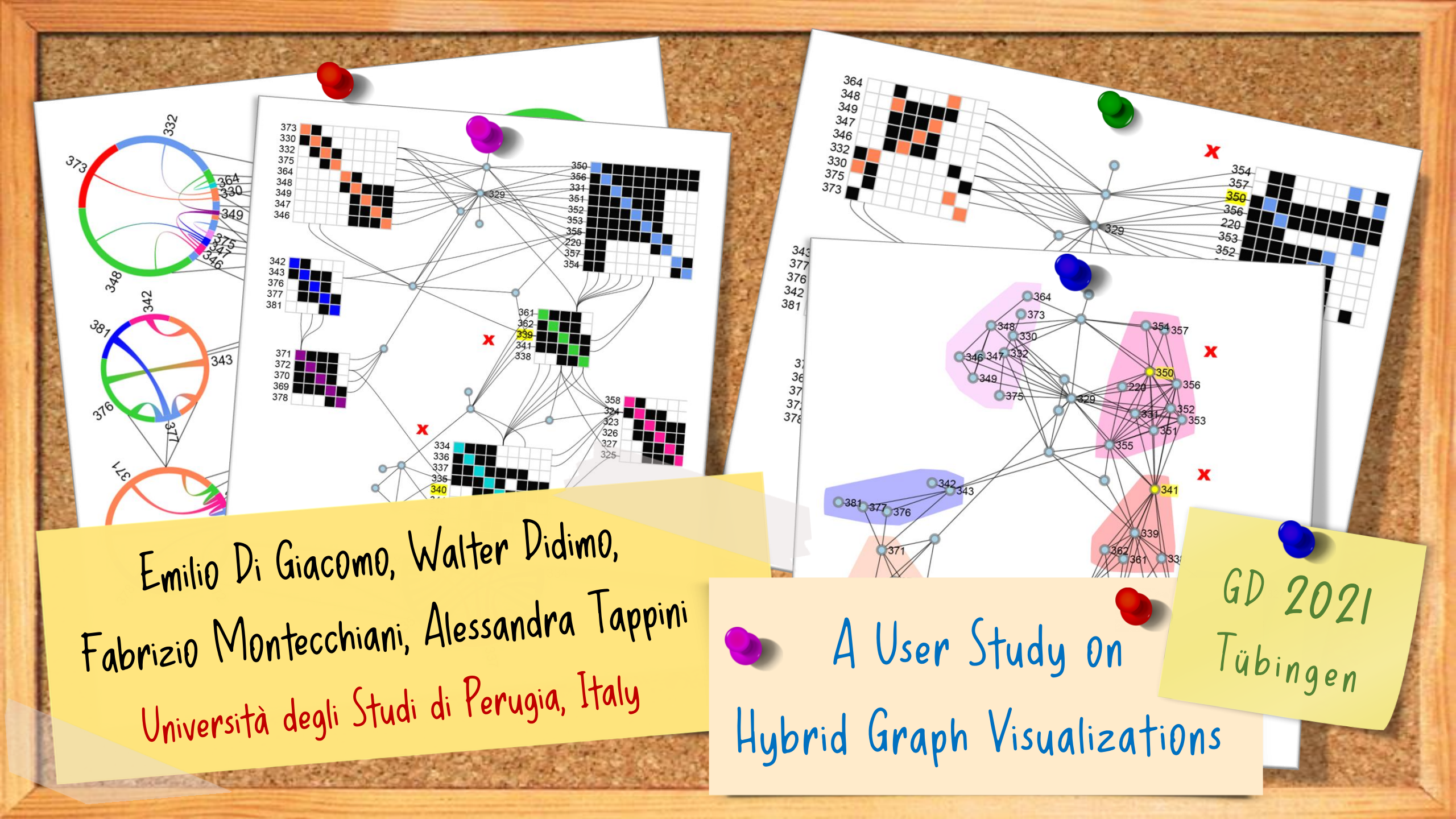


Emilio Di Giacomo, Walter Didimo,
Fabrizio Montecchiani, Alessandra Tappini
Università degli Studi di Perugia, Italy

