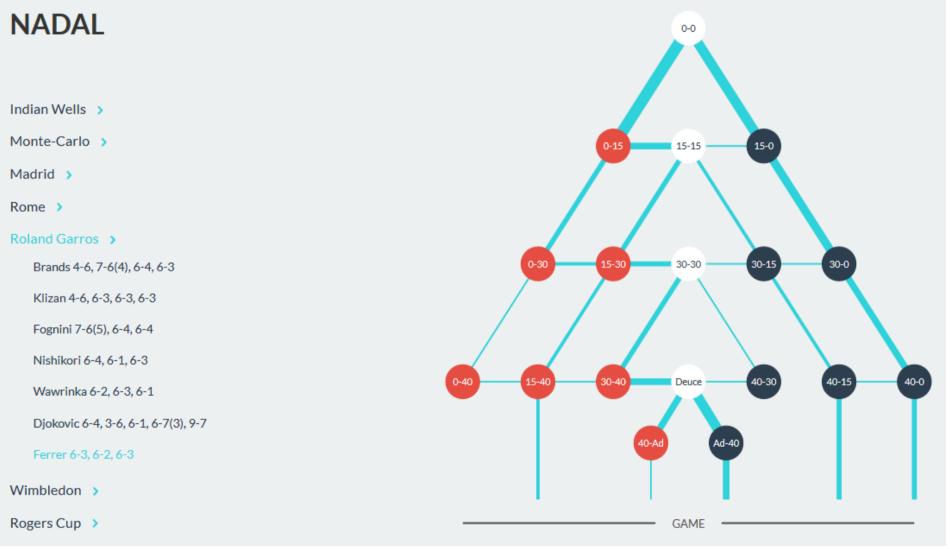
https://www.youtube.com/watch?v=mkJ-Uy5dt5g



org charts aren't always trees, though

http:// www.bonkersworld.net/ organizational-charts/

# DECISION PROCESS



http://gamesetmap.com/nadalgametree/

## BRANCHING PROCESSES

Think about it: is a family tree really a tree?

### GeneaQuilts

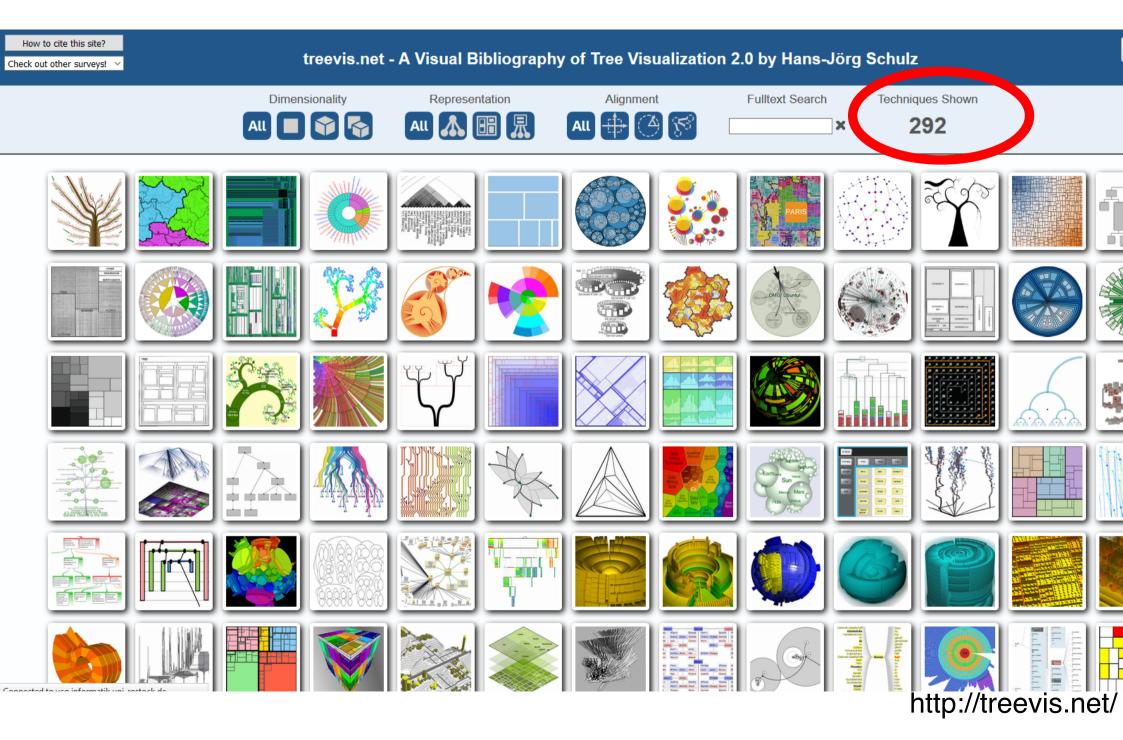
A System for Exploring Large Genealogies

A.Bezerianos P.Dragicevic J.-D.Fekete J.Bae B.Watson

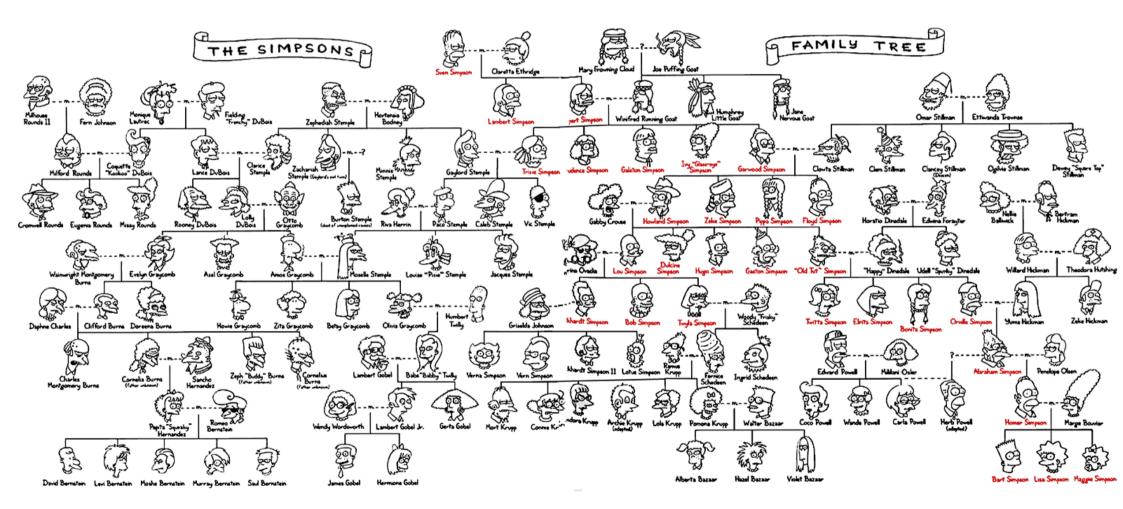
https://www.youtube.com/watch?v=gncBzqI7R-Q

### **TREE REPRESENTATION**

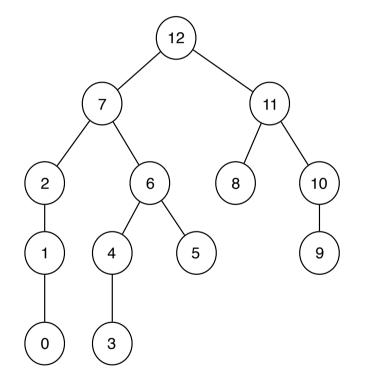
**TECHNIQUES** 



# NODE-LINK



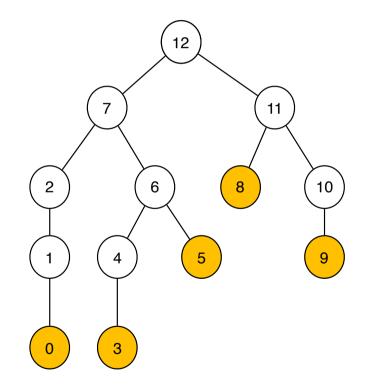
http://simpsons.wikia.com/wiki/



THE LAYOUT WE WANT – HOW DO WE GET THERE?

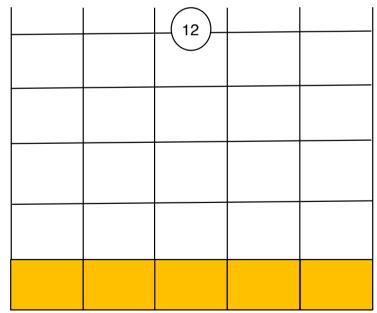
#### SIMPLE APPROACH

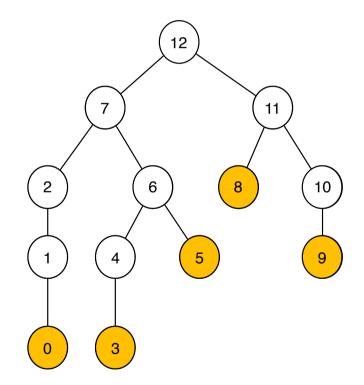
- 1) COUNT THE LEAVES
- 2) PLACE THE ROOT



#### SIMPLE APPROACH

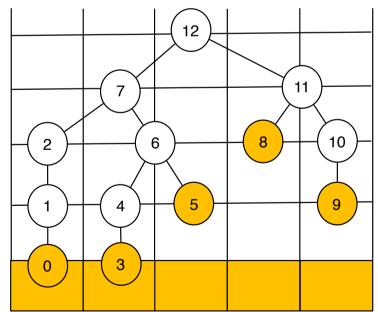
- 1) COUNT THE LEAVES
- 2) PLACE THE ROOT
- 3) RECURSIVELY DIVIDE

