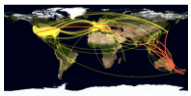
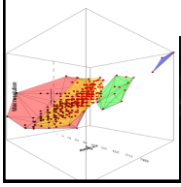
Aviz

Visual Analytics Project




# Visualization of Complex Networks

Jean-Daniel Fekete
INRIA
http://www.aviz.fr/~fekete





# Visualization?

**Visualization** is any technique for creating images, diagrams, or animations to *communicate a message*

[Wikipedia, Visualization, May 2016]

**Information visualization** is the study of (interactive) visual representations of abstract data to *reinforce human cognition*

[Card, S. and Mackinlay, J. and Shneiderman B., Readings in Information Visualization, 1999]

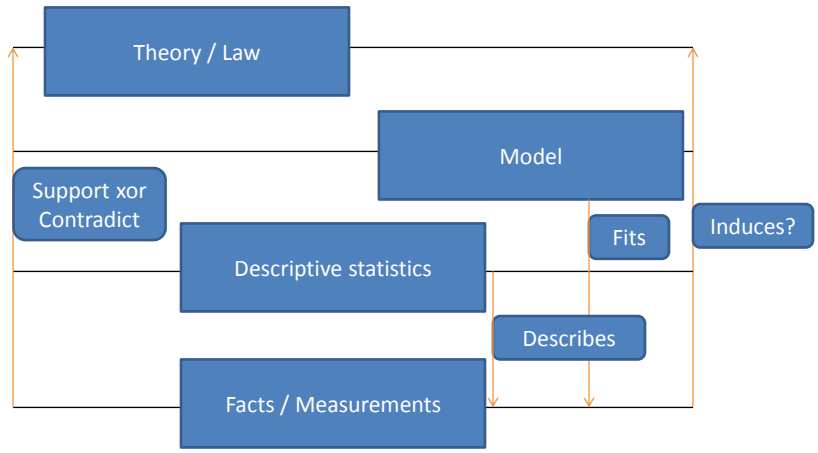
# Network Visualization

Information visualization applied to network structures:

- The study of interactive visual representations of *networks* to reinforce human cognition



# Where does Visualization Stands?



# Example

| I | | II | | III | | IV | |
|---|---|---|---|---|---|---|---|
| x | y | x | y | x | y | x | y |
| 10.0 | 8.04 | 10.0 | 9.14 | 10.0 | 7.46 | 8.0 | 6.58 |
| 8.0 | 6.95 | 8.0 | 8.14 | 8.0 | 6.77 | 8.0 | 5.76 |
| 13.0 | 7.58 | 13.0 | 8.74 | 13.0 | 12.74 | 8.0 | 7.71 |
| 9.0 | 8.81 | 9.0 | 8.77 | 9.0 | 7.11 | 8.0 | 8.84 |
| 11.0 | 8.33 | 11.0 | 9.26 | 11.0 | 7.81 | 8.0 | 8.47 |
| 14.0 | 9.96 | 14.0 | 8.10 | 14.0 | 8.84 | 8.0 | 7.04 |
| 6.0 | 7.24 | 6.0 | 6.13 | 6.0 | 6.08 | 8.0 | 5.25 |
| 4.0 | 4.26 | 4.0 | 3.10 | 4.0 | 5.39 | 19.0 | 12.50 |
| 12.0 | 10.84 | 12.0 | 9.13 | 12.0 | 8.15 | 8.0 | 5.56 |
| 7.0 | 4.82 | 7.0 | 7.26 | 7.0 | 6.42 | 8.0 | 7.91 |
| 5.0 | 5.68 | 5.0 | 4.74 | 5.0 | 5.73 | 8.0 | 6.89 |

Raw Data from Anscombe's Quartet



[Source: Anscombe's quartet, Wikipedia]

# Statistical Analysis

For all columns, the main descriptive statistics are identical

| I | | II | | III | | IV | |
|---|---|---|---|---|---|---|---|
| x | y | x | y | x | y | x | y |
| 10.0 | 8.04 | 10.0 | 9.14 | 10.0 | 7.46 | 8.0 | 6.58 |
| 8.0 | 6.95 | 8.0 | 8.14 | 8.0 | 6.77 | 8.0 | 5.76 |
| 13.0 | 7.58 | 13.0 | 8.74 | 13.0 | 12.74 | 8.0 | 7.71 |
| 9.0 | 8.81 | 9.0 | 8.77 | 9.0 | 7.11 | 8.0 | 8.84 |
| 11.0 | 8.33 | 11.0 | 9.26 | 11.0 | 7.81 | 8.0 | 8.47 |
| 14.0 | 9.96 | 14.0 | 8.10 | 14.0 | 8.84 | 8.0 | 7.04 |
| 6.0 | 7.24 | 6.0 | 6.13 | 6.0 | 6.08 | 8.0 | 5.25 |
| 4.0 | 4.26 | 4.0 | 3.10 | 4.0 | 5.39 | 19.0 | 12.50 |
| 12.0 | 10.84 | 12.0 | 9.13 | 12.0 | 8.15 | 8.0 | 5.56 |
| 7.0 | 4.82 | 7.0 | 7.26 | 7.0 | 6.42 | 8.0 | 7.91 |
| 5.0 | 5.68 | 5.0 | 4.74 | 5.0 | 5.73 | 8.0 | 6.89 |

| | |
|---|---|
| Mean of $x$ | 9.0 |
| Variance of $x$ | 11.0 |
| Mean of $y$ | 7.5 |
| Variance of $y$ | 4.12 |
| Correlation between $x$ and $y$ | 0.816 |
| Linear regression line | $y = 3 + 0.5x$ |

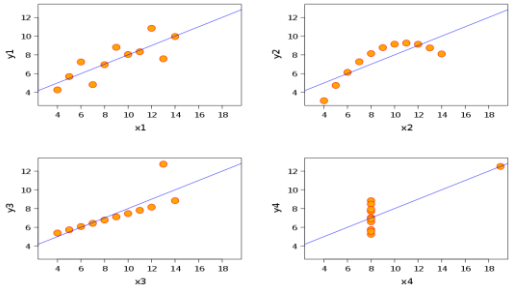


[Source: Anscombe's quartet, Wikipedia]

# Visual Representation of the Data

## Visual representation reveals a different story

| I | | II | | III | | IV | |
|---|---|---|---|---|---|---|---|
| x | y | x | y | x | y | x | y |
| 10.0 | 8.04 | 10.0 | 9.14 | 10.0 | 7.46 | 8.0 | 6.58 |
| 8.0 | 6.95 | 8.0 | 8.14 | 8.0 | 6.77 | 8.0 | 5.76 |
| 13.0 | 7.58 | 13.0 | 8.74 | 13.0 | 12.74 | 8.0 | 7.71 |
| 9.0 | 8.81 | 9.0 | 8.77 | 9.0 | 7.11 | 8.0 | 8.84 |
| 11.0 | 8.33 | 11.0 | 9.26 | 11.0 | 7.81 | 8.0 | 8.47 |
| 14.0 | 9.96 | 14.0 | 8.10 | 14.0 | 8.84 | 8.0 | 7.04 |
| 6.0 | 7.24 | 6.0 | 6.13 | 6.0 | 6.08 | 8.0 | 5.25 |
| 4.0 | 4.26 | 4.0 | 3.10 | 4.0 | 5.39 | 19.0 | 12.50 |
| 12.0 | 10.84 | 12.0 | 9.13 | 12.0 | 8.15 | 8.0 | 5.56 |
| 7.0 | 4.82 | 7.0 | 7.26 | 7.0 | 6.42 | 8.0 | 7.91 |
| 5.0 | 5.68 | 5.0 | 4.74 | 5.0 | 5.73 | 8.0 | 6.89 |