A User Study on Hybrid Graph Visualizations

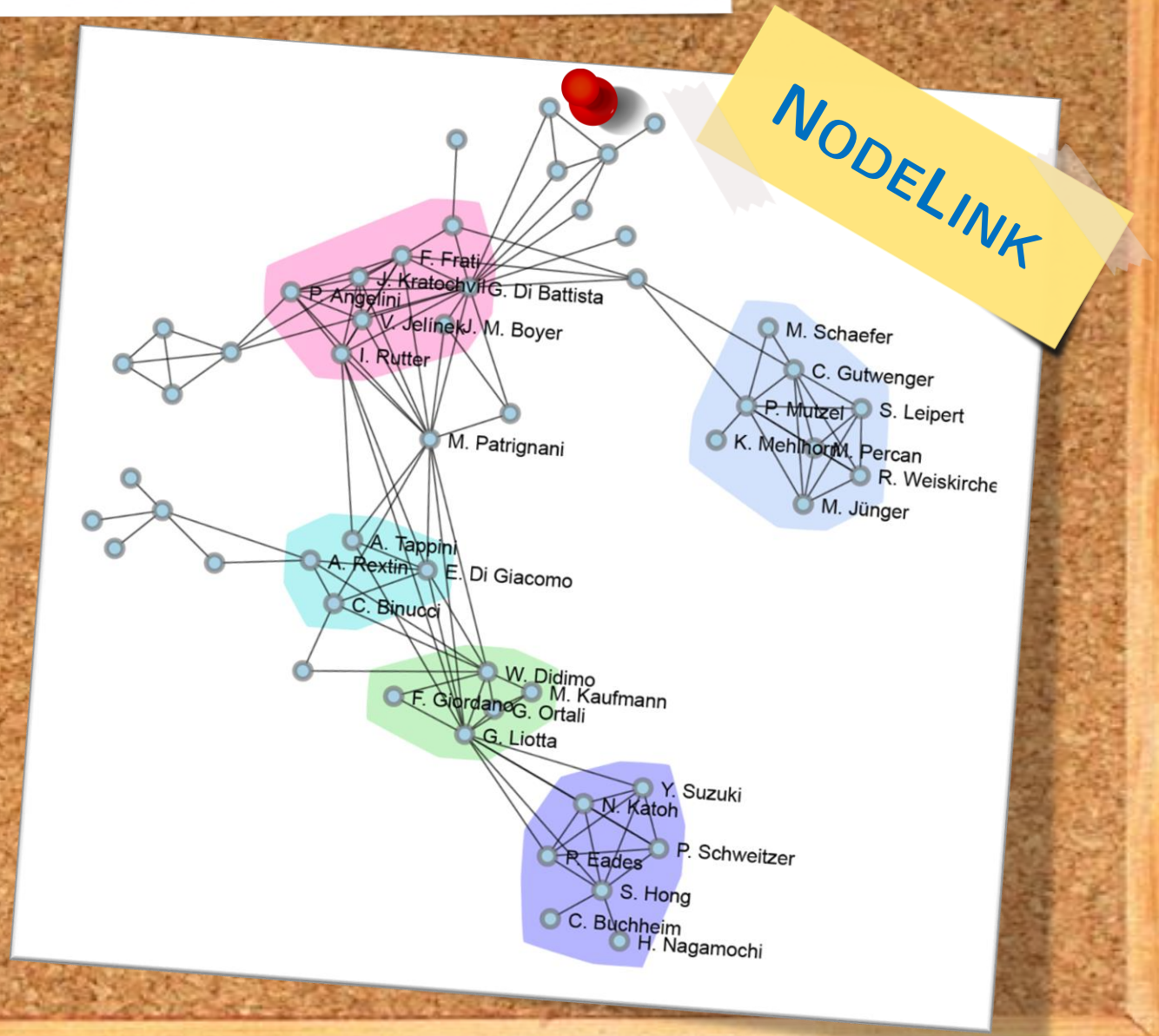
GD 2021
Tübingen

Hybrid Graph Visualizations

Real-world networks are

- globally sparse
- locally dense

- Communities (clusters) contain highly connected sets of nodes
- Clusters are loosely connected to each other