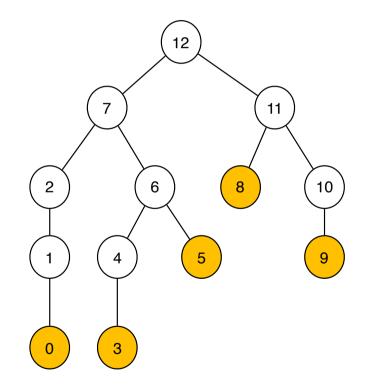




#### SIMPLE APPROACH

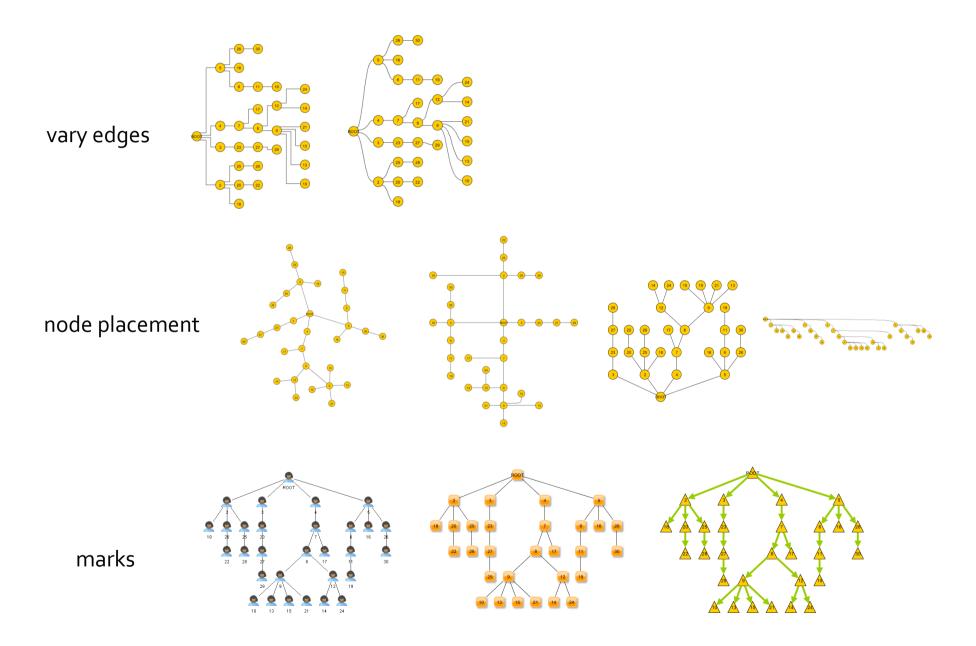
- 1) COUNT THE LEAVES
- 2) PLACE THE ROOT
- 3) RECURSIVELY DIVIDE





# PROS/CONS

- nodes at the same distance from the root are horizontally aligned
- positive: simple to understand, clear symmetries
- negative: needs large area, often bad aspect ratio (much wider than tall)



Images created with yEd: http://www.yworks.com

# SPECIFIC ALGORITHMS

- usually described recursively
- well known: Reingold-Tilford algorithm
- lots of research in this direction:
  - Wetherell and Shannon 1978, Tidy Drawings of Trees
  - Reingold and Tilford 1981, Tidier Drawing of Trees
  - Walker 1990, A Node-positioning Algorithm for General Trees
  - Buchheim et al 2002, Improving Walker's Algorithm to Run in Linear Time

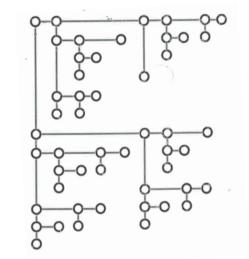
# AESTHETICS

aesthetics of node-link tree algorithms describe properties that improve the perception of the data that is being layed out

- area: match area of your layout to the size of the display and data
- **aspect ratio**: usually optimal if close to 1
- **subtree separation**: try not to overlap subtrees
- **root-leaf distance**: minimize distance from root to leaves
- edge lengths: minimize total, average, maximum, edge lengths & try to make edge lengths uniform
- **angular resolution**: increase angles formed by edges
- **symmetry**: symmetric layouts usually considered pleasing

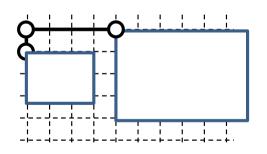
# HV DRAWING

- for binary trees
- straight line grid drawing
  - every child of a vertex u, is either horizontally aligned with and to the right of u, or vertically aligned with and below u
  - the bounding rectangles (smallest rectangles with horizontal and vertical sides covering the drawings) of the subtrees of u do not intersect

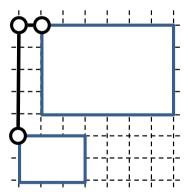


# HV DRAWING STRATEGY

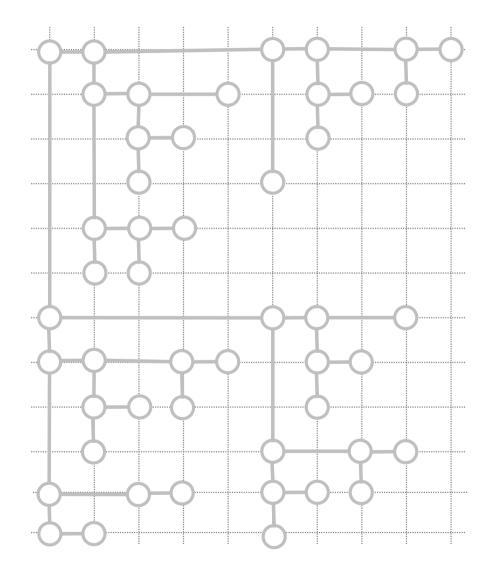
- divide: recursively construct hv-drawings for left and right subtrees
- conquer: perform either a horizontal combination or a vertical combination

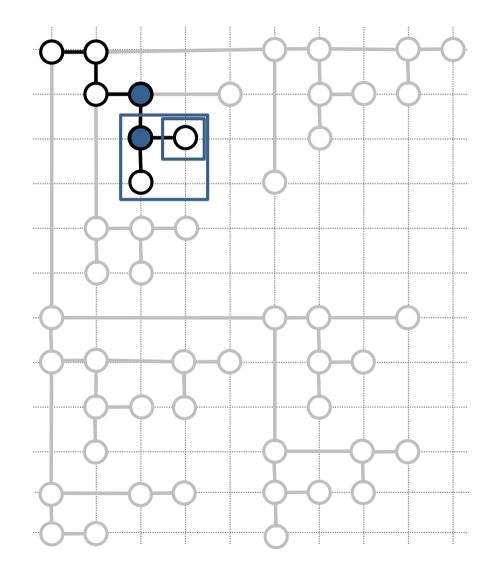


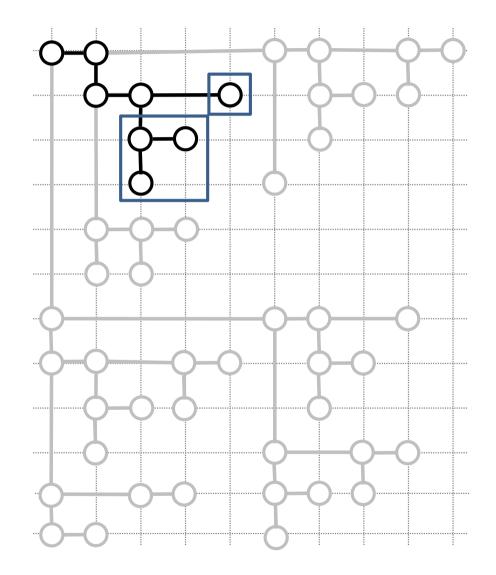
horizontal combination



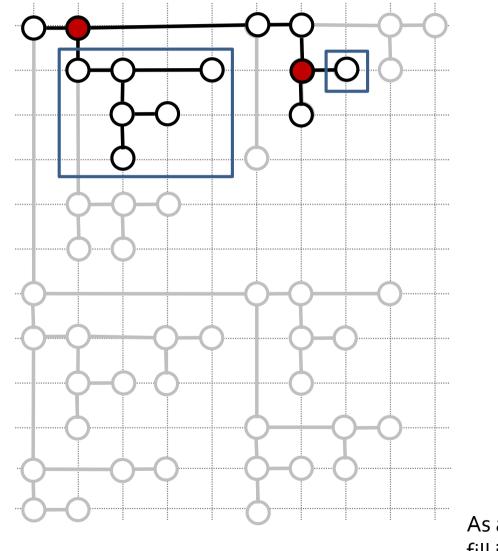
vertical combination







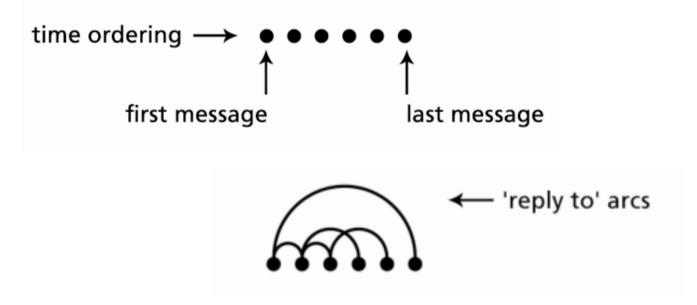
#### (not covered in class)



As an exercise, fill in the rest by yourself

## LAYOUT DIMENSIONALITY: 2D – THREAD ARCS

email visualization



http://threadvis.github.io/

## THREADVIS

- time-scaling
- coloring people

From Tobias Isenberg

Subject Re: Slides, first draft

To Jian Chen🏫

. Cc. Torsten Möllerin, Michael Sedlmairin, Me < petra.isenberg@inria.fr>

ቴ 🏩 🔺 Re: Slides, first draft	<ul> <li>Tobias Isenberg</li> </ul>	<ul> <li>14/10/2013 7:28 AN</li> </ul>
🖄 🚽 Re: Slides, first draft	Jian Chen	<ul> <li>14/10/2013 1:55 PN</li> </ul>
😭 🤣 Re: Slides, first draft	<ul> <li>Tobias Isenberg</li> </ul>	<ul> <li>14/10/2013 10:32 P</li> </ul>
🖄 - Re: Slides, first draft	<ul> <li>Torsten Möller</li> </ul>	<ul> <li>14/10/2013 11:27 P</li> </ul>
🖄 Next steps: QI	<ul> <li>Michael SedImair</li> </ul>	<ul> <li>22/10/2013 11:49 A</li> </ul>
🖄 - Re: Next steps: QI	<ul> <li>Torsten Möller</li> </ul>	<ul> <li>23/10/2013 1:58 AN</li> </ul>
🟫 Re: Next steps: QI	<ul> <li>Tobias Isenberg</li> </ul>	<ul> <li>24/10/2013 4:14 PN</li> </ul>
😭 🔶 🔶 🔶 🖓	<ul> <li>Michael SedImair</li> </ul>	<ul> <li>24/10/2013 11:01 P</li> </ul>
From Tobias Isenberg	н <u>л</u>	🔦 Reply 🔇 Reply All 👻 🌩 Forward 🔯 Archive
Subject Re: Slides, first draft To Jian Chene Cc Torsten Möllere, Michael SedImaire, Me < petra.isenberg@inria.fr>@	•	f. Ale

