Aviz
Visual Analytics Project

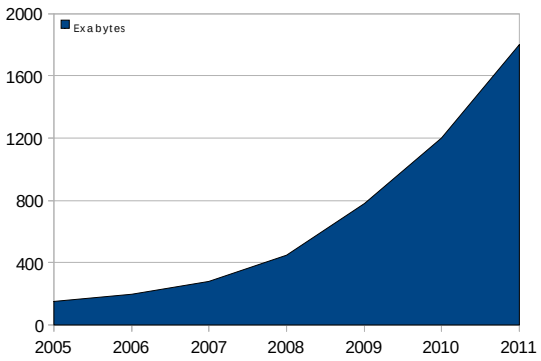
Visualizing Networks using Adjacency Matrices: Progresses and Challenges

Jean-Daniel Fekete
AVIZ Project-Team
INRIA Saclay – Île-de-France
www.aviz.fr

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE
INRIA
centre de recherche SACLAY - ÎLE-DE-FRANCE

Problem: Understanding Data

- Data production up by 30% each year since 1999 (SIMS, Berkeley)
- Available data increases exponentially

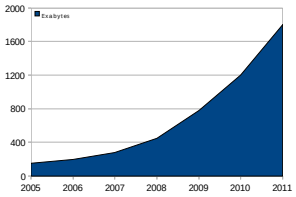


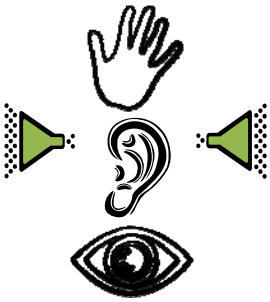
[source: The Diverse and Exploding Digital Universe, IDC, 2008]

2

Increase Cognition

Data/Information	Action/Perception	Cognition

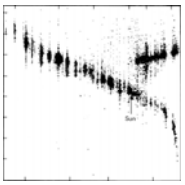


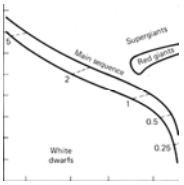


3

Strategies to Increase Cognition

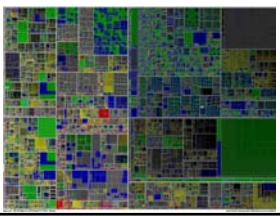
1. **Delegate to the computer**
   (Artificial Intelligence)
   → Difficult to spot "interesting unexpected" information





2. **Add new communication channels**
   (Neuro-connexions, Wearable)
   → Low bandwidth, very experimental, BCI

3. **Increase the channels bandwidth**
   (Human-Computer Interaction)
   → Known limits around 1M Items



4

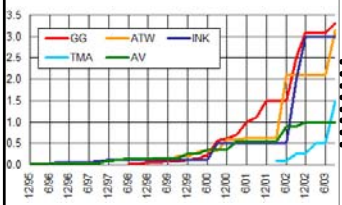
Scientific Goals

Design visual exploration methods
to help understand large datasets

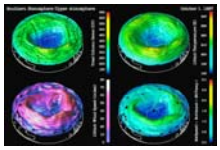
1. Design **multi-scale visual representations**
   to better represent complex data structures
2. Design **multi-scale interactions**
   to better navigate in complex data structures
3. Design **multi-scale analysis** methods
   compatible with the interactive analysis process
4. Design **software systems**
   to integrate these visualizations, interactions and analyses
5. Designing **evaluation methods**
   to validate the results.

Increase Cognition

Information	Action/Perception	Cognition

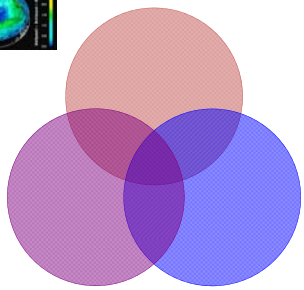


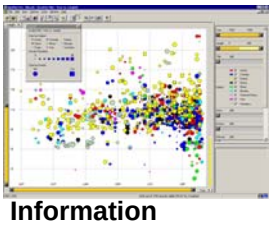
Visualization : 3 research fields



Scientific Visualization

- Subfield of Computer Graphics
- 25 years of History





Mapping and Statistics

- Specific field
- 2000 years of History

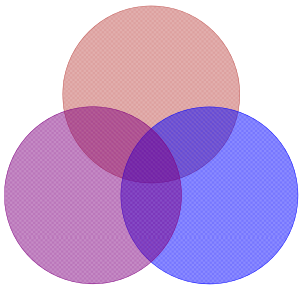
Information Visualization

- Subfield of Human-Computer Interaction
- 15 years of History

Visualization : 3 research perspectives

Computer Science

- Algorithms and Data structures
- Geometry
- Graphics



Design

- New representations
- Communication

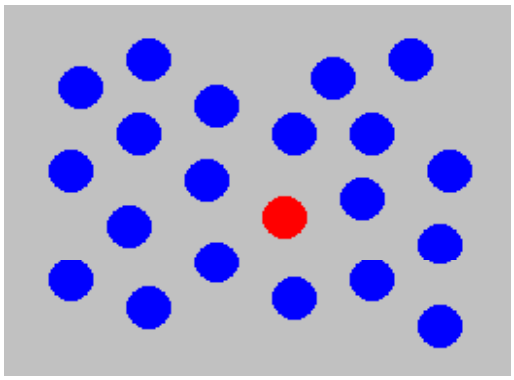
Psychology

- Perception
- Cognition
- Interaction

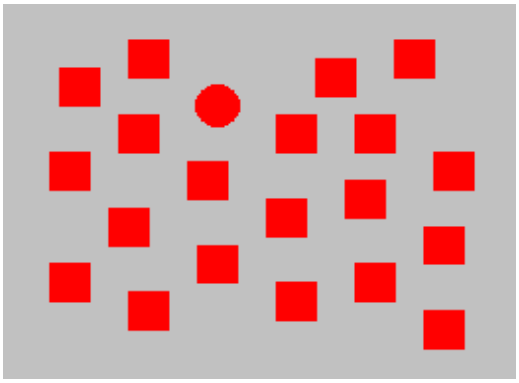
Principles of Visual Thinking

- The human eye and perception are remarkable at finding visual patterns
- Transforming abstract data into visual representation enables to relying on this skills
- Among all the possible visual representations, only a few are effective
  - Need to find them and classify them
- Psychology provide us with a plausible model: preattentive perception (Triesman, 85)
  - No effort
  - In a glimpse
  - In constant time
- Are you preattentive?
  - Can you see a **RED ROUNDED DOT?**

Preattentive Perception (1)



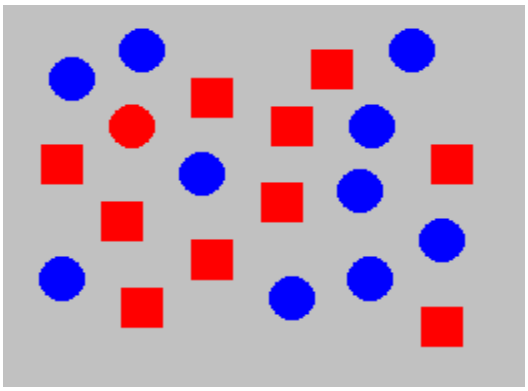
Preattentive Perception (2)



Preattentive Perception

- Several visual features can be perceived preattentively:
  - Orientation of line/blob, length, thickness, size, curvature, cardinality, endings, intersections, inclusion, hue, blinking, direction of movement, stereoscopic depth, 3D hints, direction of light
- Problems:
  - Preattentive features interfere between one another
    - It was thought that all preattentive features were interfering
  - Features remain preattentive only within some limits
    - 7 colors max (Healey, 96)
    - 2 or 3 shapes
    - Etc.