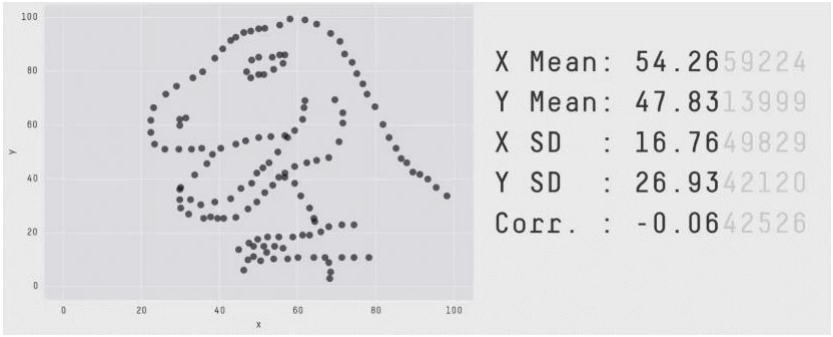




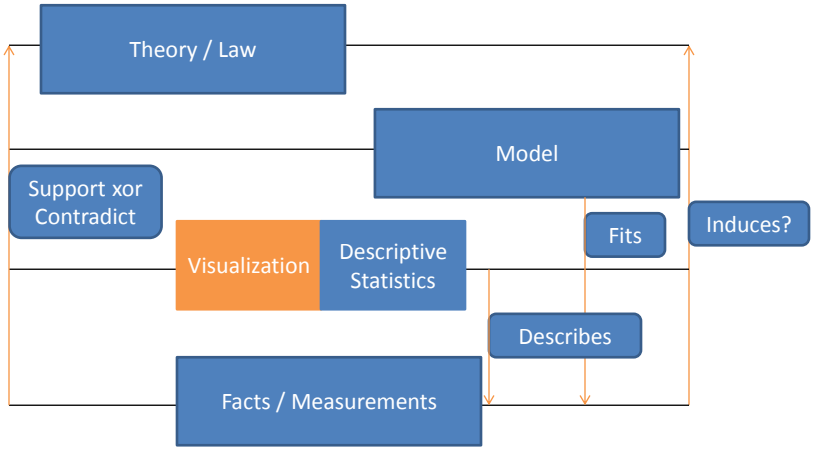

[Source: Anscombe's quartet, Wikipedia]

**Same Stats, Different Graphs: Generating Datasets with Varied Appearance and Identical Statistics through Simulated Annealing [CHI17]**

https://www.autodeskresearch.com/publications/samestats



# Where does Visualization Stands?

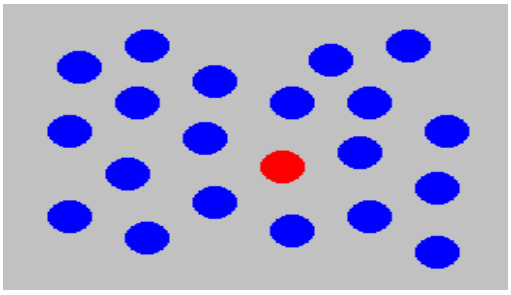




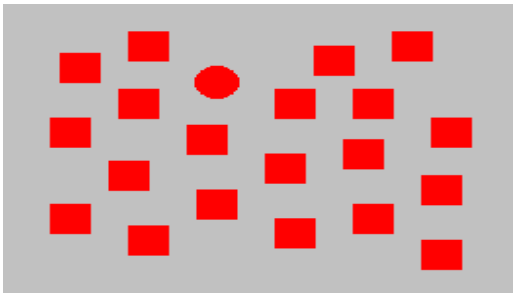

# Visualization and Visual Perception

- Visualization is grounded in the visual and cognitive capabilities of humans
  - Inferring from visual forms
- Relies on visual capabilities of the human eye and brain
  - Preattentive processing
  - Ready…is there a red circle in the next slide?

## Preattentive Processing



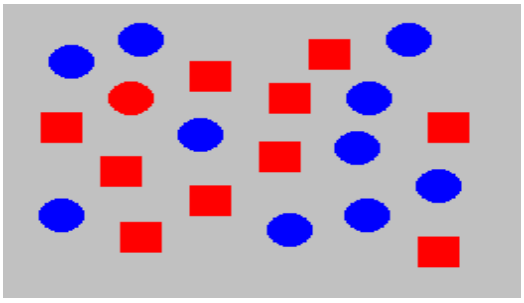
## Preattentive Processing



# Preattentive Processing

- Preattentive processing
  - 200ms response time (in a glimpse)
  - Effortless
  - Reliable estimates
- Many visual features can be perceived preattentively:
  - Orientation of line/bloc, length, width, size, curvature, cardinality, etc.
- Problems:
  - Preattentive features interfere with each other
    - Except one
  - Preattentive features have limitations
    - 7 colors max (Healey, 96)
    - 2 or 3 shapes

# Preattentive Processing



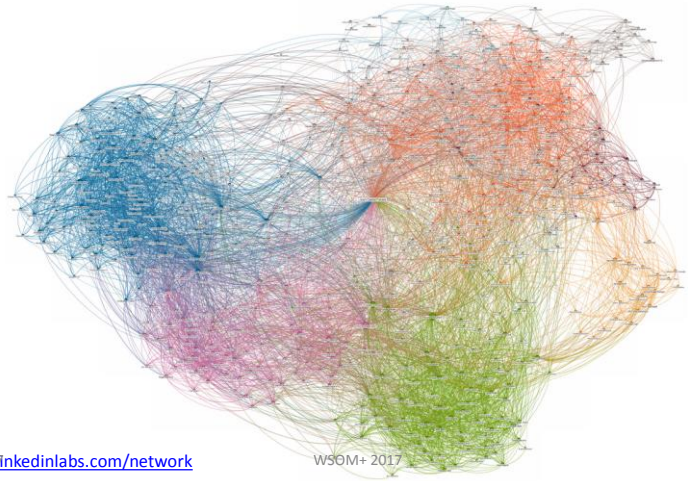
# Network Visualization

- Most (99%) network visualization tools use the node-link visual representation
- Other representations exist, more or less general
- Why use one or another?
  - Efficiency (to be defined)
  - Familiarity



# Facebook Network Dec. 2010

# LinkedIn Profession Network

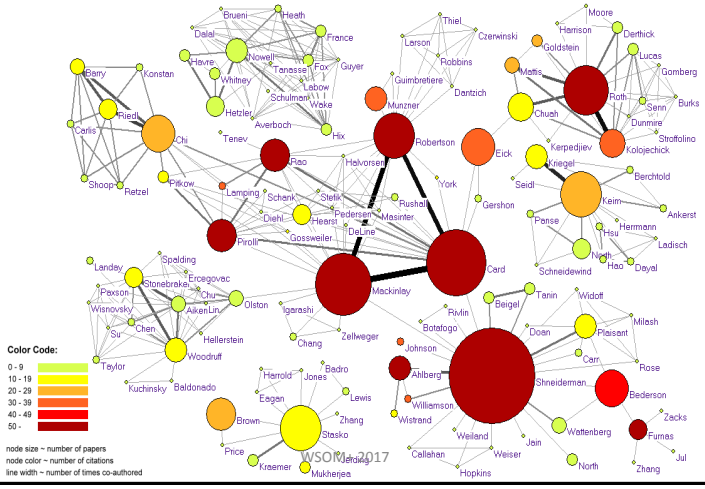


http://inmaps.linkedinlabs.com/network

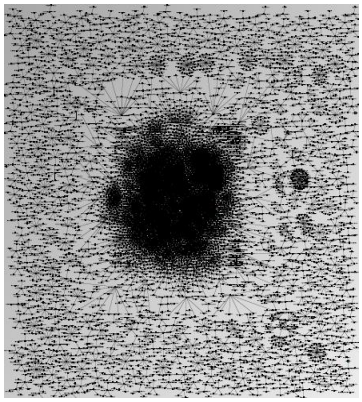


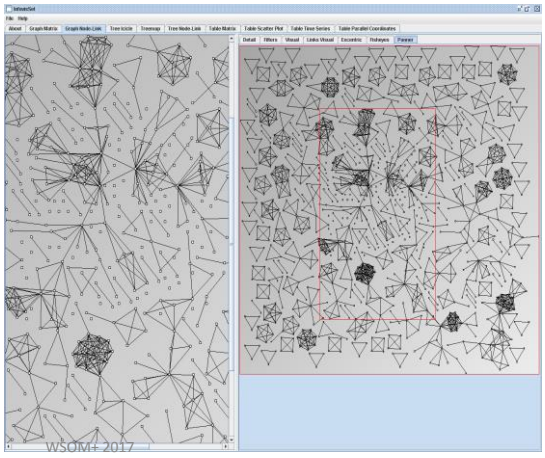
# InfoVis Co-authoring

(K. Börner et al. 04)