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Please note that I said we would meet at 0900. 🙂

Cheers,

### TREEJUXTAPOSER

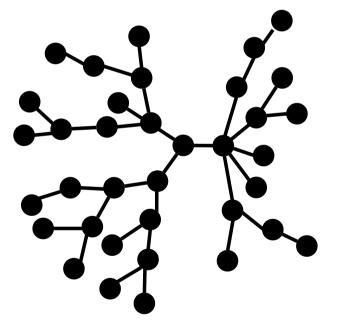
Rectilinear layout and interaction for comparison of very large trees

TreeJuxtaposer: Scalable Tree Comparison using Focus+Context with Guaranteed Visibility

http://www.cs.ubc.ca/~tmm/papers/tj/#video

### RADIAL NODE-LINK DRAWING

variation of layered drawing from beginning of lecture



### RADIAL NODE-LINK DRAWING

- nodes drawn on concentric circles
- nodes drawn within wedges of the circular layout

#### (not covered in class)

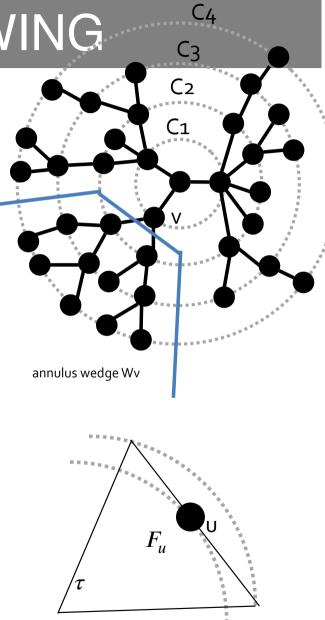
### RADIAL NODE-LINK DRAWING

- radius of C<sub>i</sub> given by function p(i)
- subtree of v drawn within  $W_v$
- to guarantee planarity (no edge crossings), wedge has to be convex
- several algorithms exist for figuring out the correct angles, e.g.

$$\beta_u = \left(\frac{l(u)\beta_v}{l(v)}, \tau\right)$$

For each child u of v:

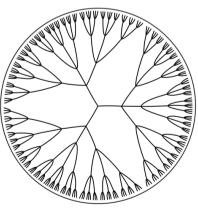
- is the angle of
- is the angle formed by region
- I(v): number of leaves in subtree rooted at v
- place u at center of



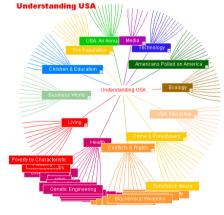
Resource: Battista et al. Graph Drawing

### HYPERBOLIC BROWSER

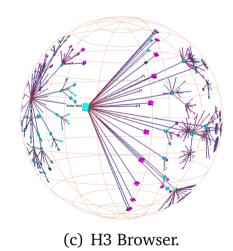
- uses hyperbolic geometry (not euclidean geometry)
- a hyperbolic plane can be displayed using the Poincaré disk model
  - a tree structure of any size fits within a finite area (circle)
  - node is displayed in center
  - all oder nodes move away from center and become exponentially smaller



(a) Uniform hyperbolic tree.



(b) StarTree by Inxight Software.



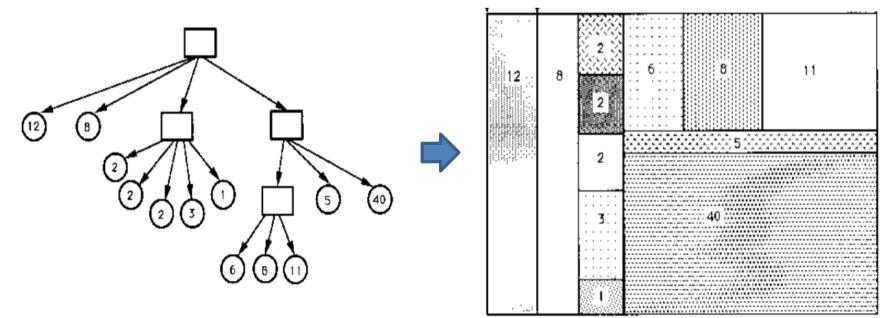
### CHI 1996 VIDEO OF HYPERBOLIC BROWSER

Special thanks to my colleagues and teachers at the Visible Language Workshop and the MIT Media Lab, to my advisor Bill Mitchell, and to Andrew Eskind of the George Eastman House.

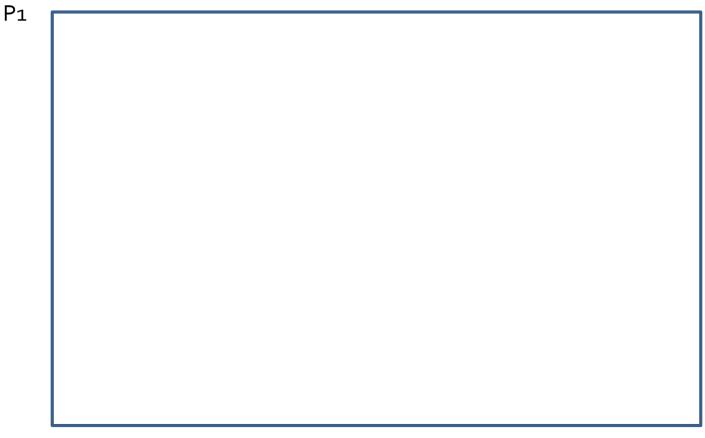
copyright 1995 MIT Media Laboratory

### A CLASSIC CONTAINMENT LAYOUT

- example tree to rebuild with treemap algorithm
- size of each node as numbers in leaves



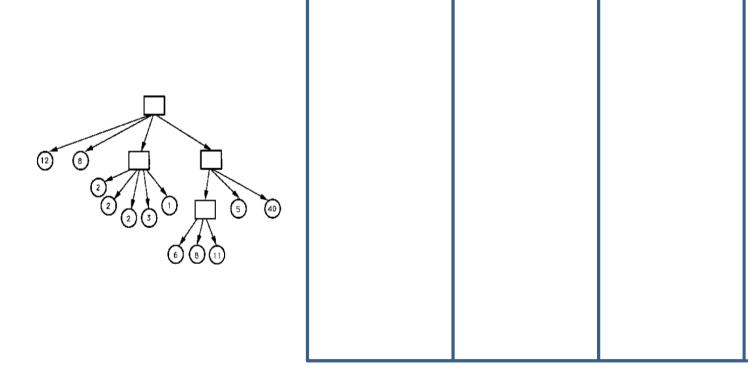
- Take a rectangular display area P1(x1,y1), Q1(x2,y1)
- This area represents the root of the tree



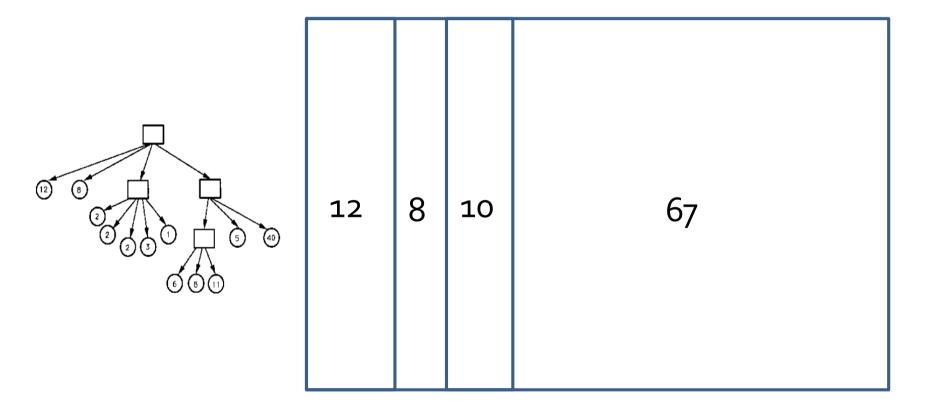
**Q**1

### recursive algorithm

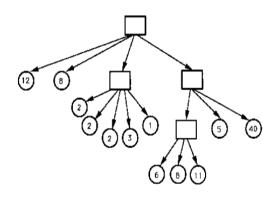
 the number of children of the current node define the number of partitions of the current node