Hybrid Graph Visualizations

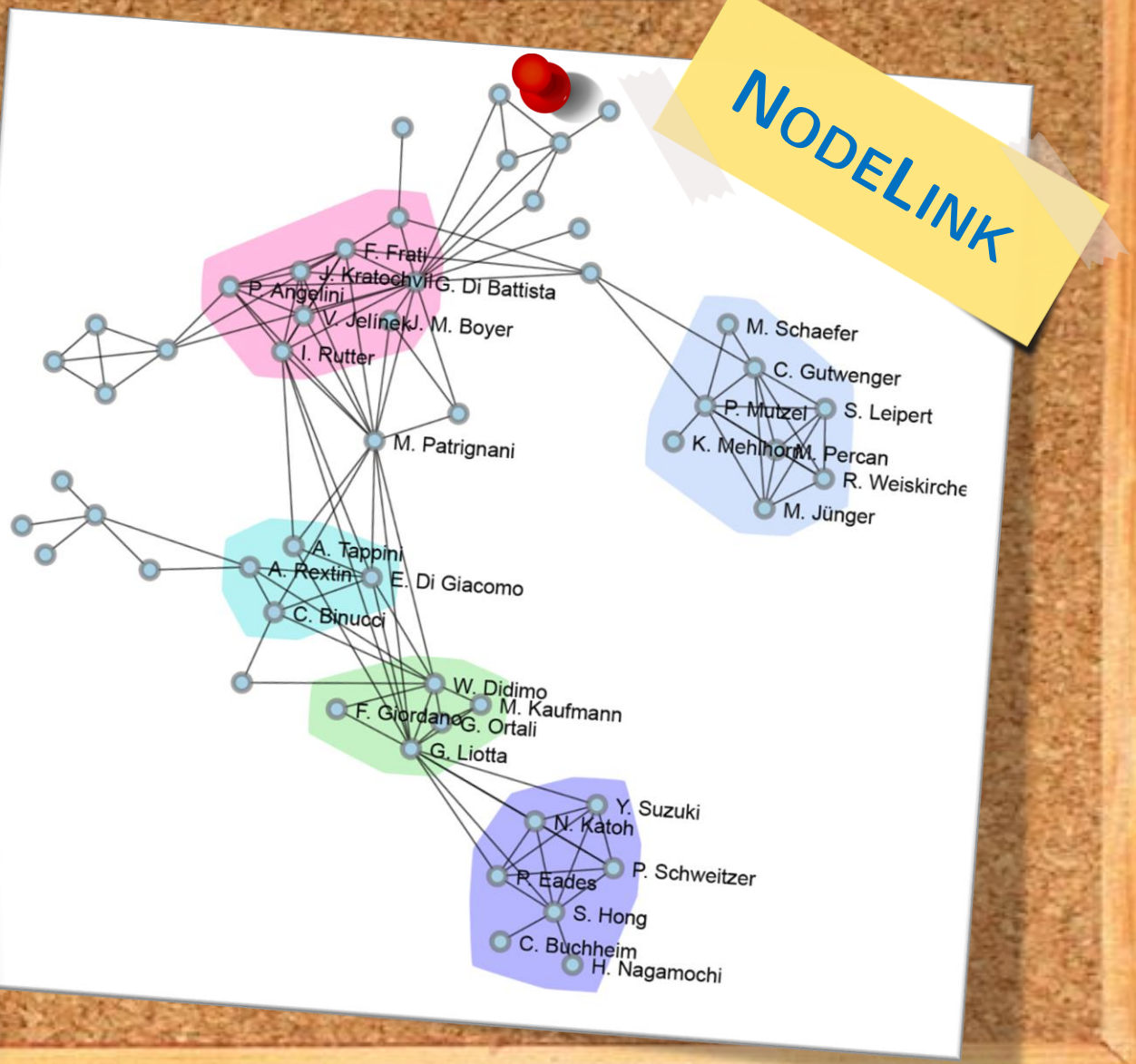
Real-world networks are

- globally sparse
- locally dense

- Communities (clusters) contain highly connected sets of nodes
- Clusters are loosely connected to each other

Visual exploration tasks:

- Get an overview of the network
- Analyze the communities in detail



Hybrid Graph Visualizations

Problem: How to support both global and local tasks?