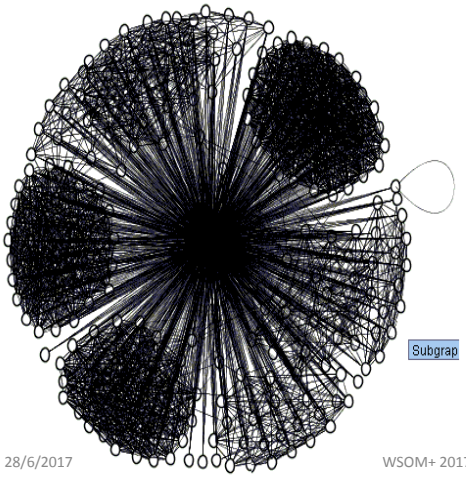
# Generally, after loading…

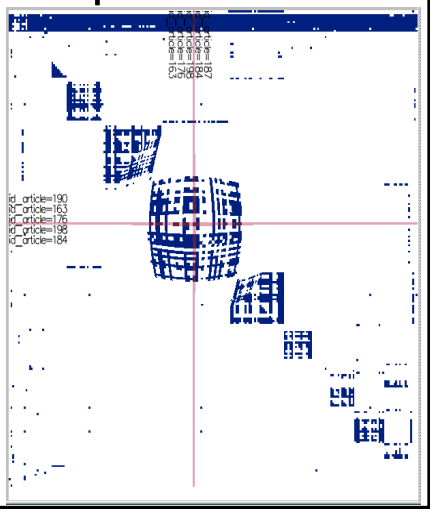




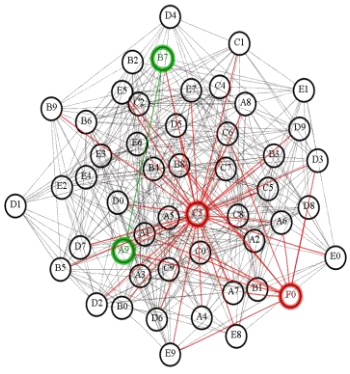


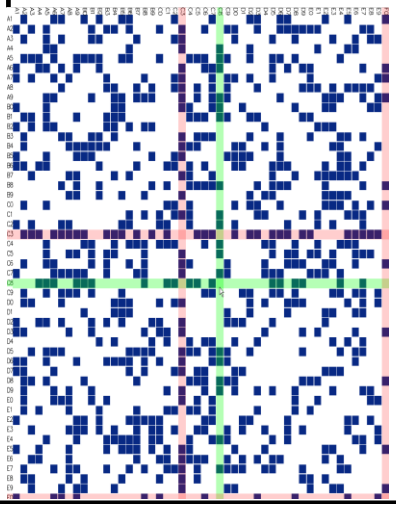
# Web Site Example



# Readability Experiment







## Controlled Experiment: Node Link Diagrams vs. Adjacency Matrices

**The Tasks:**

- Tasks related to the overview
  - Number of vertices
  - Number of arcs
- Tasks related to graph elements
  - Finding an element (a vertex, a link)
  - Finding the most connected vertex (a central actor, a pivot, a hub)
  - Finding a common neighbor
  - Finding a path
- Random graphs (3 sizes et 3 densities)
- 2 representations: Node-Link + Matrix

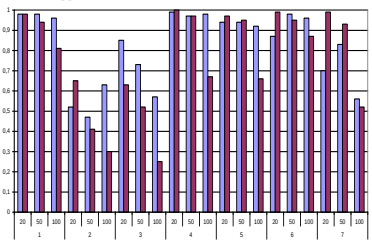
**Results:**

- Node-link diagrams are preferable for small sparse graphs (20 vertices)

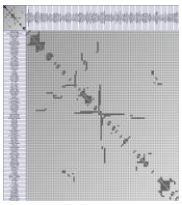
**Matrices are more readable *wrt* dense graphs and medium/large graphs ( > 20 vertices) *wrt* the selected tasks, except path finding**

**References:**

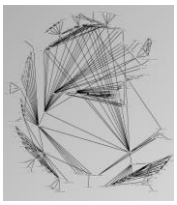
Mohammad Ghoniem, Jean-Daniel Fekete and Philippe Castagliola *Readability of Graphs Using Node-Link and Matrix-Based Representations: Controlled Experiment and Statistical Analysis*, Information Visualization Journal, 4(2), Palgrave Macmillan, Summer 2005, pp. 114-135.



Percentage of correct answers for the 7 tasks, 3 densities and 2 representations. NL in purple, Matrix in blue



# Matrix vs. Node-Link



**+**

- Usable without reordering
- No node overlapping
- No edge crossing
  - ➔ Readable for dense graphs
- Fast navigation
- Fast manipulation
  - ➔ Usable interactively
- More readable for some tasks

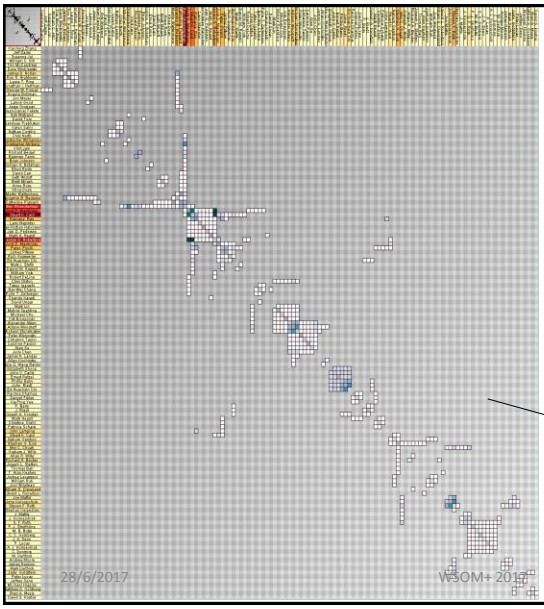
**−**

- Less familiar
- Use more space
- Weak for path following tasks

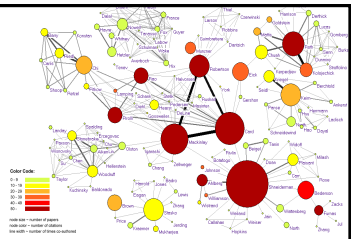
- Familiar
- Compact
- More readable for path following
- More effective for small graphs
- More effective for sparse graphs

- Useless without layout
- Node overlapping
- Edge crossing
  - ➔ Not readable for dense graphs
- Manipulation requires layout computation