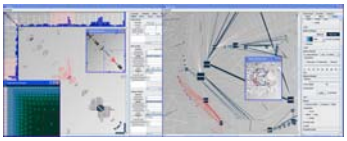
Perception préattentive (3)



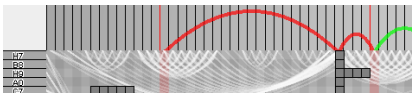
Breakthrough in Social Network Visualization: Improving Matrices

Several representations:

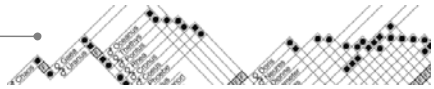
1. **Combined**
   - MatrixExplorer (Henry&Fekete InfoVis'06)



2. **Augmented**
   - MatLink (Henry&Fekete Interact'07, **Best Paper**)

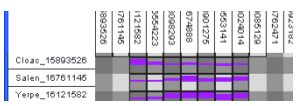


   - GeneaQuilts (Bezerianos et al. InfoVis'10)

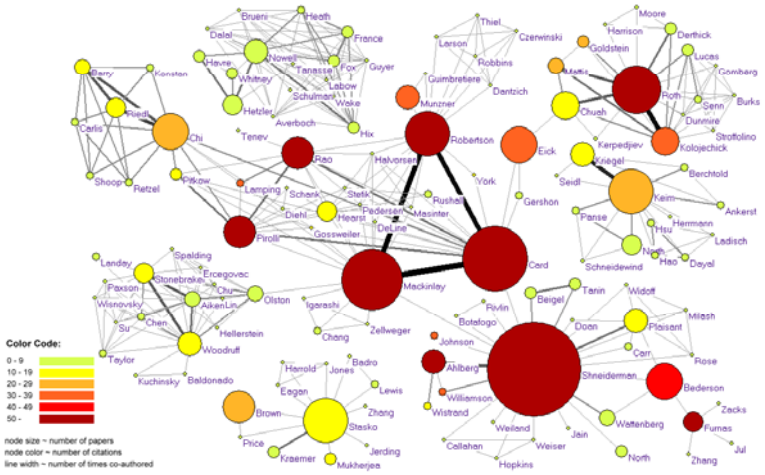


3. **Hybrid**
   - NodeTrix (Henry et al. InfoVis'07)
   - CoCoNutTrix (Isenberg et al. CG&A'09)

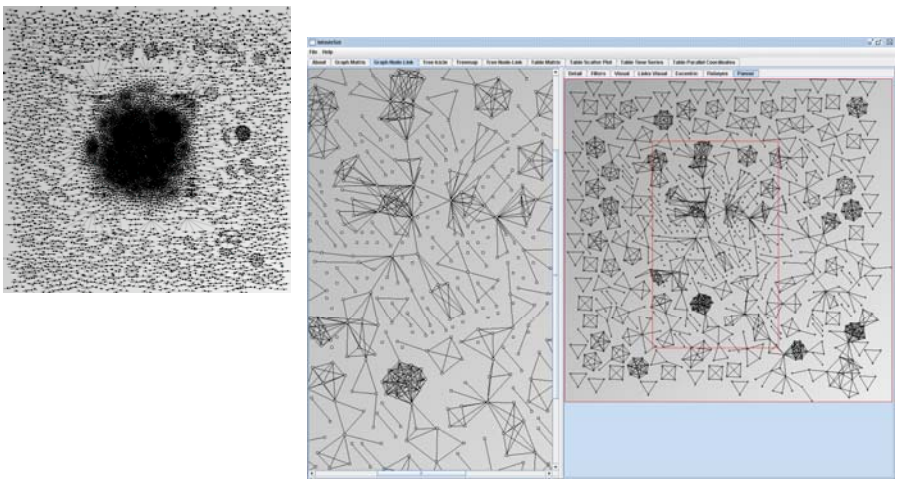
4. **Multiscale**
   - ZAME (Elmqvist et al. PacificVis'08)



InfoVis Co-authoring (K. Börner et al.)



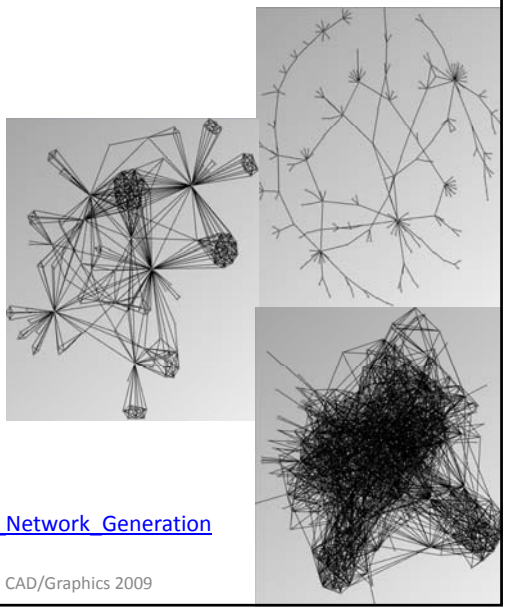
Generally, after loading…



The problem

Social networks can be:

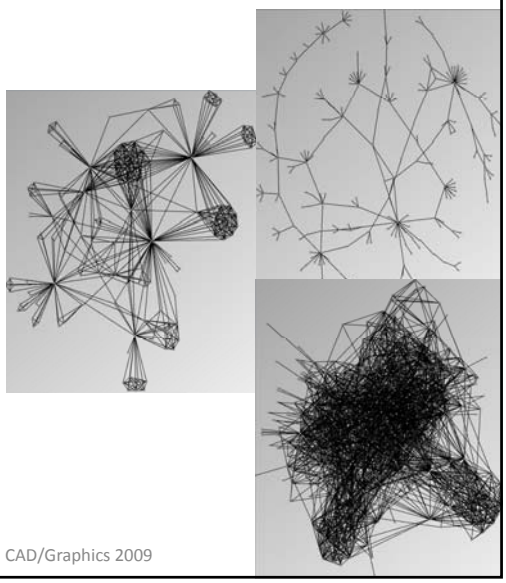
- Tree-like
- Small-world
- Almost-complete



http://www.infovis-wiki.net/index.php/Social_Network_Generation

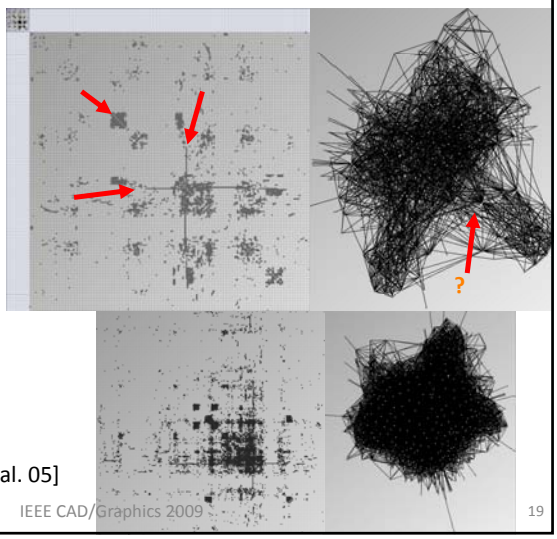
What social scientists are looking for

- What are the communities?
- How actors are linked within the community?
- How communities are linked?
- Who is central?