Idea: Combine different drawing styles $\longrightarrow$ Hybrid visualizations

Hybrid Graph Visualizations

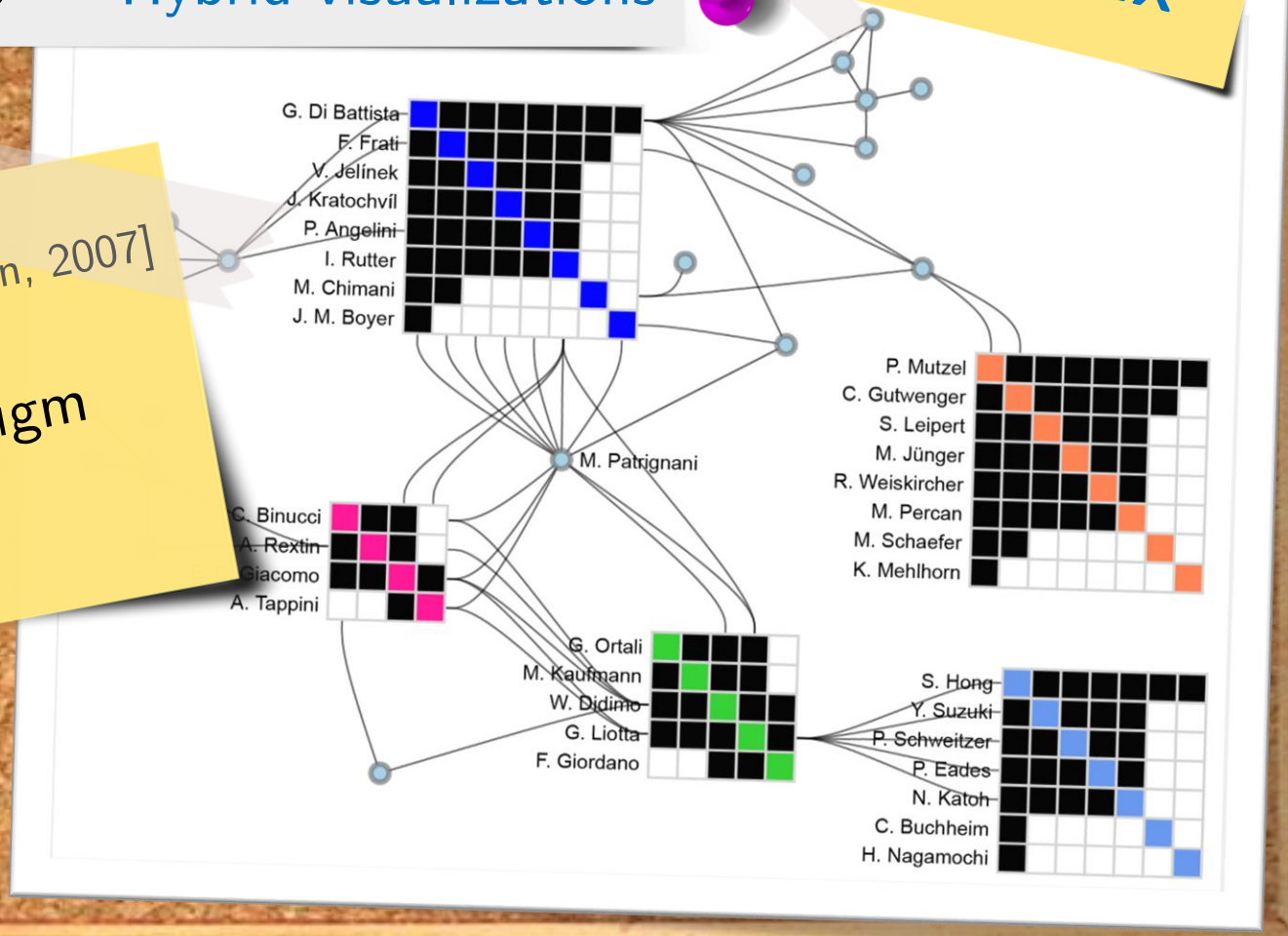
Problem: How to support both global and local tasks?