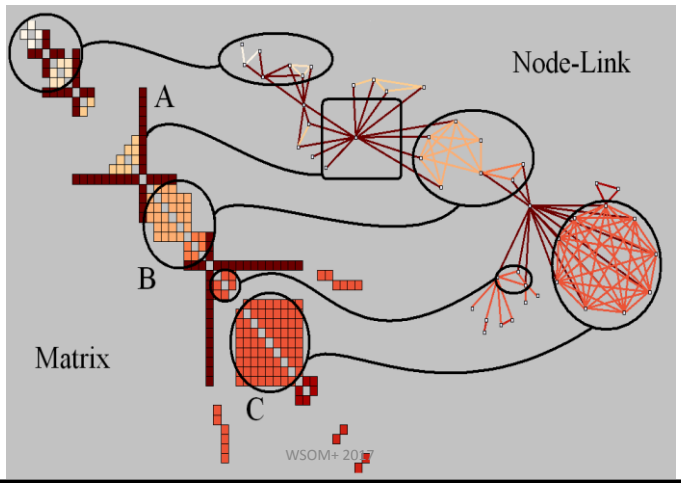


Explore



Communicate

## Visual Patterns with Ordered Matrices

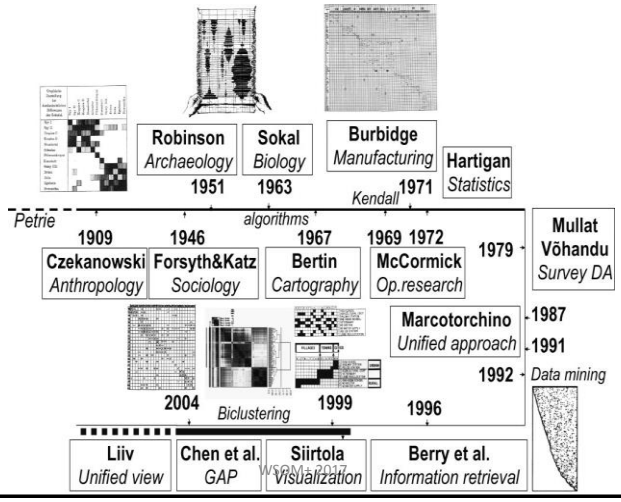





## The Ordering Problem

- Seriation instead of clustering
  - Finding a linear order for rows and columns
  - Postpone the decision of separating into clusters
  - Avoid creating clusters when they don't make sense
- Naïve approach:
  - Define an objective function (e.g. favor diagonal placement and dense blocks)
  - Try all permutations and keep the best wrt the function
- Problem: for a n×m table, there are n!×m! permutations
- Problem 2: there is no consensual objective function

## Liiv: visual abstract of the history of seriation from different disciplines






# Seriation and Matrix Ordering

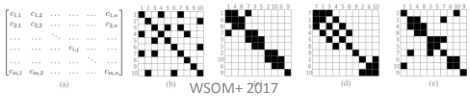
Innar Liiv, **Seriation and Matrix Reordering Methods: An Historical Overview**, Statistical analysis and data mining, 2010 – Wiley

Michael Behrisch, Benjamin Bach, Nathalie Henry Riche, Tobias Schreck, Jean-Daniel Fekete. **Matrix Reordering Methods for Table and Network Visualization**. Computer Graphics Forum, Wiley, 2016, 35, pp.24.

**Matrix Reordering Methods for Table and Network Visualization**

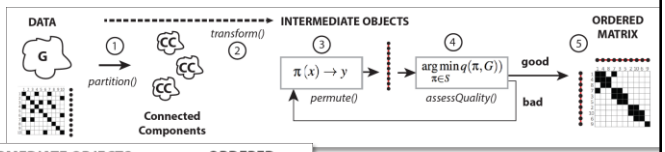
Michael Behrisch[1], Benjamin Bach[2], Nathalie Henry Riche[3], Tobias Schreck[4], Jean-Daniel Fekete[5]

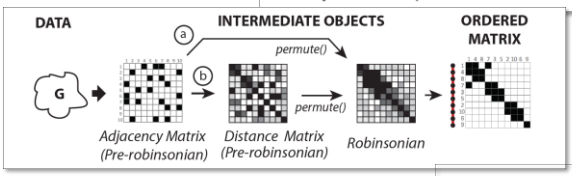
[1]Universität Konstanz, Germany
[2]Microsoft Research-Inria Joint Centre, France
[3]Microsoft Research, USA
[4]University of Technology Graz, Austria
[5]Inria, France



# Matrix Ordering Pipeline

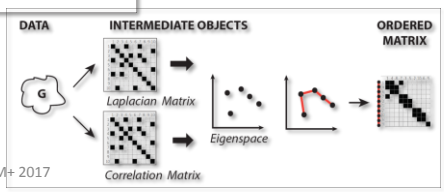
- Generic




Robinsonian Approach

Spectral Approach

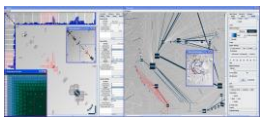


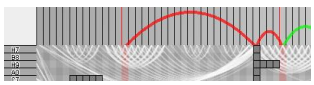


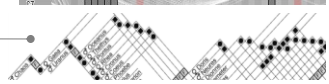

## Advances in Network Visualization: Improving Matrices

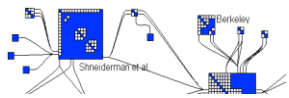
Several representations:

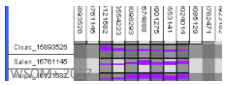
1. **Combined**
   - MatrixExplorer (Henry&Fekete InfoVis'06)
2. **Augmented**
   - MatLink (Henry&Fekete Interact'07, Best Paper)
   - GeneaQuilts (Bezerianos et al. InfoVis'10)
3. **Hybrid**
   - NodeTrix (Henry et al. InfoVis'07)
   - CoCoNutTrix (Isenberg et al. CG&A'09)
4. **Multiscale**
   - ZAME (Elmqvist et al. PacificVis'08)

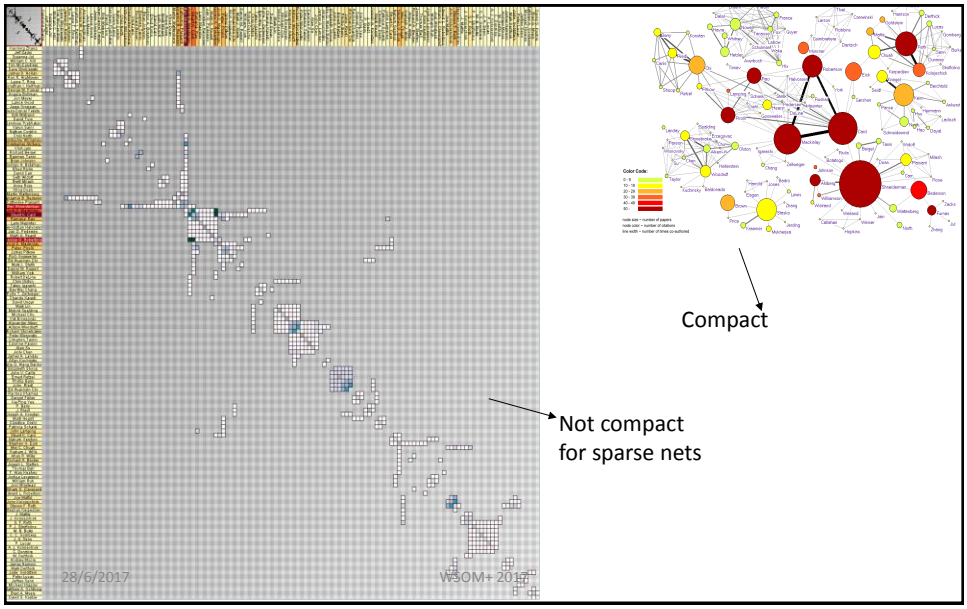








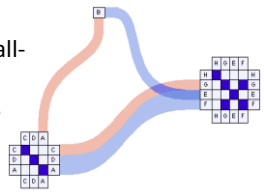



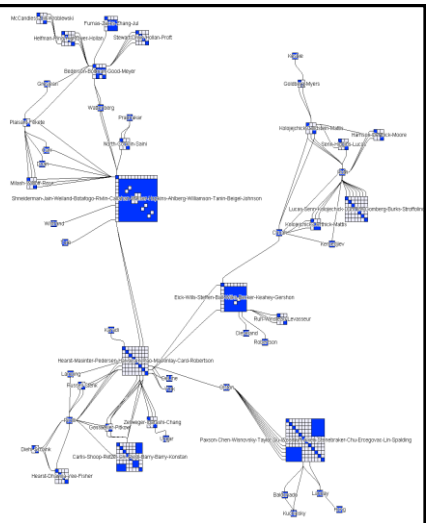



# NodeTrix [Henry et al.07]

Hybrid representation

- Designed for small-world networks
  - Globally sparse
  - Locally dense
- Visualizing dense sub-graphs as matrices
- Interact to create, edit and remove the matrices