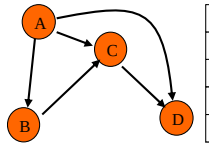
Proposing a readable representation for dense graphs

- What are the communities?
- How actors are linked within the community?
- How communities are linked?
- Who is central?

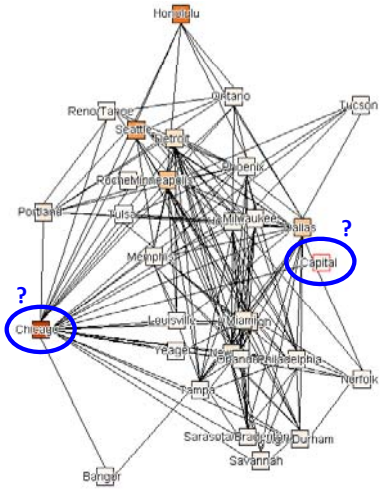


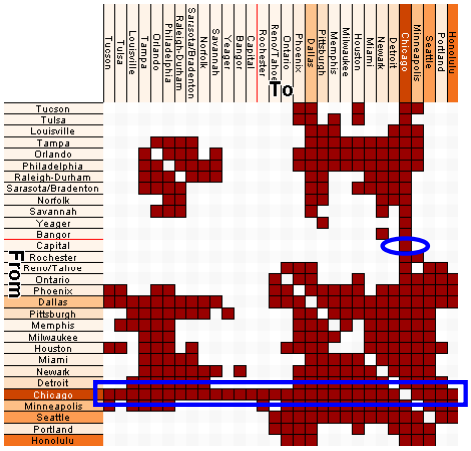
[Ghoniem et al. 05]