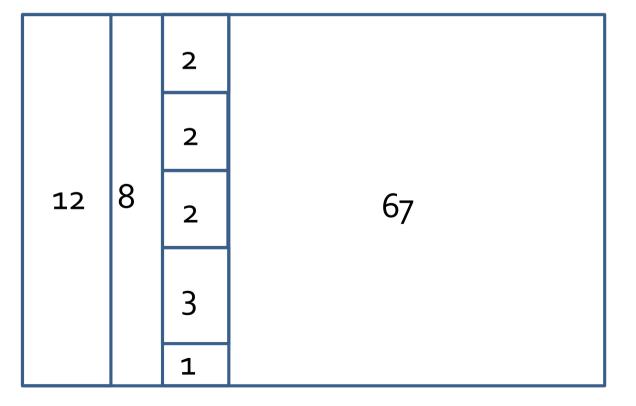


### the weight of each node determines the size of each partition

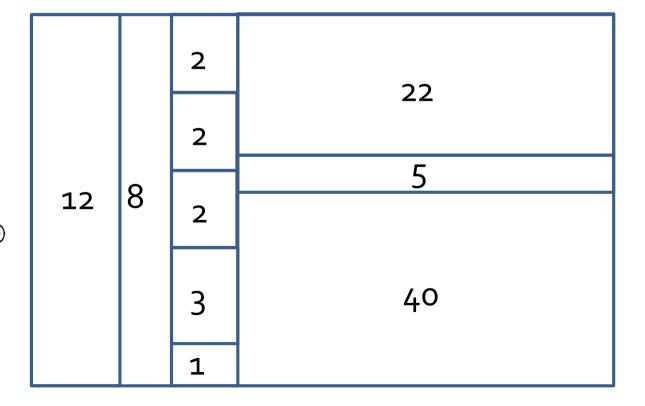


# at each change of level, rotate orientation of split by 90 degrees

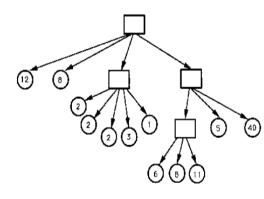


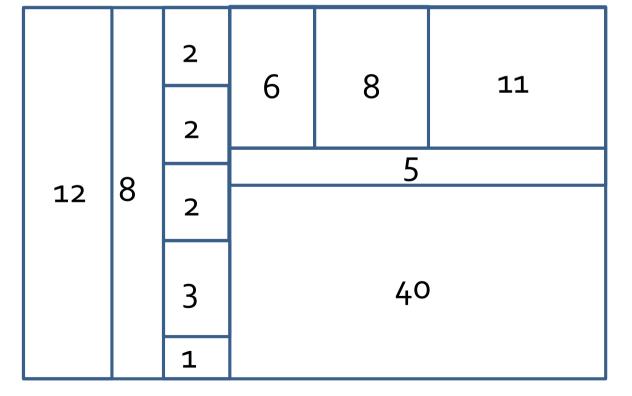


# at each change of level, rotate orientation of split by 90 degrees



# at each change of level, rotate orientation of split by 90 degrees



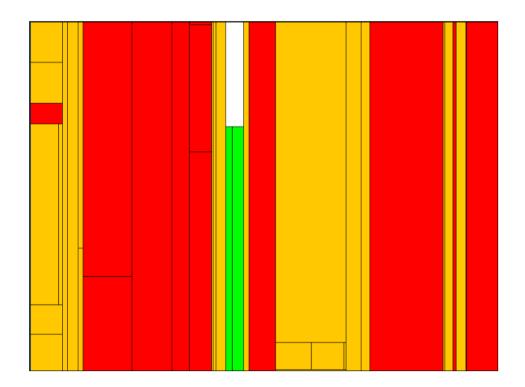


## TREEMAP

- a 2-D space-filling layout
- for further references and to try out a treemap in various applications: <u>http://www.cs.umd.edu/hcil/</u> <u>treemap-history/</u>

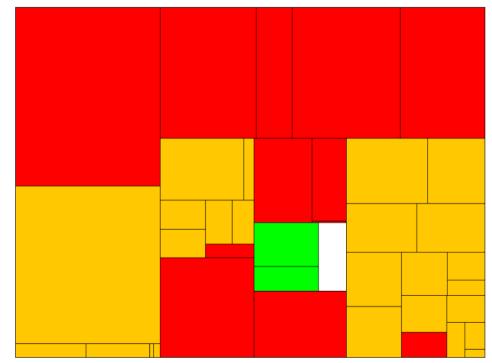
## TREEMAP VARIATIONS

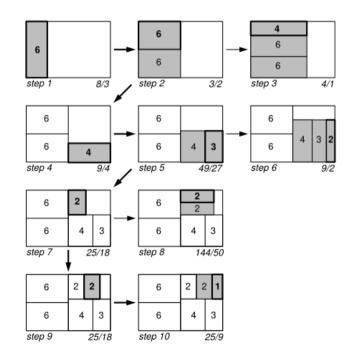
- problem with original treemap: lots of long stripes
- for long stripes the areas are difficult to compare



## SQUARIFIED TREEMAP

- calculates more squared regions
- problem: order not as easily read, not very stable with dynamically changing data





### ORDERED TREEMAP

### several algorithms in comparison

	1	2	3	4	1	2	3	4	1	2	5	10
	5	6	7	8	5	8	9	10	3	4	7	12
1 2 3 4 5 6 7 8 9 10111213141516	9	10	11	12	6	11	13	14	6	8	9	14
	13	14	15	16	7	12	15	16	11	13	15	16

#### slice and dice

B. Shneiderman. Tree visualization with tree-maps: 2-d space-filling approach. ACM Transactions on Graphics, 11:92–99, 1992.

strip

B. B. Bederson, B. Shneiderman, and M. Wattenberg. Ordered and quantum treemaps: Making effective use of 2d space to display hierarchies. ACM Transactions on Graphics, 21:833–854, 2002.

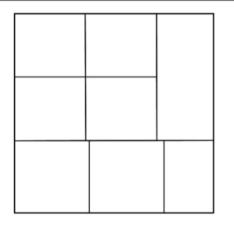
#### squarified

M. Bruls, K. Huizing, and J. van Wijk. Squarified treemaps. EuroVis, pages 33–42, 2000.

#### ordered squarified

B. Shneiderman and M. Wattenberg. Ordered treemap layouts. In Infovis01, pages 73–78, 2001.

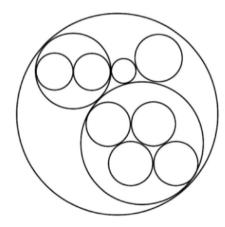
#### OTHER VARIATIONS OF TREEMAPS



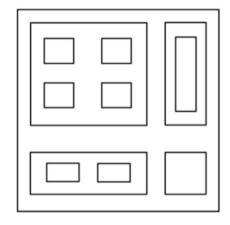
original squarified: emphasizes leafs and their attributes



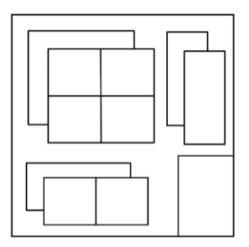
steptree: emphasizes structure with extrusion



circular treemap: emphasizes structure with non-space-filling primitive



nested layout: emphasizes structure with whitespace

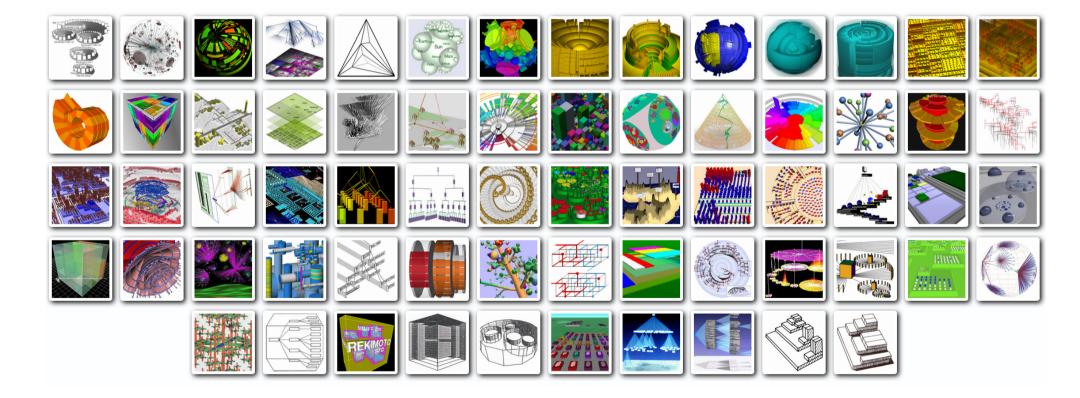


cascaded layout: emphasizes structure with overlap

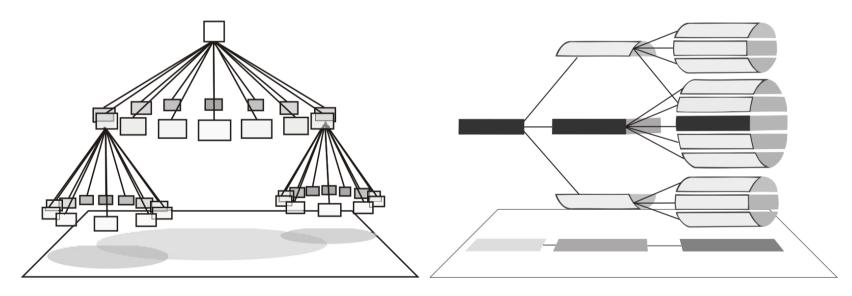
#### TRY THE IMPLICIT TREE VISUALIZATION TOOLKIT: HTTP://VCG.INFORMATIK.UNI-ROSTOCK.DE/~HS162/ITVTK/START.HTML

	1			
Children (1100) Charles (1100)	View 1	(		
	Interactive Mode Batch Mode	۶		
Statistics	Presets			
ie: javaclasses.csv	Circular Treemap 3D 🗸			
Full Tree	Circular Treemap 3D			
Ir. of nodes: 2971	Information Pyramids			
lax depth: 7	Nested Squarified Treemap			
lax child count: 1278	Nested Treemap			
	Steptree =			
Interaction 🔔 👘 🚺	Sunburst 2D			
investore Chinet	Sunburst 3D (Cylinder)			
avalian().Co)ect	Sunburst 3D (Wheel) *		0	
javax.swing.AbstractAction			CHIHADOGAN AD VUIDOACH	
javax.swing.border.AbstractBorder	Relationship Methods			
<ul> <li>javax.swing.AbstractButton.ButtonCh</li> </ul>	Adjacency 👻			
javax.swing.AbstractCellEditor				
java.util.AbstractCollection	Layout Methods			
javax.swing.text.AbstractDocument	Circle/Sphere Packing 👻			
javax.swing.text.AbstractDocument.A				197 ( 9 a a a 19 a a a a a a a a a a a a a a
javax.lang.model.util.AbstractElement	Surface Properties			0.8.000000
java.util.concurrent.AbstractExecutor:	Rendering Properties			
java.nio.channels.spi.AbstractInterrup				
javax.swing.tree.AbstractLayoutCach	Root Node Dimensions			
javax.swing.tree.AbstractLayoutCach				
javax.swing.AbstractListModel			AC ACCOUNT AND A SAME	
java.util.AbstractMap			HICKLIC POOLE LEE L	
java.util.AbstractMap.SimpleEntry				
java.util.AbstractMap.SimpleImmutable				
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### **3D LAYOUTS**



## HISTORIC EXAMPLE: CONETREE / CAMTREE



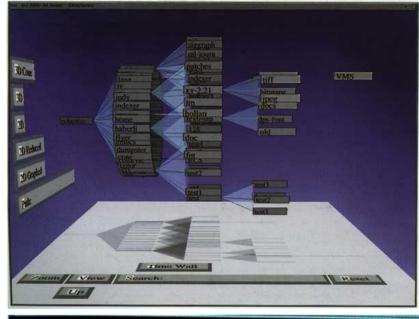
ConeTree

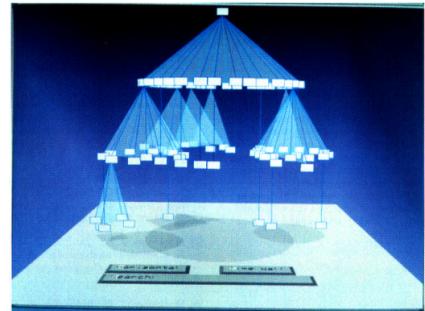
CamTree

[Robertson et al., 1991] George Robertson, Jock D. Mackinlay, Stuart Card. Cone Trees: Animated 3D Visualizations of Hierarchical Information. In *Proceedings of the ACM CHI 91* 