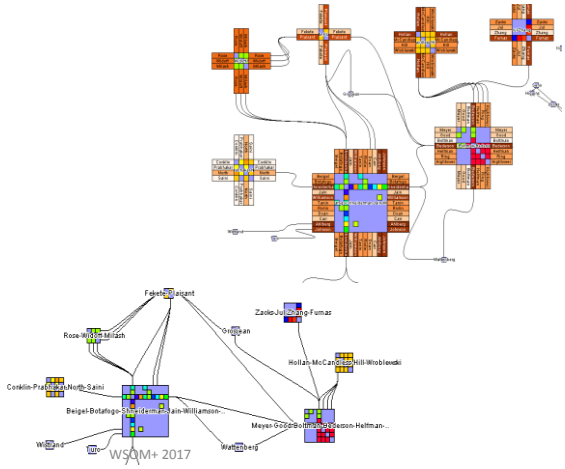


# NodeTrix: the NetVis Nirvana?

- ✓ Can you see every node?
- ✓ Can you count each node's degree?
- ✓ Can follow every link from its source to its destination?
- ✓ Can you identify clusters and outliers?

- Node Labels
- Link Labels (excentric labels?!)
- … even cluster labels
- Node Attributes
- Link Attributes
- … even clusters attributes
- Directed Graph (links width?!)

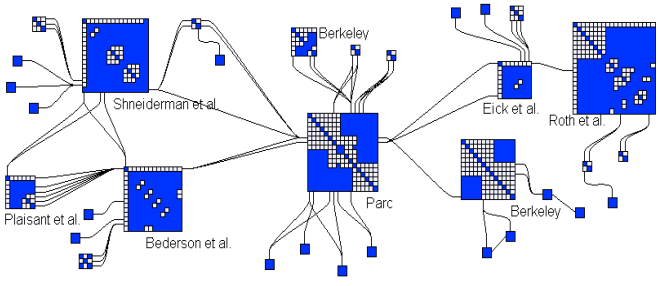
… But… beware the graphics overload!

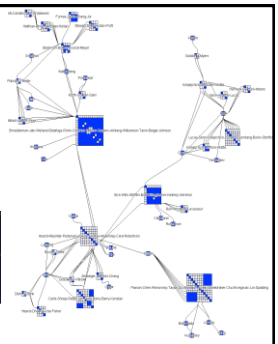




# Visual Patterns

https://github.com/IRT-SystemX/nodetrix

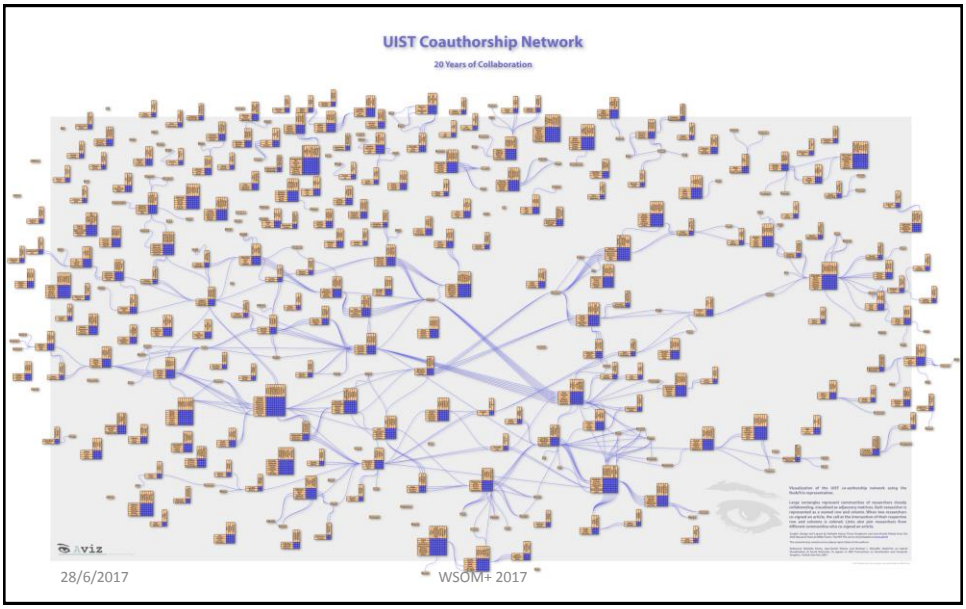


Infovis Coauthorship (133 actors)

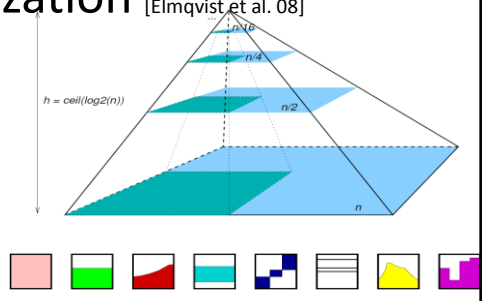
# Bigger



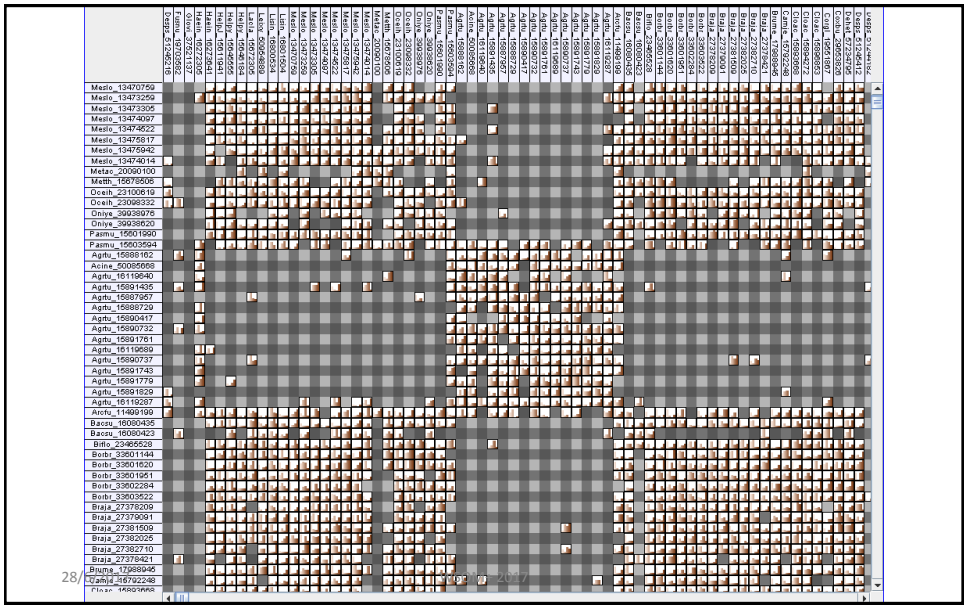


# ZAME: Interactive Large-Scale Graph Visualization [Elmqvist et al. 08]

Visualize very large networks:
- Larger than $10^7$ vertices and edges
- Reorder
- Create a pyramid
- Aggregate attributes
- Visualize using enhanced glyphs