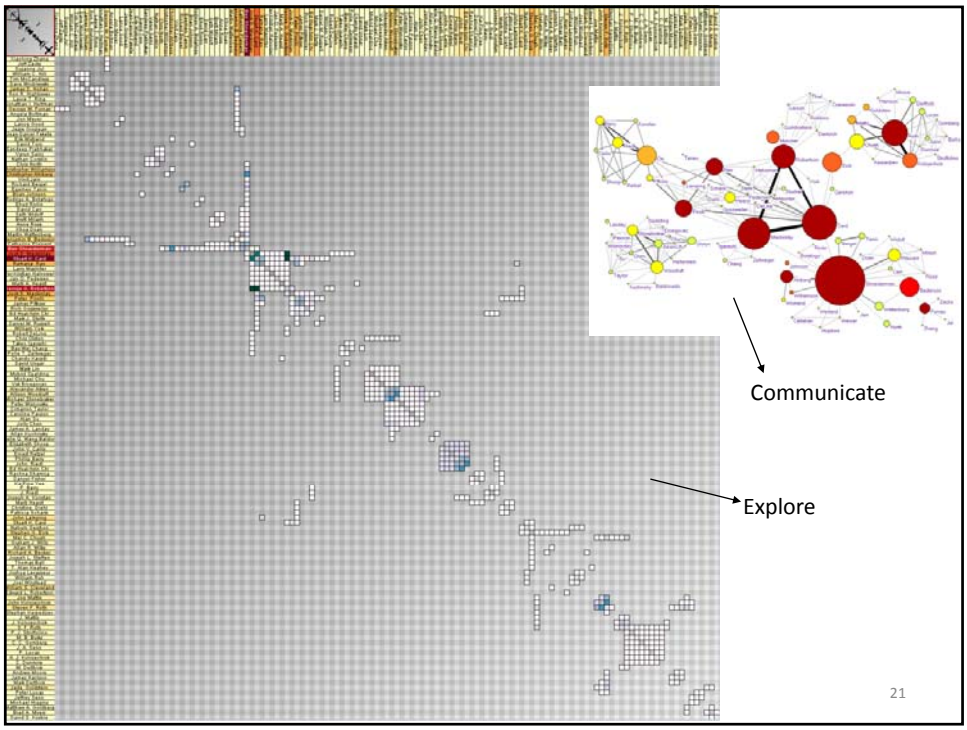
Matrix Visualization

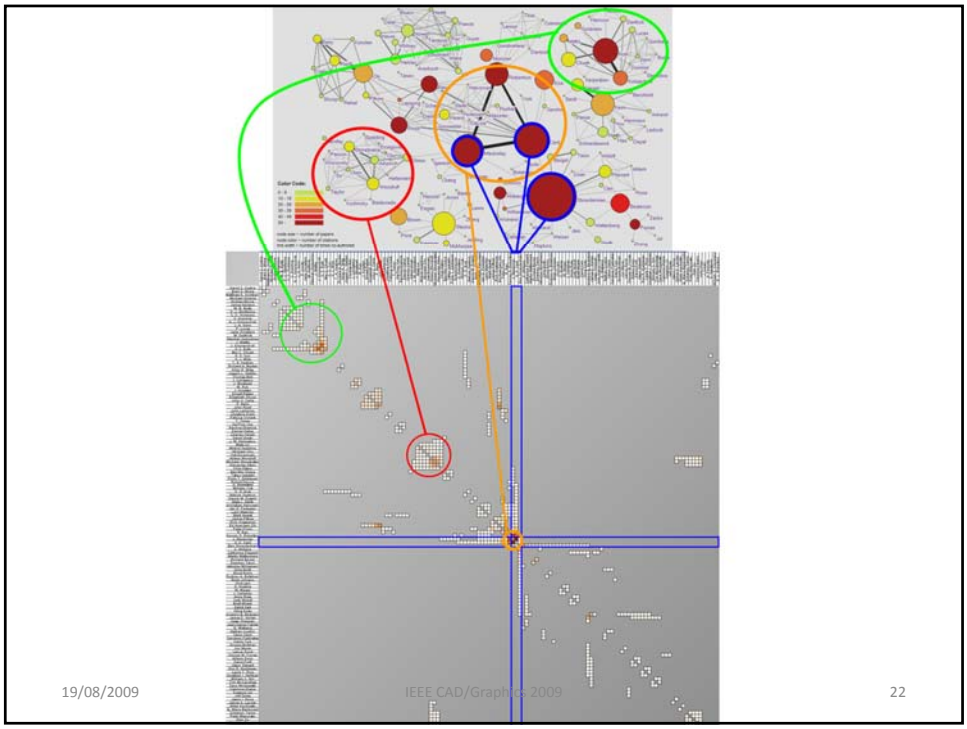


	A	B	C	D
A		X	X	X
B			X	
C				X
D				

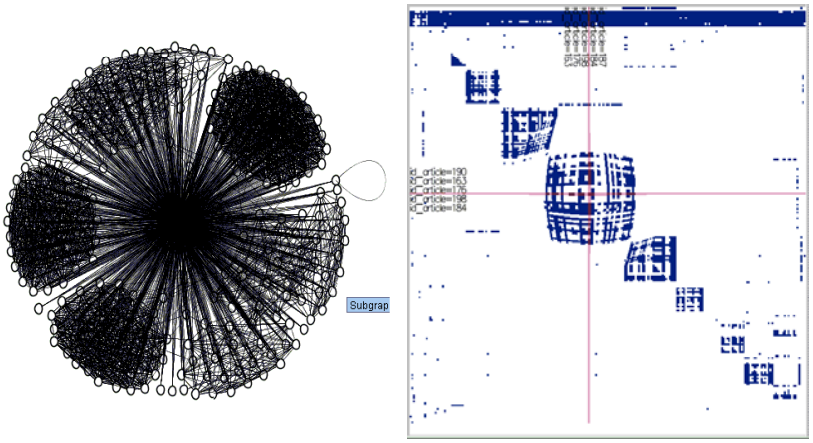





Communicate
Explore
21


19/08/2009
IEEE CAD/Graphics 2009
22

Web Site Example



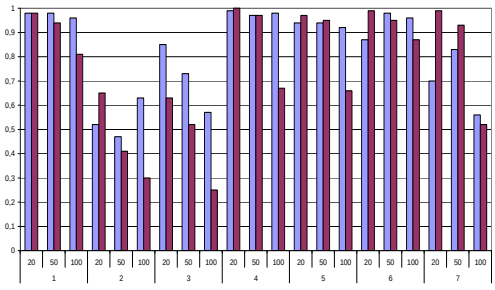
Controlled Experiment: Node Link Diagrams vs. Adjacency Matrices

- **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)

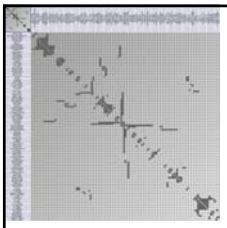
Matrices are more readable *wrt* dense graphs and medium/large graphs (> 20 vertices) *wrt* the selected tasks, except path finding

References:

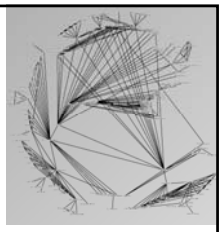
Mohammad Ghoniem, Jean-Daniel Fekete and Philippe Castagliola *Readability of Graphs Using Node-Link and Matrix-Based Representations: Controlled Experiment and Statistical Analysis*, Information Visualization Journal, 4(2), Palgrave Macmillan, Summer 2005, pp. 114-135.



Completion time for the 7 tasks, 3 densities and 2 representations (Node-Link in blue, Matrix in red)

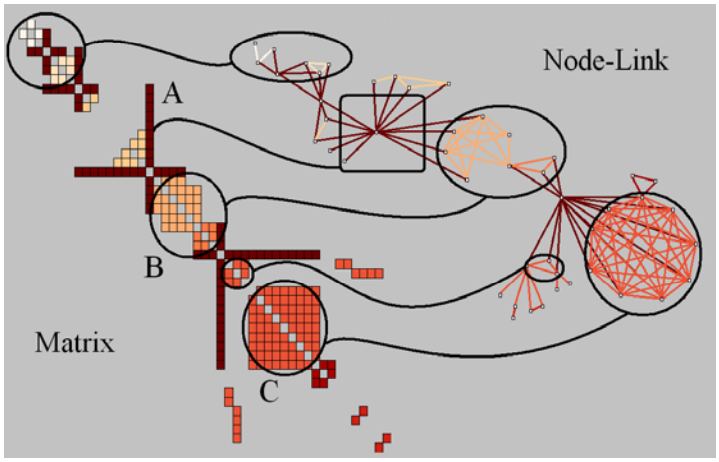


Matrix vs. NodeLink



	Matrix	NodeLink
+	• Usable without reordering • No node overlapping No edge crossing ➔ Readable for dense graphs • Fast navigation • Fast manipulation ➔ Usable interactively • More readable for some tasks	• Familiar • Compact • More readable for path following • More effective for small graphs • More effective for sparse graphs
–	• Less familiar • Use more space • Weak for path following tasks	• Useless without layout • Node overlapping Edge crossing ➔ Not readable for dense graphs • Manipulation requires layout computation

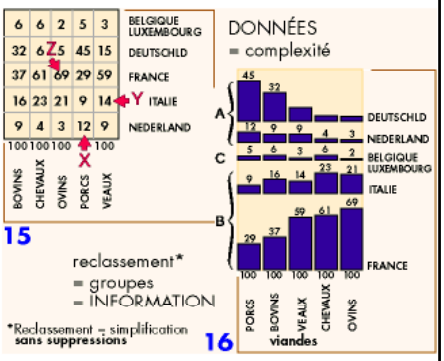
Visual Patterns with Ordered Matrices



The Reorderable Matrix

- Introduced by Bertin 67 as a representation for relational data
- Table or Network
- The value table provides details
- The reordered table provides details AND overall structure in the same representation

- Problems:
- how to compute a good ordering?
  - Row and column permutations
- how to assess its quality?



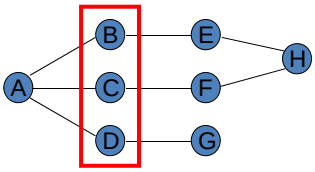
Reordering the Matrix

- Interactive or Automated
- Naïve approach:
  - Define an objective function (e.g. favor diagonal placement and dense clusters)
  - Try all permutations and retain the one that maximizes it
  - Problem : for a n×m table, there are n!×m! configurations
- Four families of methods to reorder a matrix:
  1. Robinsonian
  2. Dimension reduction
  3. Graph linearization methods
  4. Heuristics

Mixed approach

[Henry and Fekete, IHM'06] [Henry and Fekete, InfoVis'06]

- Place actors with similar connection patterns next to each other



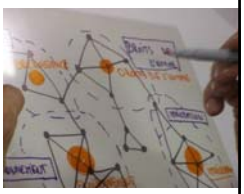
	A	B	C	D	E	F	G	H
A	0	1	1	1	0	0	0	0
B	1	0	0	0	1	0	0	0
C	1	0	0	0	0	1	0	0
D	1	0	0	0	0	0	1	0
E	0	1	0	0	0	0	0	1
F	0	0	1	0	0	0	0	1
G	0	0	0	1	0	0	0	0
H	0	0	0	0	1	1	0	0

	A	B	C	D	E	F	G	H
A	0	1	1	1	2	2	2	3
B	1	0	2	2	1	3	3	2
C	1	2	0	2	3	1	3	2
D	1	2	2	0	3	3	1	4
E	2	1	3	3	0	2	4	1
F	2	3	1	3	2	0	4	1
G	2	3	3	1	4	4	0	5
H	3	2	2	4	1	1	5	0