Idea: Combine different drawing styles ⟶ Hybrid visualizations

NODETRIX

NodeTrix model [Henry, Fekete, McGuffin, 2007]

- Global structure ⟶ Node-link paradigm
- Clusters ⟶ Adjacency matrices



Hybrid Graph Visualizations

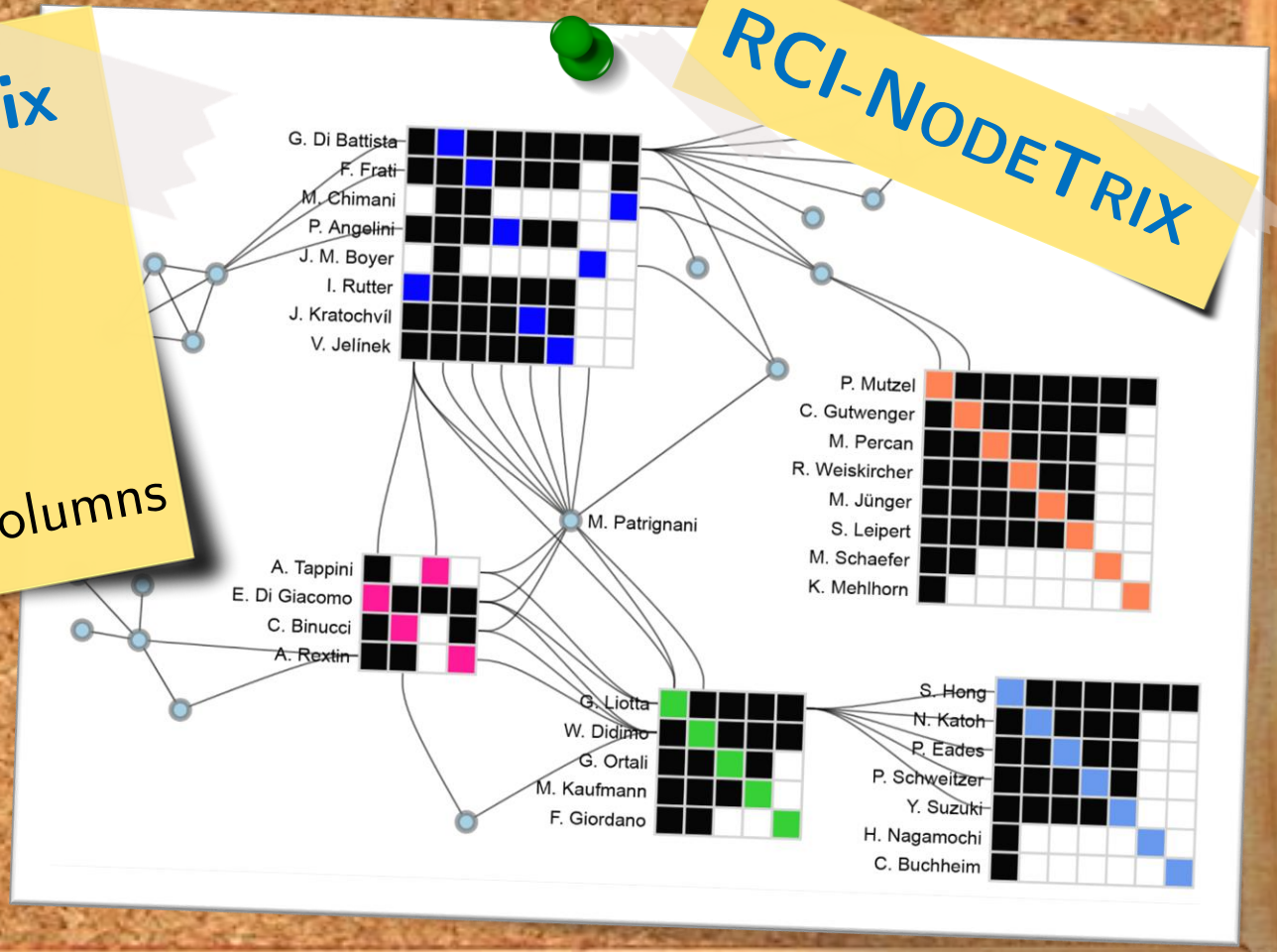
Different paradigms for the clusters $\longrightarrow$ Different hybrid visualizations

Hybrid Graph Visualizations

Different paradigms for the clusters ⟶ Different hybrid visualizations

RowColumn Independent NodeTrix model [Liotta, Rutter, Tappini, 2020]