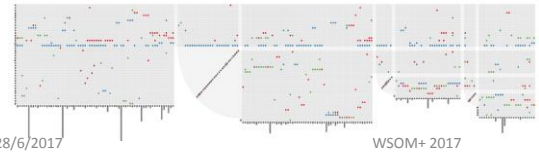




# Other Related Research

- Van Ham et al. 2004-2005 have shown techniques to navigate in large matrices
- Brandes&Nick 2011 have visualized temporal networks (friendship evolution)
- Dinkla et al. 2012 have introduced Compressed Adjacency Matrices





# Dynamic

**PhD defense**

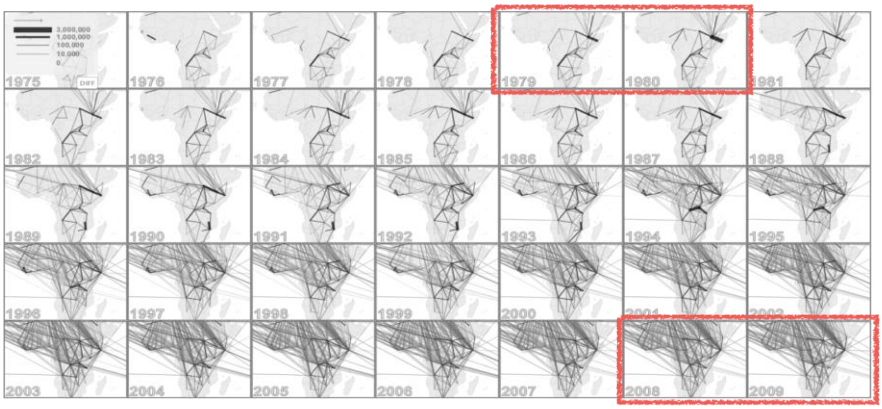
# Connections, Changes, and Cubes: Unfolding Dynamic Networks for Visual Exploration

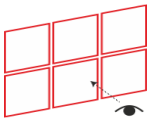
- Benjamin Bach
- 9 May 2014

**Advisors:**
Jean-Daniel Fekete
Emmanuel Pietriga

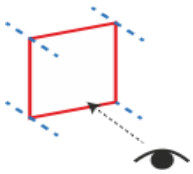
**Jury:**
Chantal Reynaud
Jarke J. van Wijk
Tim Dwyer
Silvia Miksch
Guy Melançon





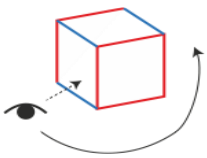



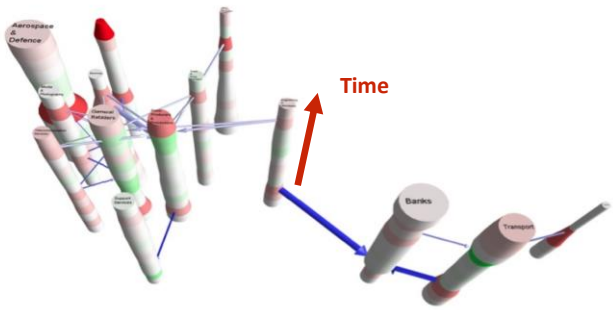
Boyandin et al., 2012



**Maray** Friedrich and Eades, 2001
**TempoVis** Ahn et al, 2011

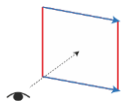


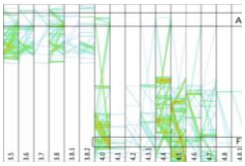





**2.5D visualization** Dwyer, 2004
**Visual Unrolling** Brandes & Corman, 2003
Gaertler & Wagner, 2005

## Timelines





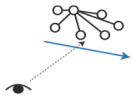
**Parallel Edge Splatting** Burch et al, 2011

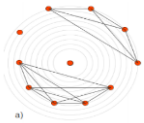
**Massive Parallel Sequence Views** Willems et al, 2012