→ Add information to the adjacency matrix

Participatory Design

- What Social Science researchers
  - Use? *(representations, software)*
  - Analyze? *(datasets)*
  - Do? *(tasks, exploration process)*
  - Want? *(goal)*

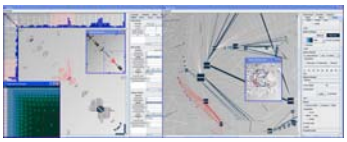


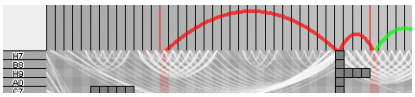
http://insitu.lri.fr/~nhenry/MatrixExplorer

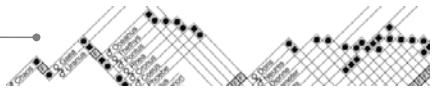
Breakthrough in Social Network Visualization: Improving Matrices

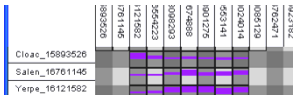
Several representations:

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)



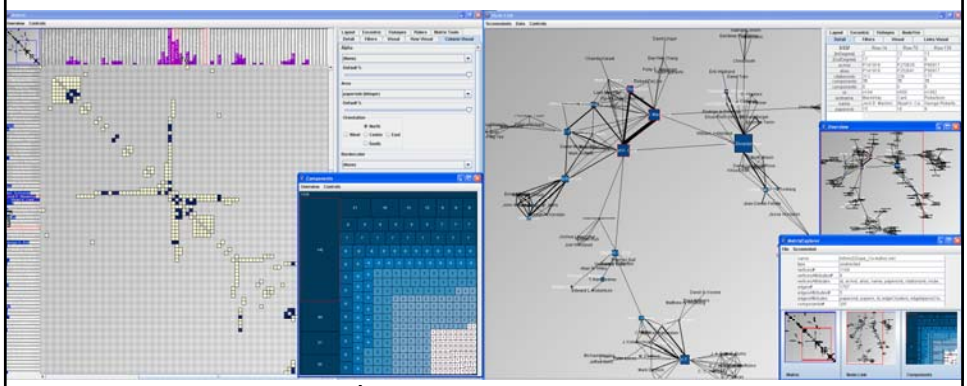






MatrixExplorer [Henry&Fekete06]

Combined representation

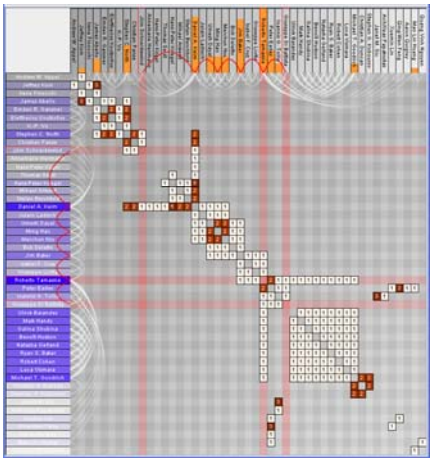


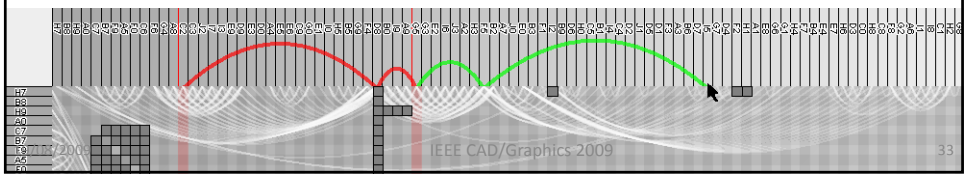
- Matrices to explore
- Node-Link diagrams to present findings

MatLink[Henry&Fekete07]

Augmented representation

- Augmenting matrices with interactive links
- Solving the path-related tasks problem for matrices





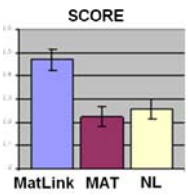
MatLink significantly improves matrices

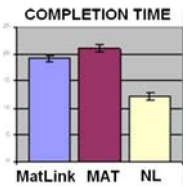
- Controlled experiment
  - 3 vis. x 6 datasets x 5 tasks

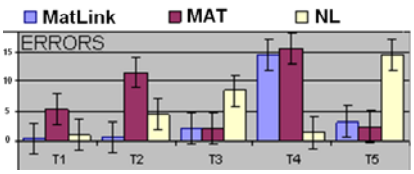
  Matrix , Node-Link, MatLink

  Data: From almost-trees
  To complete-graphs
  Including small-world networks

  Tasks: 1. CommonNeighbour,
  2. ShortestPath,
  3. MostConnected,
  4. ArticulationPoint,
  5. LargestClique



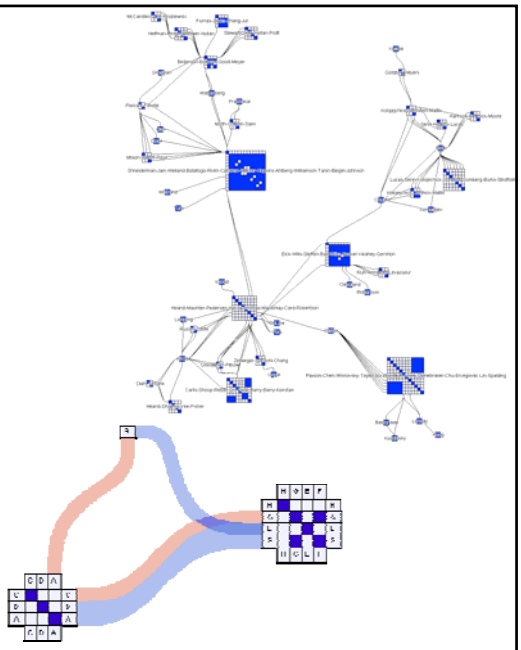




NodeTrix[Henry et al.07]

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

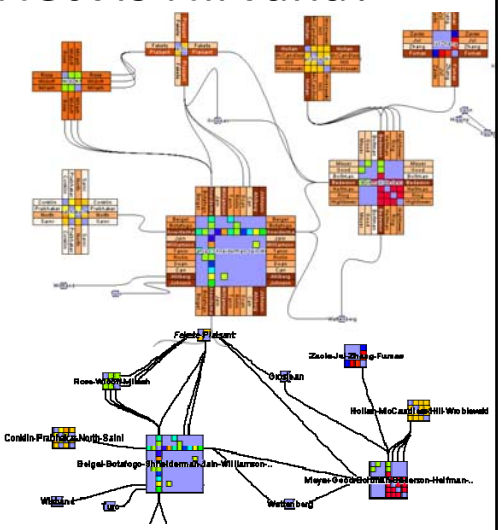


NodeTrix: the NetVis Nirvana?