- Global structure ⟶ Node-link paradigm
- Clusters ⟶ Adjacency matrices with independent permutations for rows and columns



Hybrid Graph Visualizations

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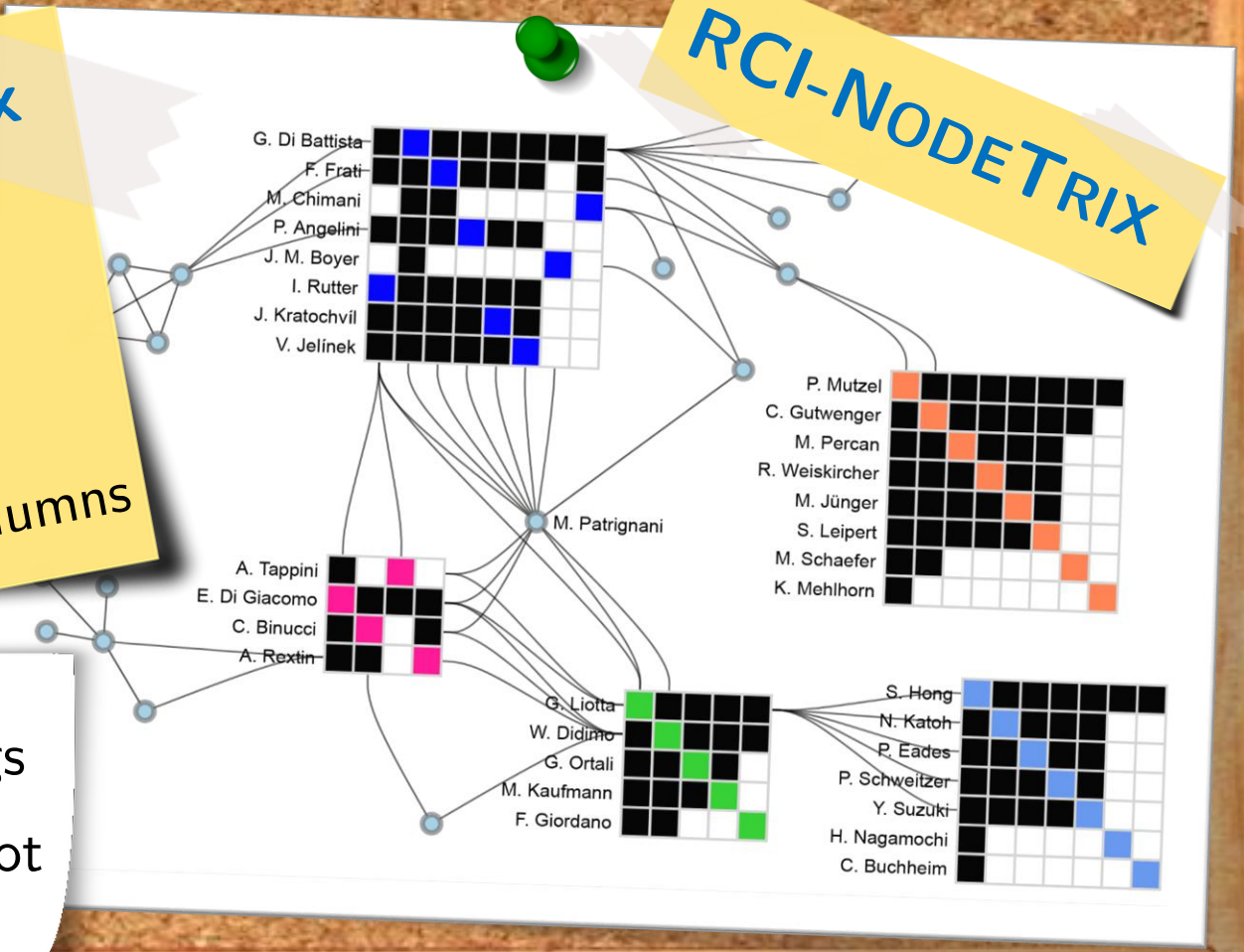
RCI-NodeTrix