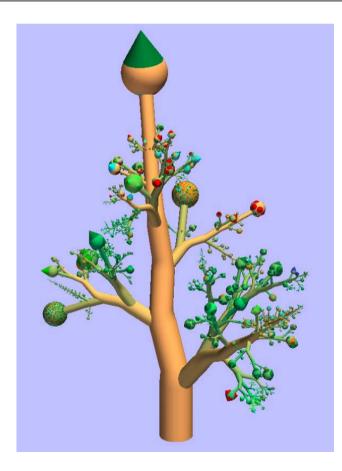
### CONE/CAMTREE

- children of a node are laid out in a cylinder "below" the parent
- siblings located on the same 2D circle
- use of animation
- shadows to enhance structure





## BOTANICAL VISUALIZATION OF HUGE HIERARCHIES





- advantages
  - fit more data into same aspect ratio
  - aesthetically pleasing
- disadvantages
  - occlusion
  - requires interaction or animation
  - no overviews

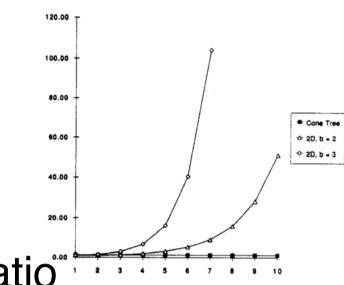


Figure 1: Aspect Ratio of 2D and 3D Trees.

### TREE VISUALIZATION SUMMARY

- there are lots of tree visualizations
  - there is also lots of free software, try it out, (see links earlier in the lecture plus e.g.):
    - <u>http://www.informatik.uni-rostock.de/~hs162/optreedemo/</u> <u>TestBed.htm#</u>
    - <u>http://w3.win.tue.nl/nl/onderzoek/onderzoek informatica/visualization/</u> sequoiaview/
  - there are a few overview articles, e.g.:
    - A Generative Layout Approach for Rooted Tree Drawings by Hans-Jörg Schulz, Zabed Akbar, and Frank Maurer - at IEEE PacificVis 2013
    - The Design Space of Implicit Hierarchy Visualization: A Survey by Hans-Jörg Schulz, Steffen Hadlak, and Heidrun Schumann - in IEEE TVCG 17(4)

### TREE VISUALIZATIONS

- can be categorized by
  - edge representations (implicit, explicit)
  - dimensionality of layout
  - radial vs. axis-parallel
- can be modified by
  - layout parameters
  - which marks are used
  - visual variables on marks (which meta-data is represented?)

### **GRAPHS / NETWORKS**

## DEFINITION GRAPH

- A set of **vertices**  $V = \{v_i\}$
- A set of **edges**  $E = \{e_{ij}\}$  with  $e_{ij} = \{v_i, v_j\}$
- When the order of vertices of an edge is meaningful, the graph is directed

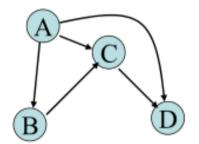
### GRAPH MEASURES

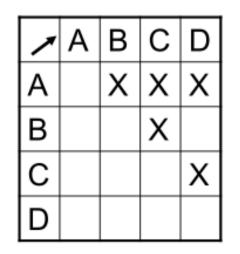
- SIZE = #nodes
- DENSITY = edges/vertices (roughly)
- PATH = sequence of edges connecting (different) vertices
- VERTEX DEGREE = #edge connections
- DISTANCE = #hops between vertices

## TWO CLASSICAL VISUAL REPRESENTATIONS

### Node-Link Diagram

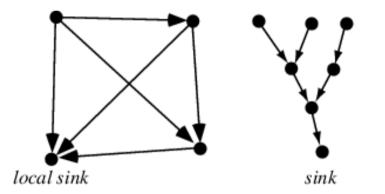
### **Adjacency Matrix**

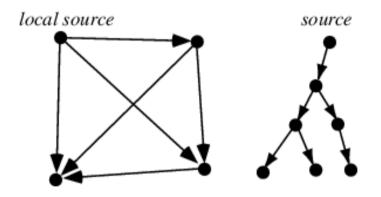




## TASKS

### Find # of neighbors of a vertex (e.g. source vs. sink)

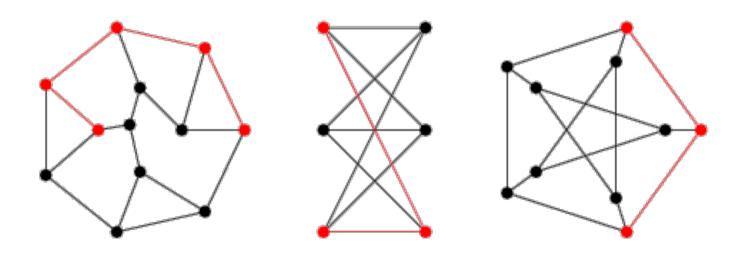




http://mathworld.wolfram.com/DigraphSink.html http://mathworld.wolfram.com/Source.html

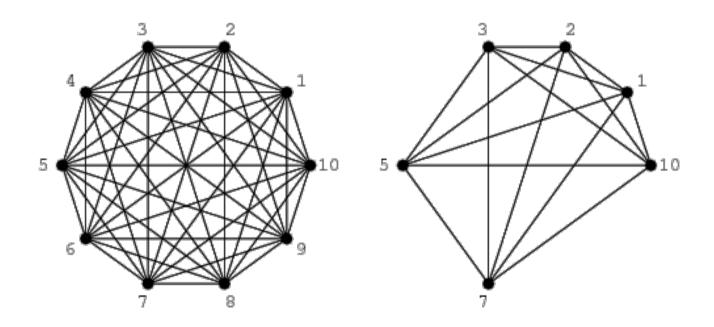
## TASKS

### See paths (overviews, shortest, cycles)



## TASKS

### **Identify Sub-graphs**



# TASKS

## **HIGHER-LEVEL**

involves many elements involves more human judgment

- which nodes are important?
- where are clusters?
- what are attribute and connection correlations?
- how does the network change over time?

## TASKS

- Many many more specific tasks
- Each application domain will add more

#### Task Taxonomy for Graph Visualization

Bongshin Lee, Catherine Plaisant, Cynthia Sims Parr Human-Computer Interaction Lab University of Maryland, College Park, MD 20742, USA

+1-301-405-7445

{bongshin, plaisant, csparr}@cs.umd.edu

#### ABSTRACT

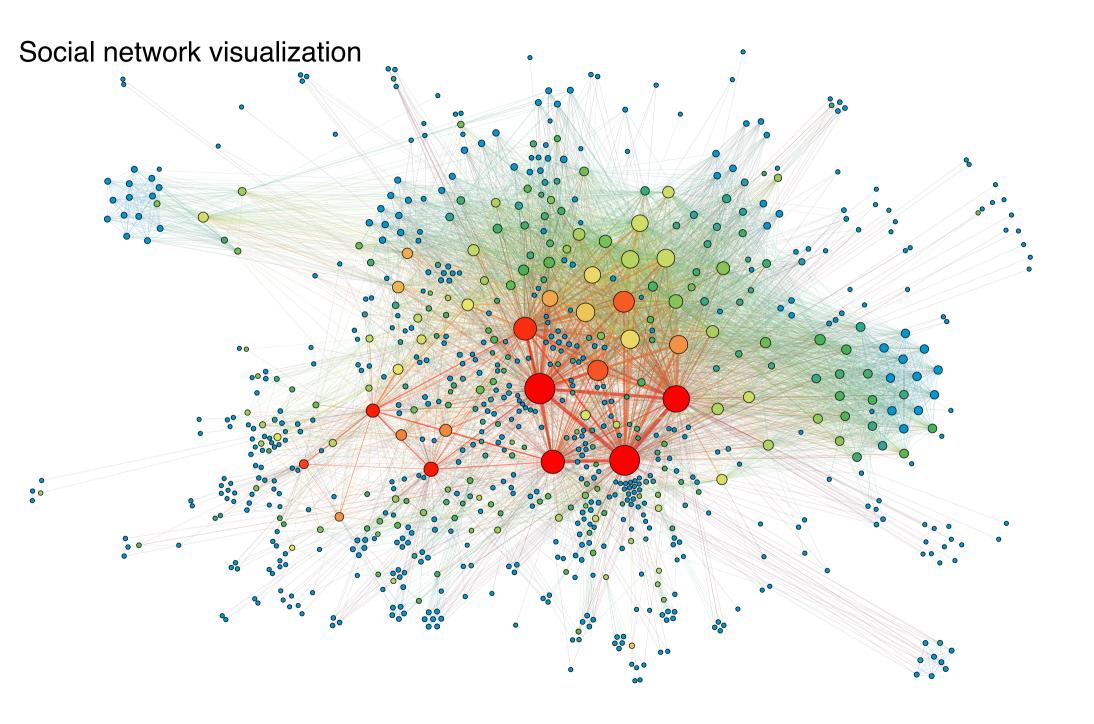
Our goal is to define a list of tasks for graph visualization that has enough detail and specificity to be useful to: 1) designers who want to improve their system and 2) to evaluators who want to compare graph visualization systems. In this paper, we suggest a list of tasks we believe are commonly encountered while analyzing graph data. We define graph specific objects and demonstrate how all complex tasks could be seen as a series of low-level tasks performed on those objects. We believe that our Jean-Daniel Fekete, Nathalie Henry INRIA Futurs/LRI Bat. 490 Université Paris-Sud, 91405 ORSAY, France