**GraphDice** Bezerianos et al, 2010

Reda et al, 2012

## Ego Network Representations

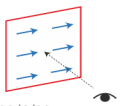


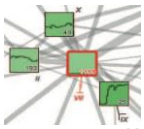


**1.5D Visualization** Shi et al., 2011

**Dynamic Ego Networks** Farrugia et al., 2011

## Temporal Aggregation

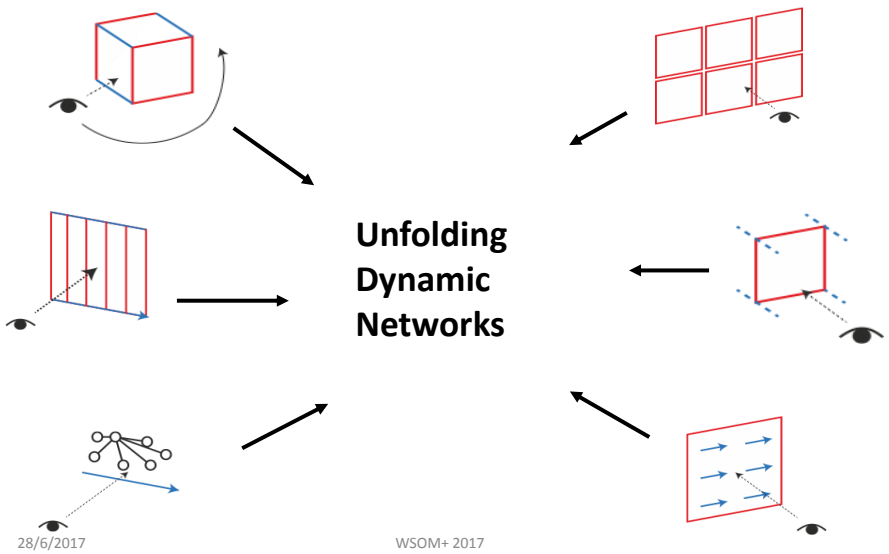




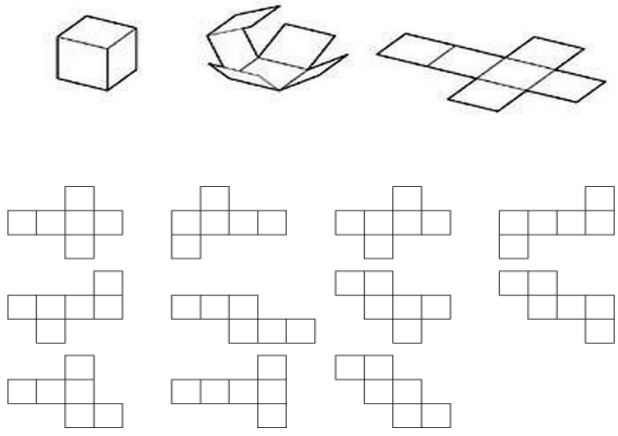
Collberg et al. 2003

**Gestalt Lines** Brandes & Nick, 2011

28/6/2017 WSOM+ 2017

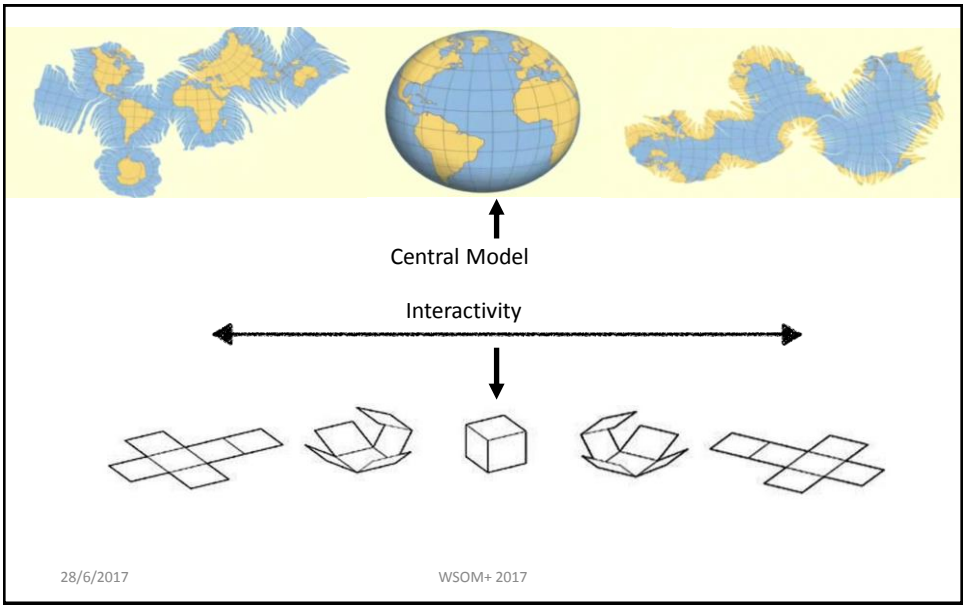



28/6/2017 WSOM+ 2017

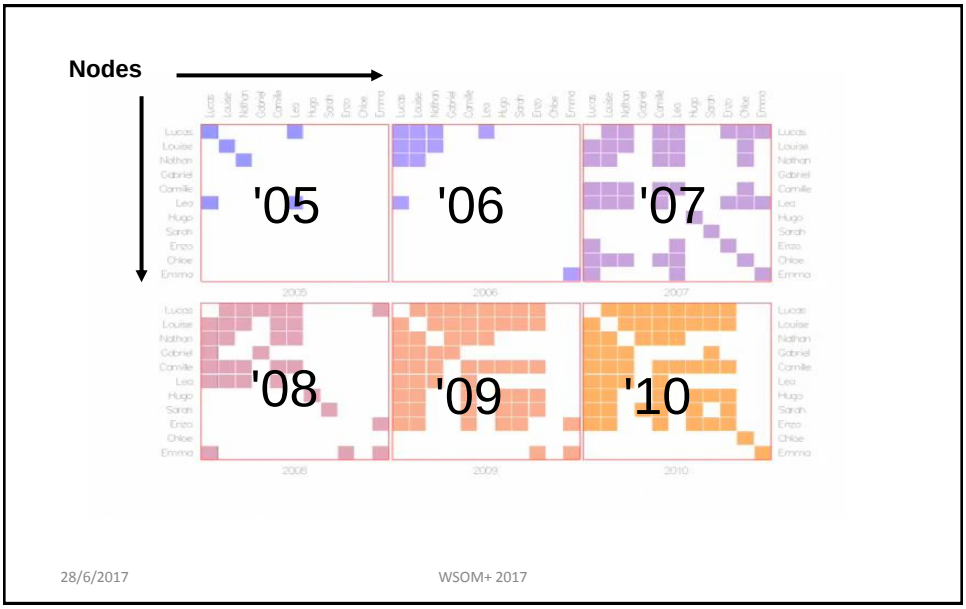


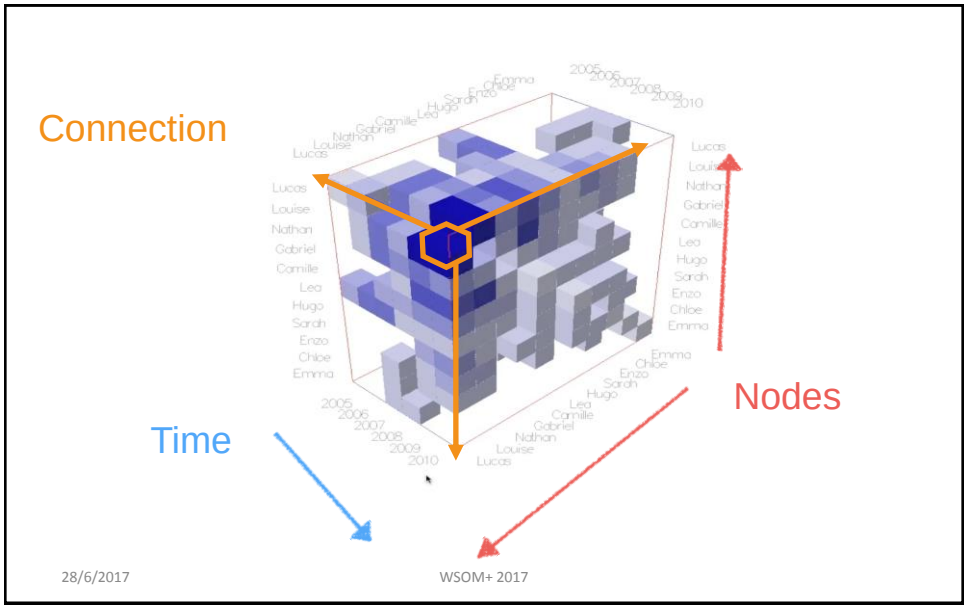


[van Wijk 2008]

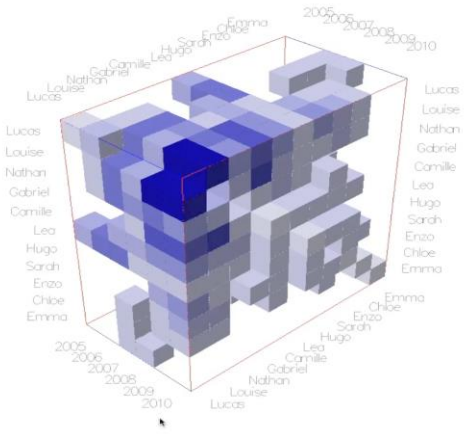

Central Model
Interactivity




Nodes
'05
'06
'07
'08
'09
'10

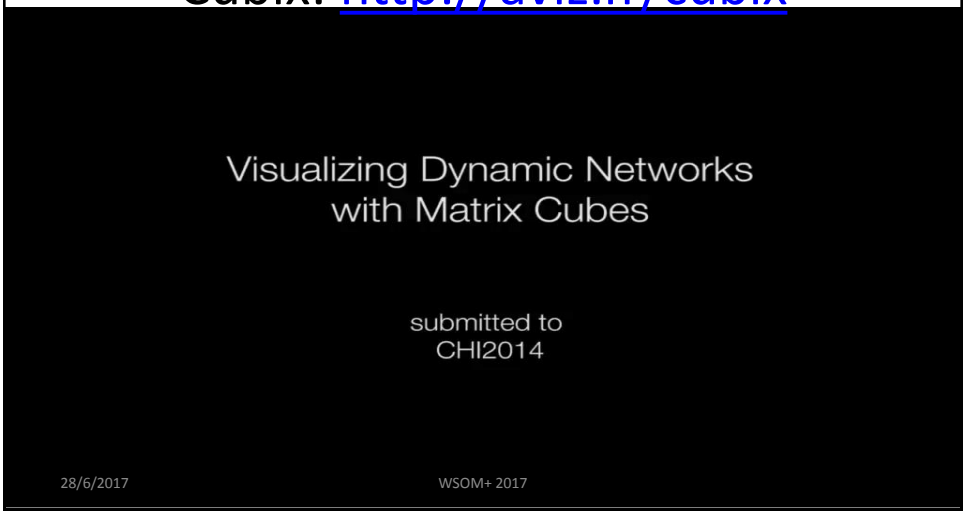





**Ceci n'est pas une visualisation 3D**

## Cubix: http://aviz.fr/cubix




## Visualizing Dynamic Networks with Matrix Cubes [CHI 2014]

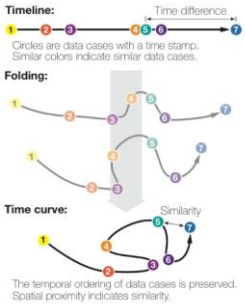
- Works for relatively small networks up to 1000 time steps
- Usable with a bit of training (10-20mn)
- Try it on your data: http://aviz.fr/cubix

- But what about bigger networks?