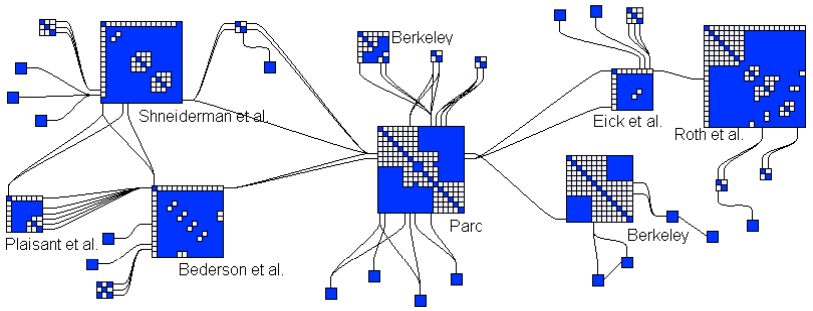
- ✓ Can you see every node?
- ✓ Can you count each node's degree?
- ✓ Can follow every link from its source to its destination?
- ✓ Can you identify clusters and outliers?

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

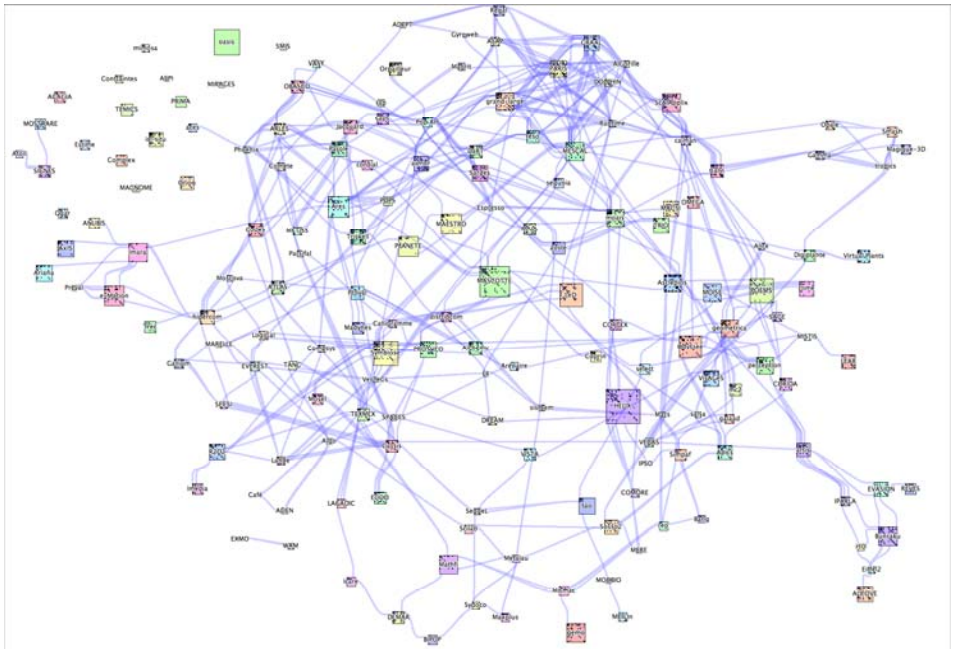
… But… beware the graphics overload!



Visual Patterns



Infovis Coauthorship (133 actors)

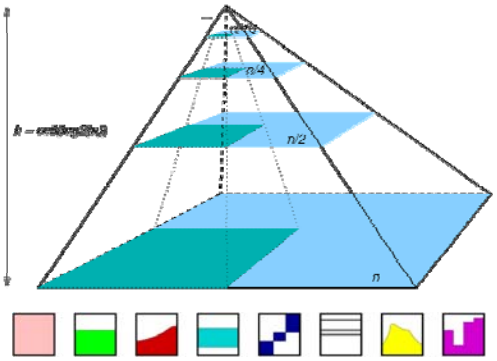


ZAME: Interactive Large-Scale Graph Visualization

Visualize very large networks:

- Larger than 10^7 vertices and edges

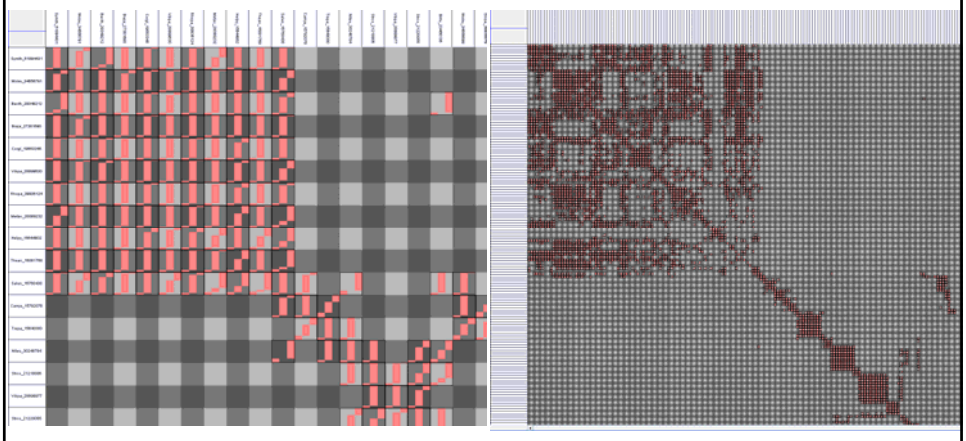
- Reorder
- Create a pyramid
- Aggregate attributes
- Visualize using enhanced glyphs

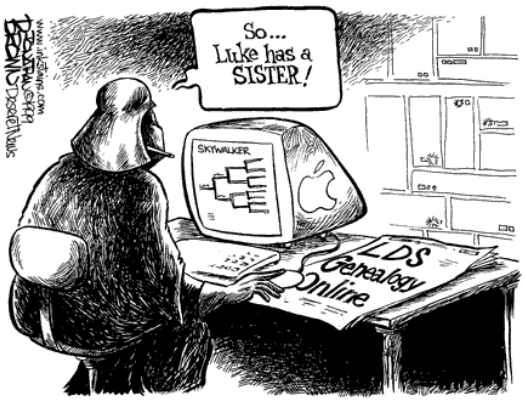


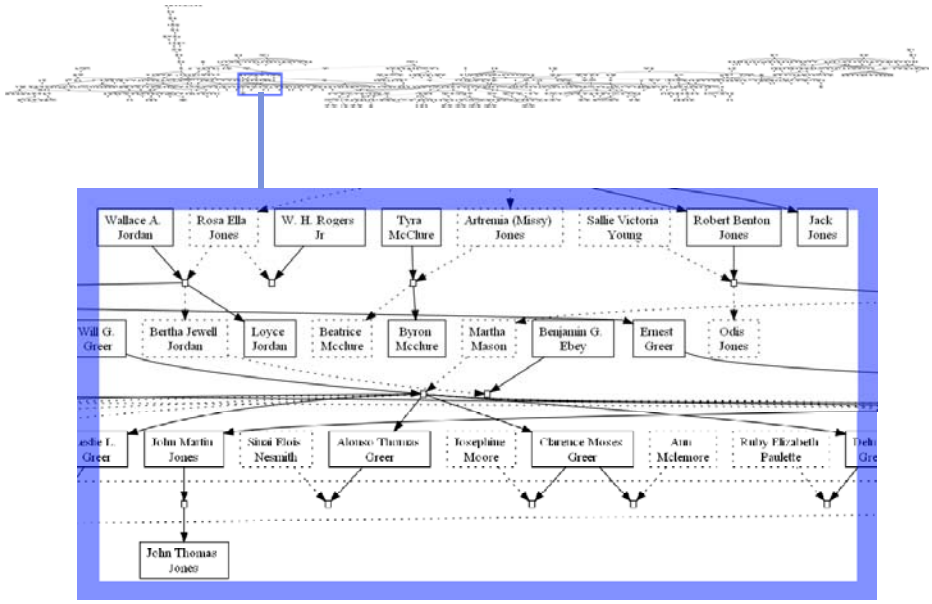
(Elmqvist et al. 08)