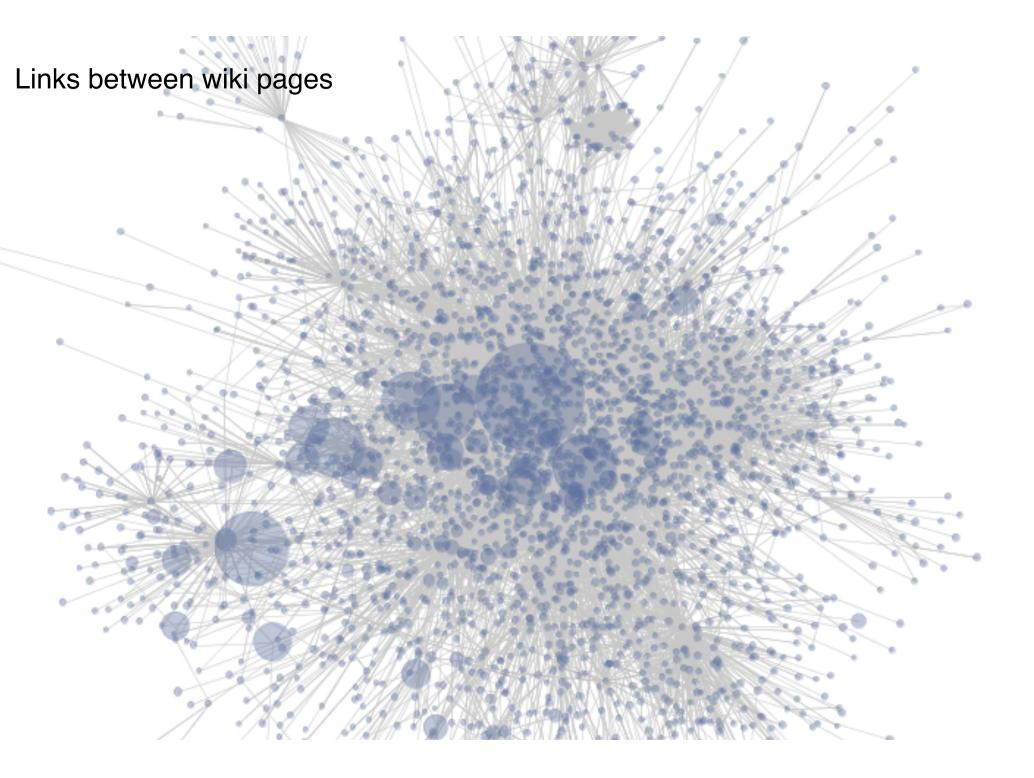
+33-1-69153460

Jean-Daniel.Fekete@inria.fr, nhenry@lri.fr

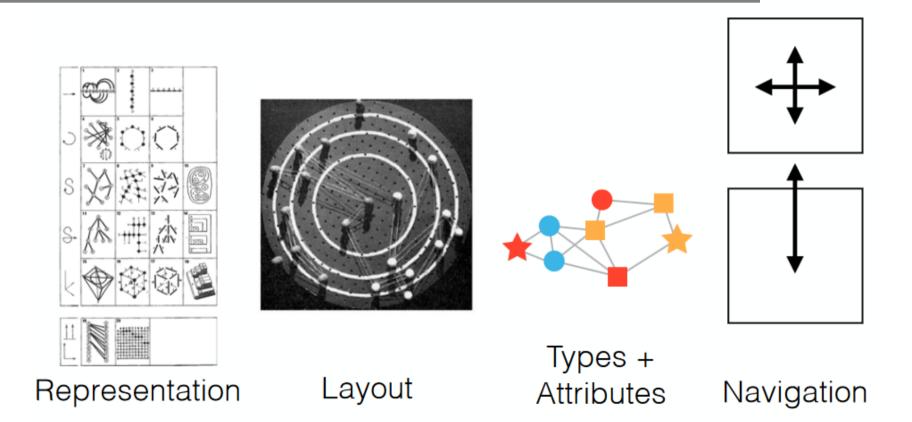
user studies of graph visualization techniques and extracted the tasks used in those studies.

After making those two lists, we considered the set of low-level Visual Analytics tasks proposed by Amar *et al.* [2]. These tasks were extracted from a corpus of questions about tabular data. We realized that our tasks all seem to be compound tasks made up of Amar *et al*'s primitive tasks applied to the graph objects. When some tasks could not be represented with those tasks and objects, we added either an object or a low-level task. In this paper, we





## GRAPH VISUALIZATION CHALLENGES



https://datascientistinsights.com/2014/02/18/art-of-resistance-the-socialnetwork-anatomy-of-a-kinetic-activist-group/

- determine if <u>Greenpeace</u> was or could become a significant disruptive geopolitical force
- first: identify who/what to concentrate resources on

https://datascientistinsights.com/2014/02/18/art-of-resistance-the-social-network-anatomy-of-a-kinetic-activist-group/

Data Scientist Insights EXPLORING THE DARKEST PLACES ON EARTH								
û	DATA SCIENCE	FIELD NOTE	TOOLS	VISUALIZATION	BIG DATA	R	CASE STUDY	
A	HOME > DATA SCIENCE > ART OF RESISTANCE – THE SOCIAL NETWORK ANATOMY OF A KINETIC ACTIVIST GROUP Art of Resistance – The Social Network Anatomy of a Kinetic Activist Group							9
	DI A KINELIC A Y DR. J on FEBRUARY 18,	2014 · 🔎 ( o ) As a data communit intelligenc	scientist that ty, we are ofter e gathering an	works in the intelligence n asked to help identify wh id analysis resources sho l and non-governmental				

## 1) get Facebook data using Netvizz

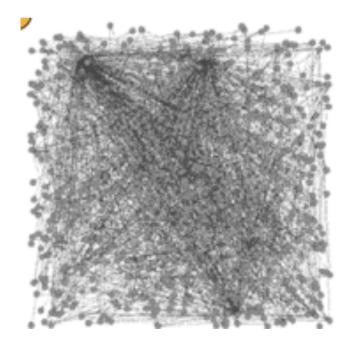
### Studying Facebook via Data Extraction: The Netvizz Application

Bernhard Rieder University of Amsterdam Turfdraagsterpad 9 1012TX Amsterdam rieder@uva.nl

#### ABSTRACT

This paper describes Netvizz, a data collection and extraction application that allows researchers to export data in standard file formats from different sections of the Facebook social networking service. Friendship networks, groups, and pages can thus be analyzed quantitatively and qualitatively with regards to demographical, postdemographical, and relational characteristics. The paper numerous publications employing conceptual and/or critical approaches. While traditional empirical methods such as interviews, experiments, and observations are widely used, a growing number of studies rely on what the authors call "data crawling", i.e. "gleaning information about users from their profiles without their active participation" [19]. This paper presents a software tool, Netvizz, designed to facilitate this latter approach

## 2) load the data into Gephi https://gephi.org/



585 nodes, interconnected by 1788 edges.

"Somewhere in that spaghetti is a potential bad guy, but where?"

# 3) choose a layout algorithm that makes sense for social networks Force Atlas 2



provides some transparency into the network but still lacks any real clarity around behavioral importance

## 4) map an attribute to size of the nodes

betweenness centrality (number of shortest paths from all vertices to all others that pass through that node)

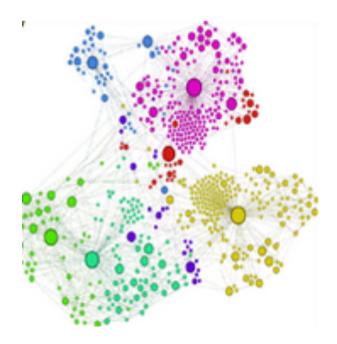


Bigger nodes are more central to behavioral dynamics.

Several nodes become central figures in the overall network.

## 5) highlight communities

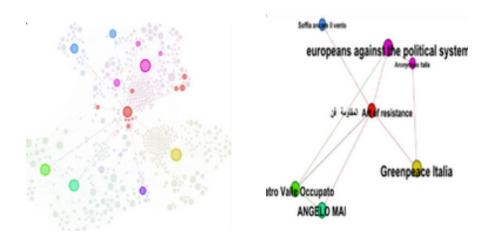
color nodes by modularity / clusters



We now begin to see a clearer picture of who is doing what with whom.

What becomes really interesting at this stage is understanding some of the more nuanced relationships.

## 6) filter, explore, label



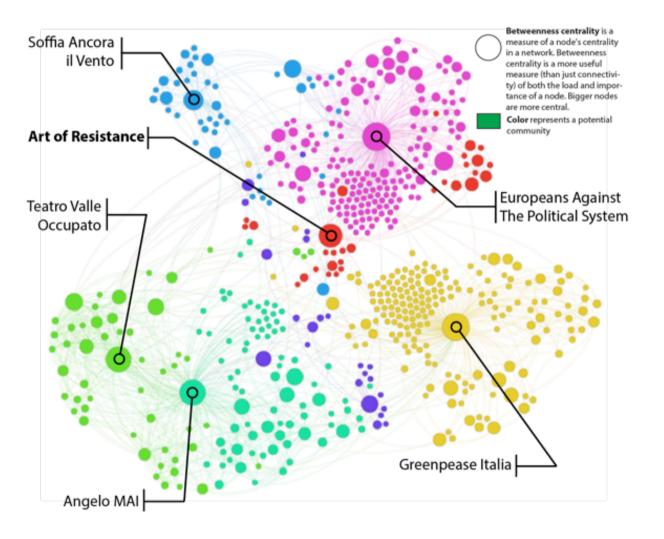
Five outlying nodes in the network (blue, maroon, yellow, dark green, and light green).

Center: an equally important red node

Emergence of a previously un-recognized activism player: <u>Art of Resistance</u>.