# Time Curves [InfoVis 2015]

*Benjamin Bach, Conglei Shi, Nicolas Heulot, Pierre Dragicevic*

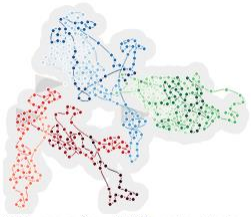
- Compute distances between multiples networks
- Use MDS to create a 2D map
- Connect them by time




http://www.aviz.fr/~bbach/timecurves/



# Time Curves on Networks



fMRI scans from 3 different subjects.

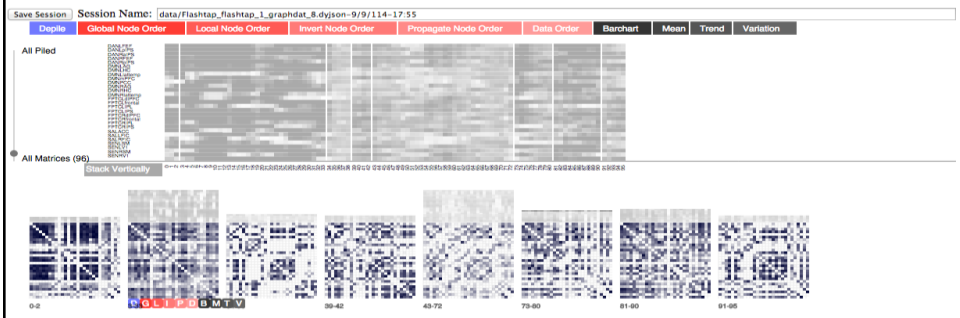
Parkinsons control RC4201 1 graphdat 20 (150)

Parkinsons control RC4205 1 graphdat 20 (150)

# Small MultiPiles: Clustering Dynamic Networks

[Bach et Al. EuroVis 2015]

http://visualizingbrainconnectivity.org/multipiles






# Video

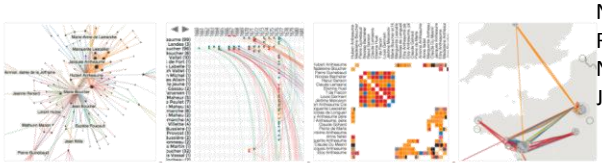
# Challenges

- Moving from research prototypes to product
- Study what is a good order
  - What structures can we see?
  - What algorithm will reveal what structure?
  - How to characterize data to fit with algorithms?
- Scalability
- Multivariate networks (several attributes on the vertices and edges)
- Dynamic networks, Dynamic hypergraphs



network cube beta

Interactive Visualizations for Dynamic and Multivariate Networks.
Free, online, and open source.



Visualizations Example Session Your Session

Manual Github Contact

Aviz Inria Microsoft Research

Benjamin Bach, Microsoft-Research, Inria
Nathalie Henry Riche, Microsoft Research
Nicole Dufournaud, EHESS
Jean-Daniel Fekete, Inria

http://networkcube.net/

# Transferring Network Visualization

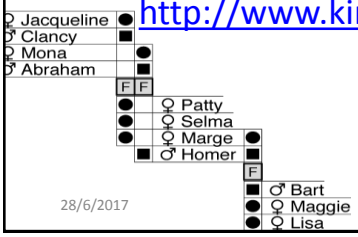
As researchers, we do not make products, but we tried many strategies:

- Publishing in high-ranked journals and conferences
- Writing open-source prototype applications
- Writing open-source libraries
- Writing open-source web sites



# Prototype Applications

- Cubix: http://www.aviz.fr/cubix
- GeneaQuilts: http://www.aviz.fr/geneaquilts
  - Integrated with **PUCK** (Program for the Use and Computation of Kinship data) http://www.kintip.net/puck-topmenu-37




# Open Source Libraries

- Reordering of Networks and Tables:
  - https://github.com/jdfekete/reorder.js
- NodeTrix library:
  - https://github.com/IRT-SystemX/nodetrix



# Open Source Web Sites

- Multipiles: http://www.aviz.fr/~bbach/multipiles/
- Time Curves: http://www.aviz.fr/~bbach/timecurves/
- NetworkCube/Vistorian: http://networkcube.net/, http://vistorian.net/

# Conclusion

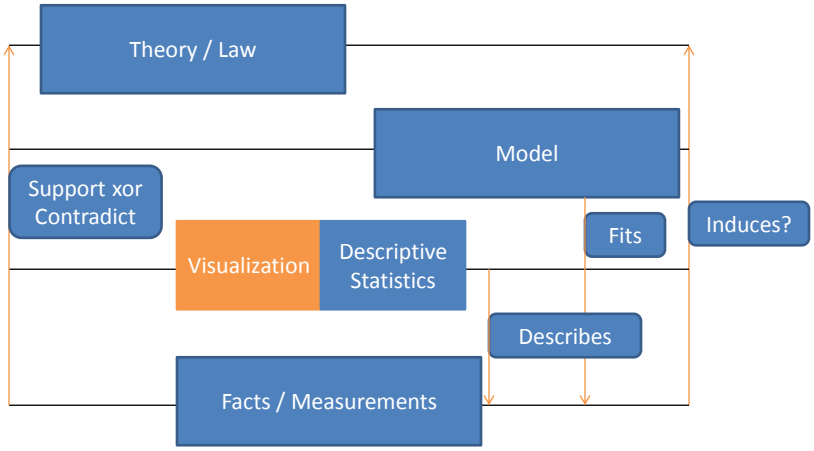
- Exploring complex data is becoming a reality with novel visualizations
  - For making sense of datasets, checking quality, etc.
- It requires a bit of time to understand the visual mapping
  - About 10mn to 1h
- It also requires a bit of time to learn the interactions
- Visualization Literacy is necessary to realize how much you will gain from investing



# Conclusion

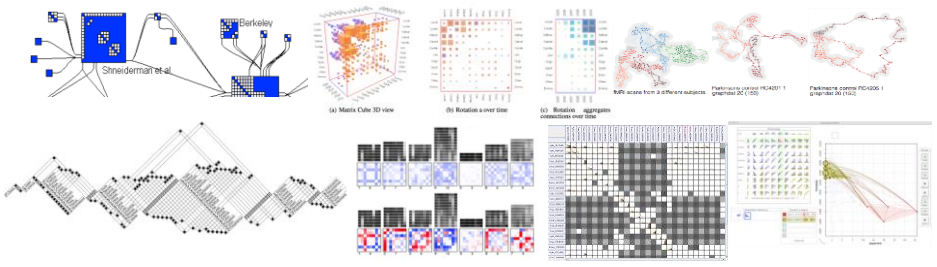
- Visualization of Networks has greatly improved in the last ten years
- Novel representations are denser and more expressive
  - Though they require a little training
- Huge and dense networks can be visualized
  - Relations between clients, suppliers, employees
  - Aggregated over long periods of time
- They need integration in complete systems (commercial or not)

# Where does Visualization Stands?






# Thanks! Questions?




http://www.aviz.fr/Research/Projects