Visualization and Navigation

- Space – Scale + Resolution
- Accelerated graphics: Tile Rendering & OpenGL + shaders

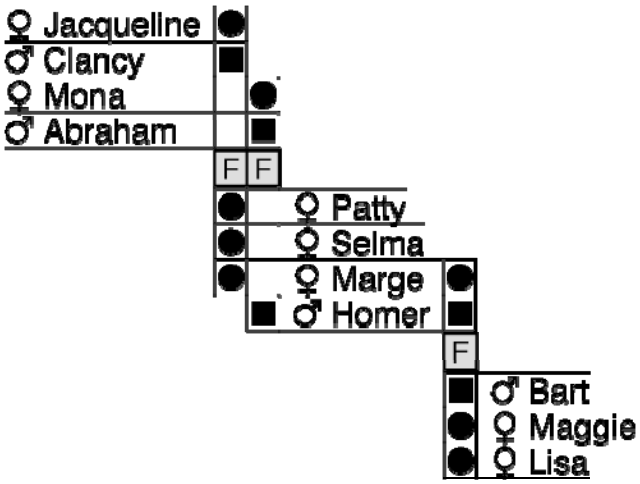



So...
Luke has a
SISTER!
SKYWALKER
LDS
Genealogy
Online


Wallace A. Jordan
Rosa Ella Jones
W. H. Rogers Jr
Tyra McClure
Artremia (Missy) Jones
Sallie Victoria Young
Robert Benton Jones
Jack Jones
Will G. Greer
Bertha Jewell Jordan
Loyce Jordan
Beatrice Mcclure
Byron Mcclure
Martha Mason
Benjamin G. Ebey
Ernest Greer
Odis Jones
John Martin Jones
Sinai Elois Nesmith
Alonso Thomas Greer
Josephine Moore
Clarence Moses Greer
Ann Mclemore
Ruby Elizabeth Poulette
John Thomas Jones