7) communicate& explain





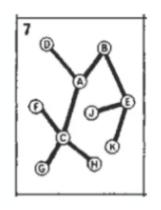
### Important to the success of your analysis

# LAYOUT FREE

**Force Directed** 

- Physical forces
- Proximity based
- Spring Model
- Kamanda&Kawai
- Frucherman&Reingold
- Davidson&Harel
- LinLog







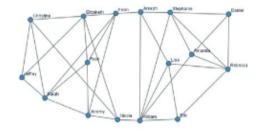
Aesthetic Criteria

- Reduce number of edge crossing
- Foster Symmetry
- Uniform edge length
- Aspect Ratio
- Equal Angles
- •

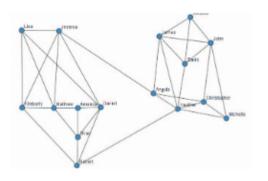
**GRAPH DRAWING** 

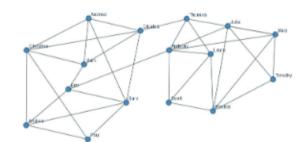


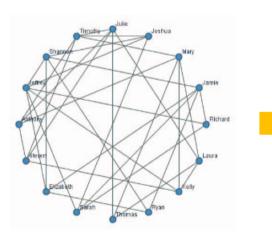


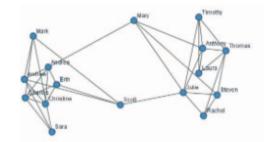


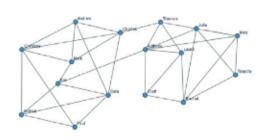
## HAND MADE







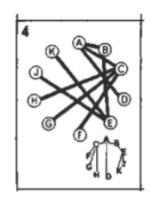


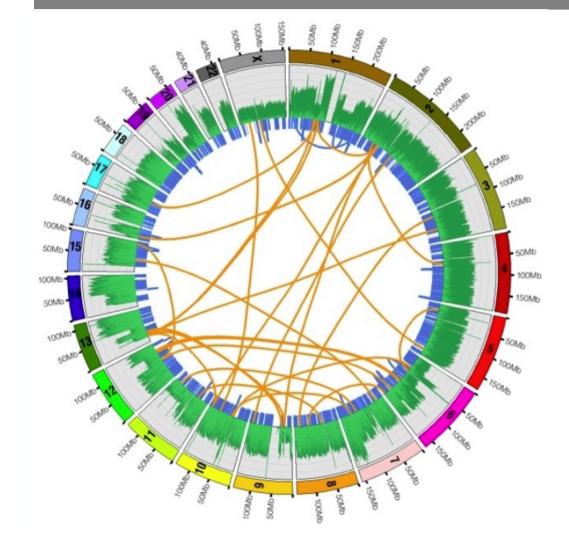




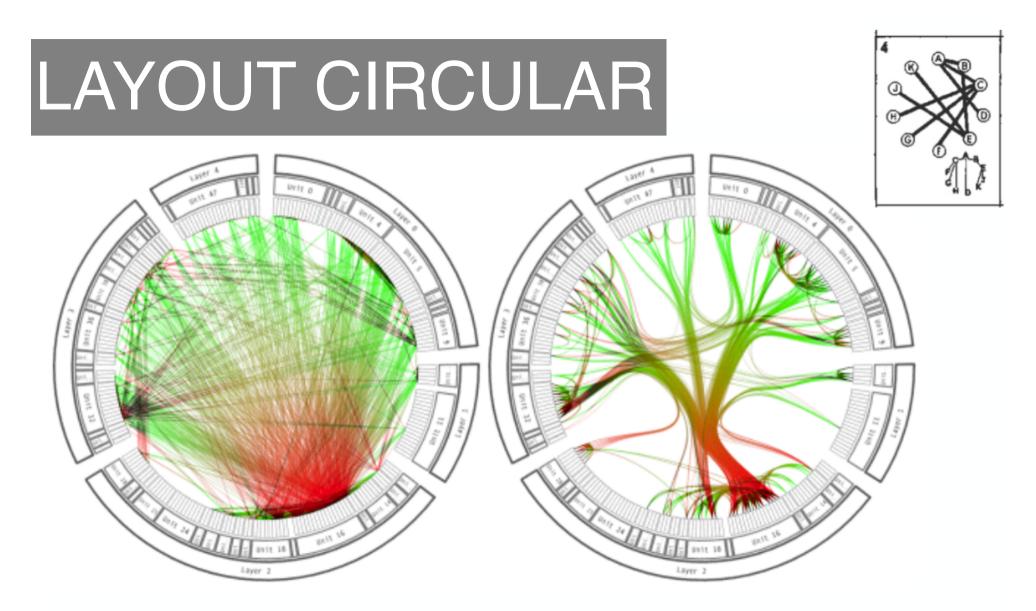
ptual organization in user-generated graph layouts lam, F.J.J.; Rogowitz, B.

## LAYOUT CIRCULAR

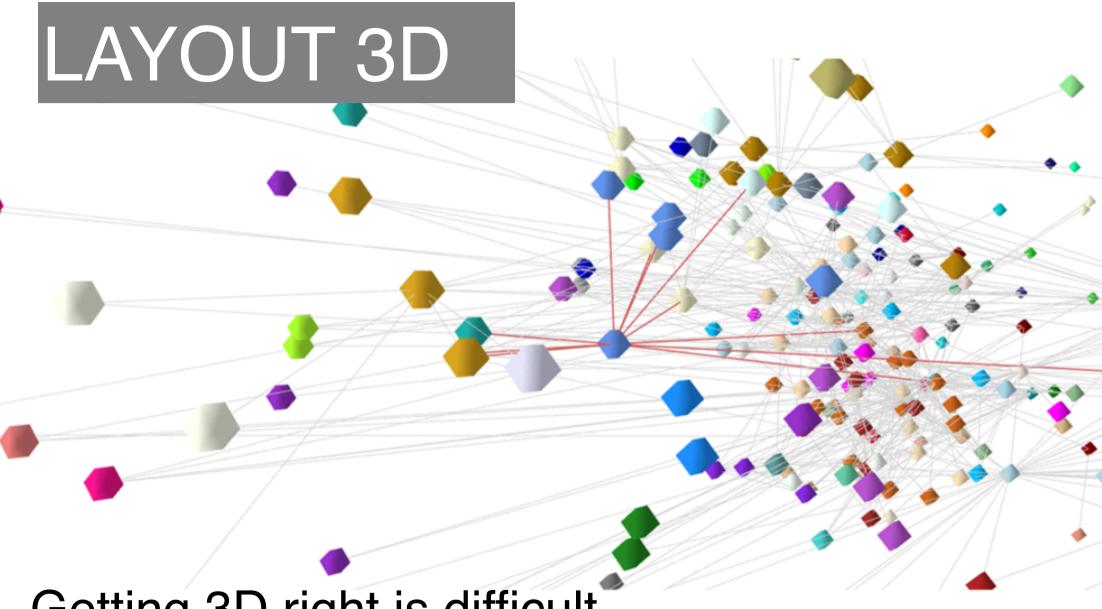




- Edges on the inside
- Vertices & attributes on the outside
- Ordering possible



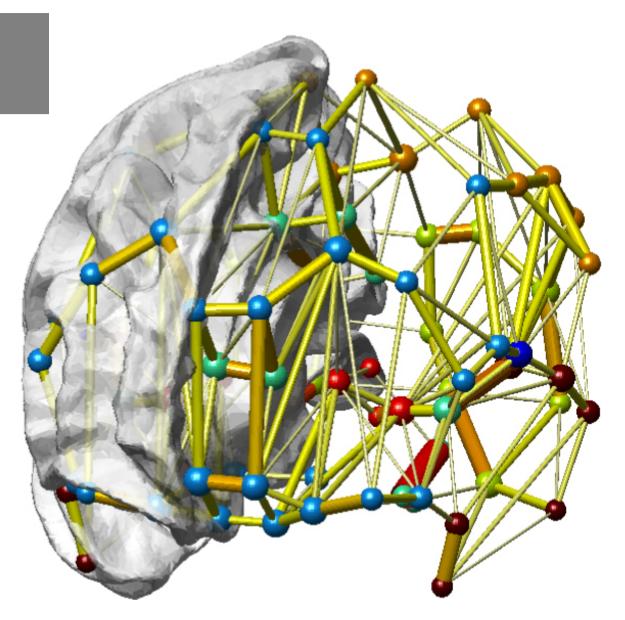




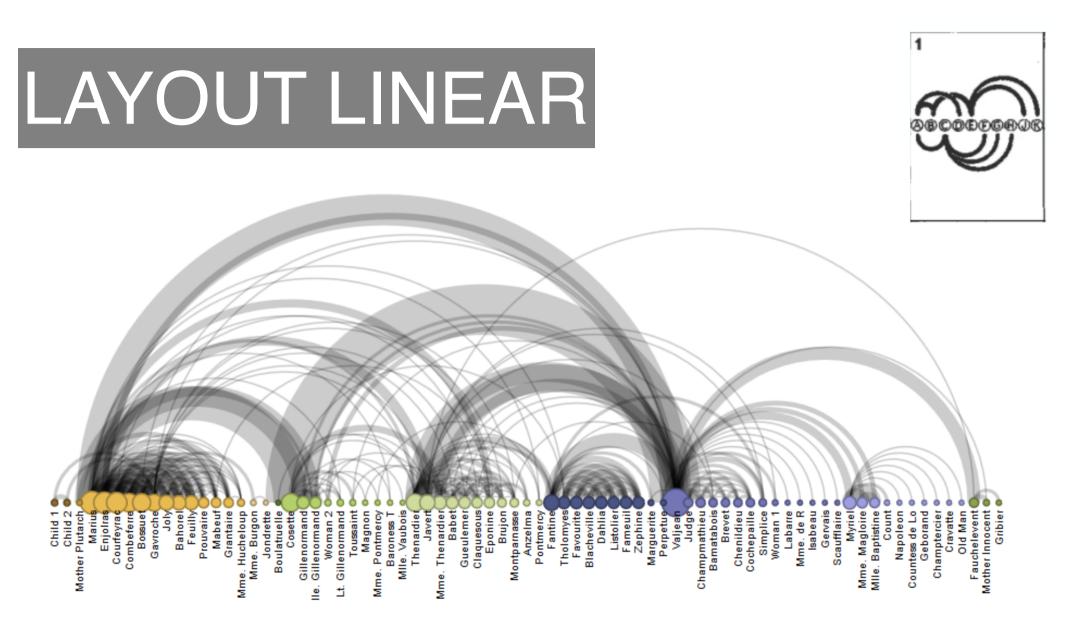
Getting 3D right is difficult https://fwaris.wordpress.com/2012/07/08/a-simple-technique-forcreating-3d-graphs-from-2d-ones/

# LAYOUT 3D

## Sometimes necessary (!?)

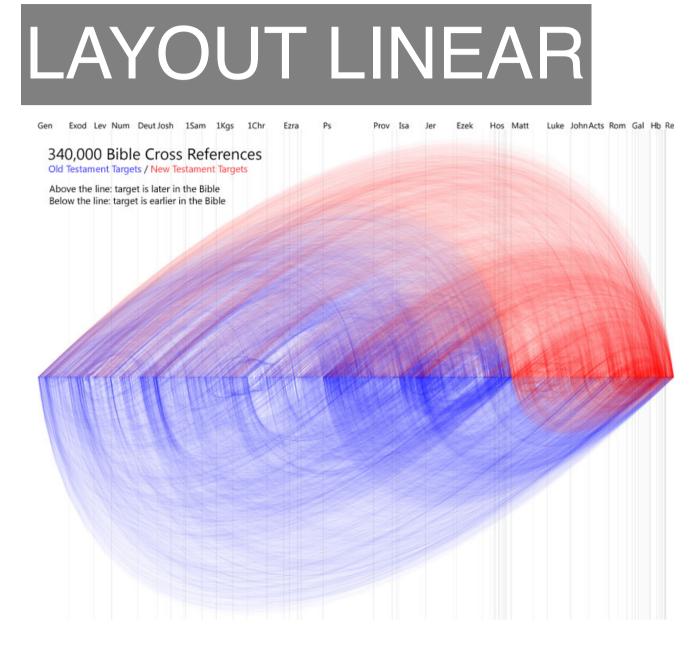


http://gephi.forumatic.com/viewtopic.php?f=26&t=2616



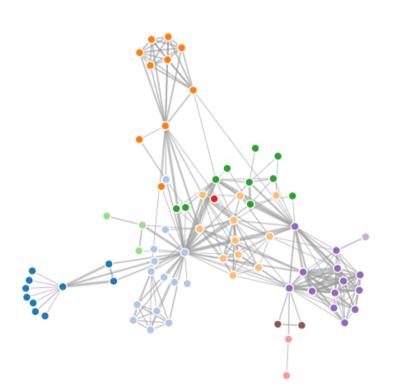
http://mbostock.github.io/protovis/ex/arc-full.html

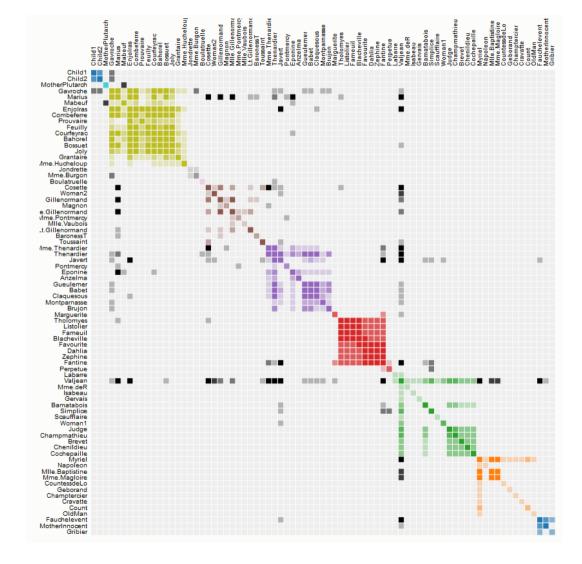
http://www.bewitched.com/song.html



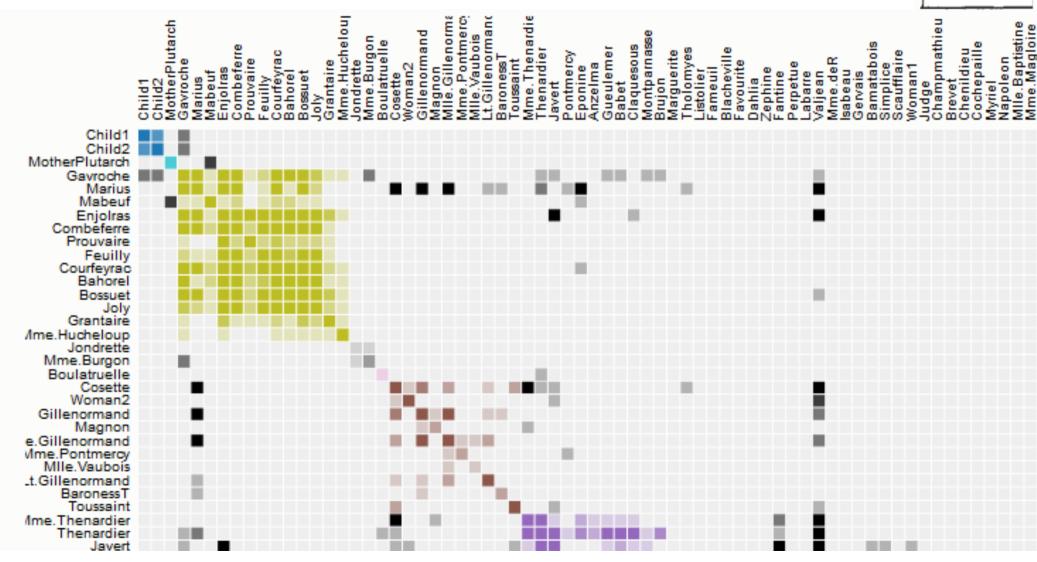
https://www.openbible.info/ labs/cross-references/

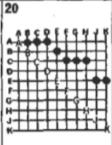
## LAYOUT ADJACENCY MATRIX





## ADJACENCY MATRIX





# PROS/CONS

### Matrix

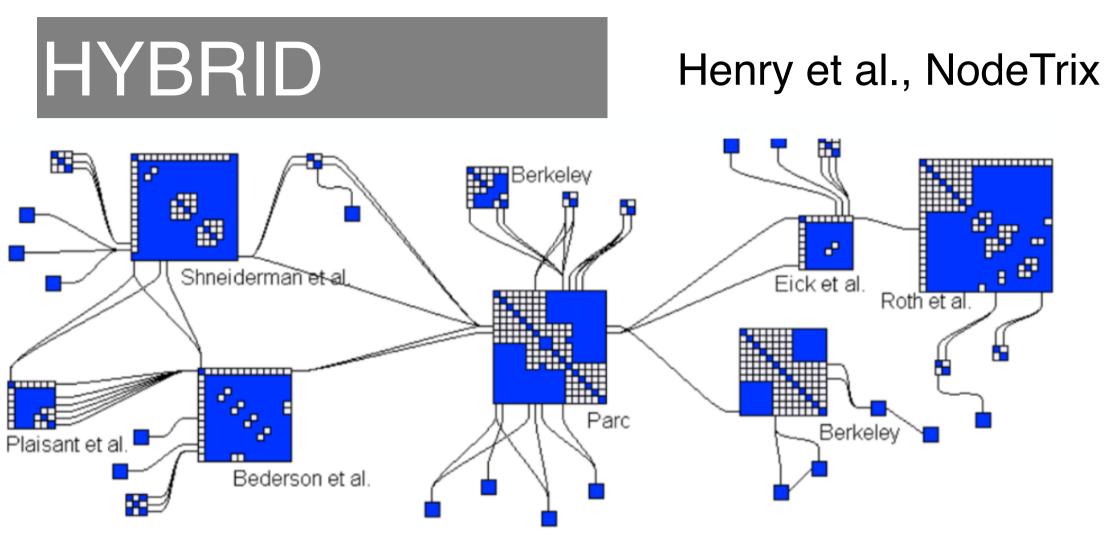
- No vertex/edge overlap or crossings
- Readable for dense graph
- Fast navigation

### Node-Link

- Familiar
- Compact
- Path following easier
- Effective for small and sparse graphs

- Less familiar
- Space intensive
- Weak for path following tasks

- Useless without layout
- Not readable for dense graphs
- Manipulation requires layout computation



Infovis Coauthorship (133 actors)

Dense = matrices, sparse = node-link

# MULTIVARIATE NETWORKS

#### Network Visualization by Semantic Substrates

Ben Shneiderman and Aleks Aris University of Maryland, HCIL

Copyright 2006

https://www.youtube.com/watch?v=f3hmn7gvocQ

## MULTIVARIATE NETWORKS

Type B

### Type A

LAaron Linus I Adam Blackwell I Alameda I Aquatics I Arthur Swordane Assan I Brandow Tropical Fish Catherine Carnes I Cesar Gil I Collie Carnes I Cr Wharton Don Rabinowitz Donna Ghostley I Ed Parker I Edward Abbey I Eva Berrima I Faron Gardner I Gardner Green I Griffin Vulture Jeri Ryan I Jessica Alba John Burton Wade Liohn Wharton I Kim I Kim Basinger I Leslie I Lily Luella Vedric I Madhi Kim I Marcus James I Melissa Ethridge I Michael Jackson I Oogjes I Paul McCartney I r'Bear I Richmond I Richmond Shire I Sinder I songwriter Jimmy Buffett I Spix I Terry Mulley **Tony Jones** 

#### AIL Animal Justice League I Animals Australia Glenys Oogjes **Banfield Hospital** Broadway Hotel I CDC I Centers for Disease Control and Preve. I Chiron I CITES I Department of Health I DOA Earth Liberation Front | Eighth Annual Society ELF FBI I Fish and Wildlife Service I Florida Department **FWS** I FWS Special Agent I Global Ways Justice League I La Trobe University Louisiana State University I Mary Washington College I Miami Beach Convention Center **PETA** I Richmond Shire Council I Sanchez I Shravaana SPEAC SPOMA Tamarack News Service I U.S. Fish and Wildlife Service I University of California Medical Center I US Department of Agriculture

#### Los Angeles I Africa Connecticut Lily Louisiana State Manchester New York Southern California U.S. United States I US I Alabama I Australia California I Florida I Henrico County I Kemp I Kenva I Melbourne I Miami I Ms I New Guinea I Northeast Congo I Proa Station I San Diego I South America Texas I Toowoomba

Type C

#### **Jigsaw,** Stasko et al., 2008

## MULTIVARIATE NETWORKS

### GraphDice: A System for Exploring Multivariate Social Networks

A. Bezerianos F. Chevalier P. Dragicevic N. Elmqvist J-D. Fekete

INRIA École Centrale Paris Purdue University

https://voutu.be/NLiHw5B0Mco

# ADDITIONAL CHALLENGES

- TIME
- INTERACTION
- EDGE DIRECTION

# NETWORK TOOLS

- · Gephi
- · Cytoscape
- · Pajek
- Java Jung toolkit
- **D3** + Cola.js

# ACKNOWLEDGEMENTS

Slides in were inspired and adapted from slides by

- Sheelagh Carpendale (University of Calgary)
- Pat Hanrahan (Stanford University)
- Benjamin Bach (University of Edinburgh)
- Jean-Daniel Fekete (Inria)