GeneaQuilts

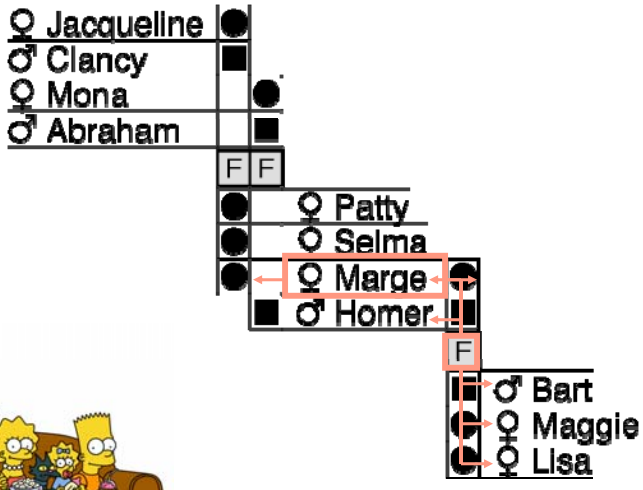
GeneaQuilts teaser



43

GeneaQuilts

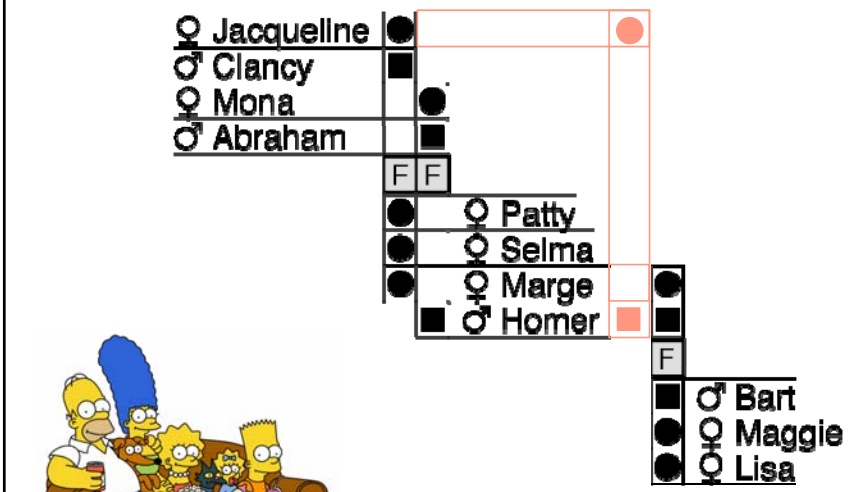
GeneaQuilts Vis



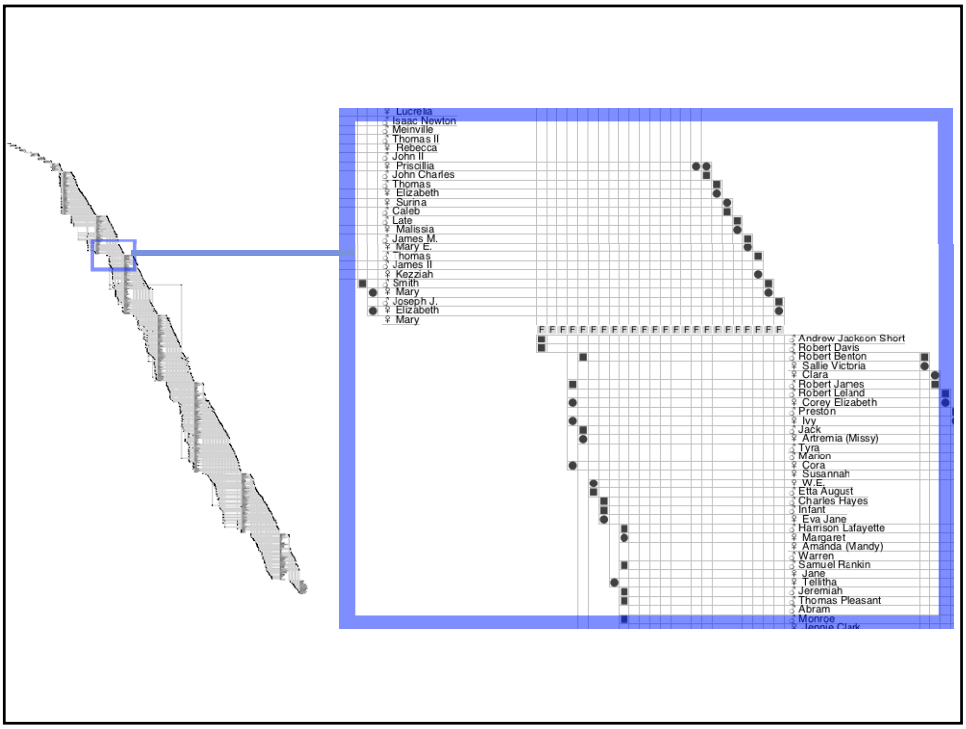
44

GeneaQuilts

GeneaQuilts Vis

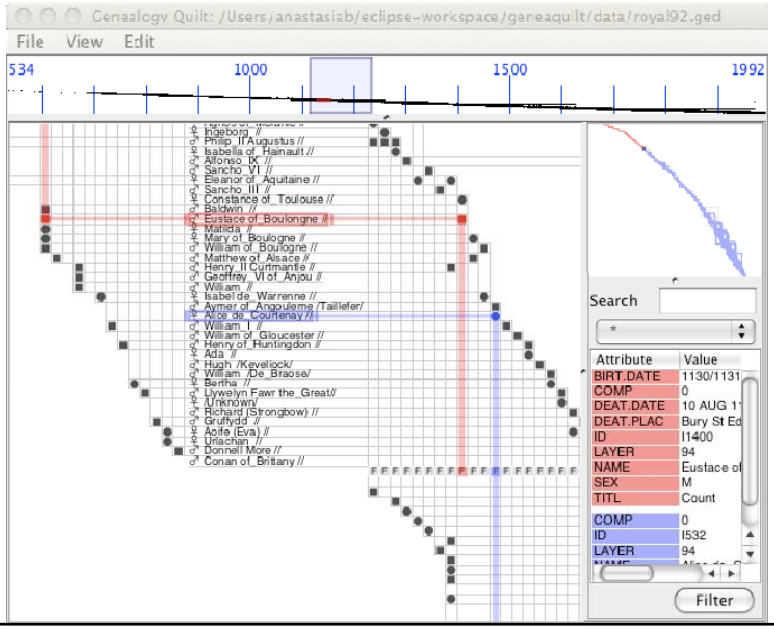


45



GeneaQuilts

GeneaQuilts system



47

GeneaQuilts

Layout algorithm

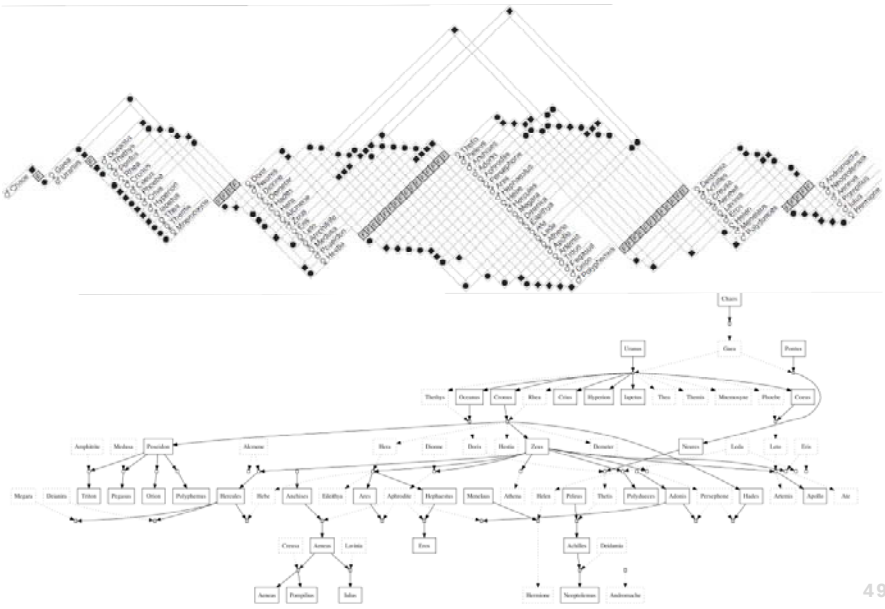
- Generations
  - layer assignment algorithm [Gansner et al.]
- Order in generations
  - minimize link crossings [Siirtola & Mäkinen]
  - ensures siblings and parents close

Use AT&T dot library

48

GeneaQuilts

Layout algorithm



49

Conclusion

- Visualization of Social Network has been greatly improved in the last 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
- Needs more research to understand how reordering leads to better understanding
- Visit our site: http://www.aviz.fr

Challenges

- Exploring Very Large / Very Dense Networks
  - Top-Down methods
  - Flexible clusterings
- Linking Exploration and Modeling
- Reordering Methods for Matrices
  - What is a good order and why?
  - Orderings for directed graphs
  - Multi-Scale Ordering (top-down methods)

References

- M. Ghoniem, J-D. Fekete and P. Castagliola. A Comparison of the Readability of Graphs Using Node-Link and Matrix-Based Representations. In Proceedings of the 10th IEEE Symposium on Information Visualization (InfoVis 04), pages 17-24, Austin, TX, October 2004. IEEE Press.
- F. van Ham, Using Multilevel Call Matrices in Large Software Projects Proc. IEEE Symp. Information Visualization 2003, IEEE CS Press, pp.227-232, 2003.
- J. Abello and F. van Ham, Matrix Zoom: A Visual Interface to Semi-External Graphs Proc. IEEE Symp. Information Visualization 2004, IEEE CS Press, pp. 183-190, 2004.
- Harri Siirtola and Erkki Mäkinen. Constructing and reconstructing the reorderable matrix.. Information Visualization, 4(1):32-48, 2005.
- N. Henry and J-D. Fekete. MatrixExplorer: a Dual-Representation System to Explore Social Networks. IEEE Transactions on Visualization and Computer Graphics (Proceedings Visualization / Information Visualization 2006), 12(5):8 pages, to be published, September-October 2006.
- N. Henry and J-D. Fekete. MatLink: Enhanced Matrix Visualization for Analyzing Social Networks. In C. Baranauskas, P. Palanque, J. Abascal and S. D. J. Barbosa, editors, Human-Computer Interaction – INTERACT 2007, volume 4663 of LNCS, pages 288–302, 2007. Springer.
- N. Henry, J-D. Fekete and M. J. McGuffin. NodeTrix: a Hybrid Visualization of Social Networks. IEEE Transactions on Visualization and Computer Graphics, 13(6):1302-1309, 2007.
- Christopher Mueller, Benjamin Martin, and Andrew Lumsdaine. A comparison of vertex ordering algorithms for large graph visualization. Visualization, 2007. APVIS '07. 2007 6th International Asia-Pacific Symposium on, pages 141-148, 5-7 Feb. 2007.
- N. Elmqvist, T-N. Do, H. Goodell, N. Henry and J-D. Fekete. ZAME: Interactive Large-Scale Graph Visualization. In Proceedings of the IEEE Pacific Visualization Symposium 2008, pages 215–222, March 2008. IEEE Press.
- A. Bezerianos, P. Dragicevic, J-D. Fekete, J. Bae and B. Watson. GeneaQuilts: A System for Exploring Large Genealogies. IEEE Transactions on Visualization and Computer Graphics, 16(6):1073–1081, Nov-Dec 2010.