☺ Reduce crossings

☹ Matrices may not be symmetric

Hybrid Graph Visualizations

- Users are less familiar with matrices
- Paths in matrices are harder to follow

Hybrid Graph Visualizations

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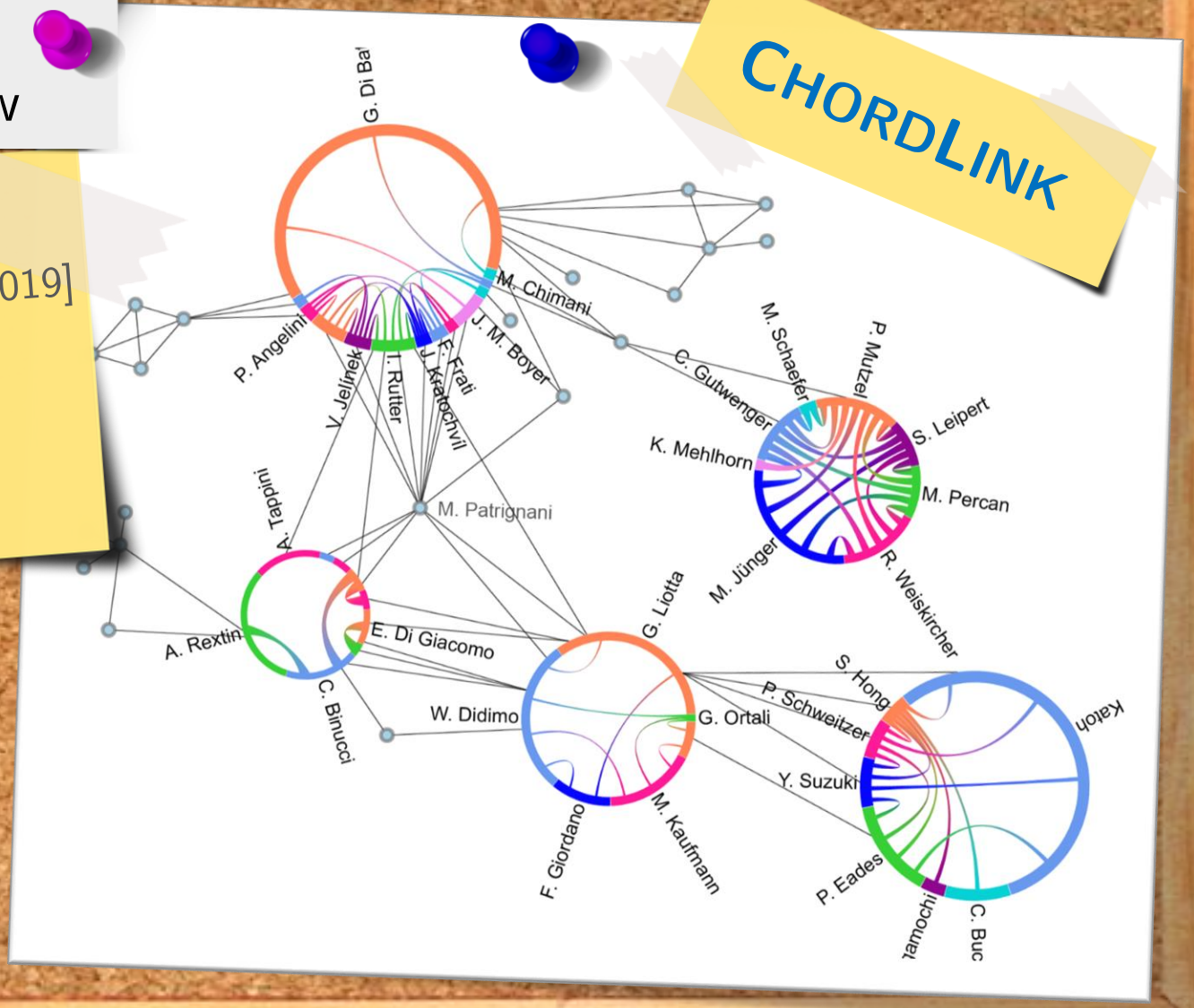
Paths in matrices are harder to follow

ChordLink model

[Angori, Didimo, Montecchiani, Pagliuca, Tappini, 2019]

- Global structure ⟶ Node-link paradigm
- Clusters ⟶ Chord diagrams



Hybrid Graph Visualizations

Users are less familiar with matrices
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ChordLink model

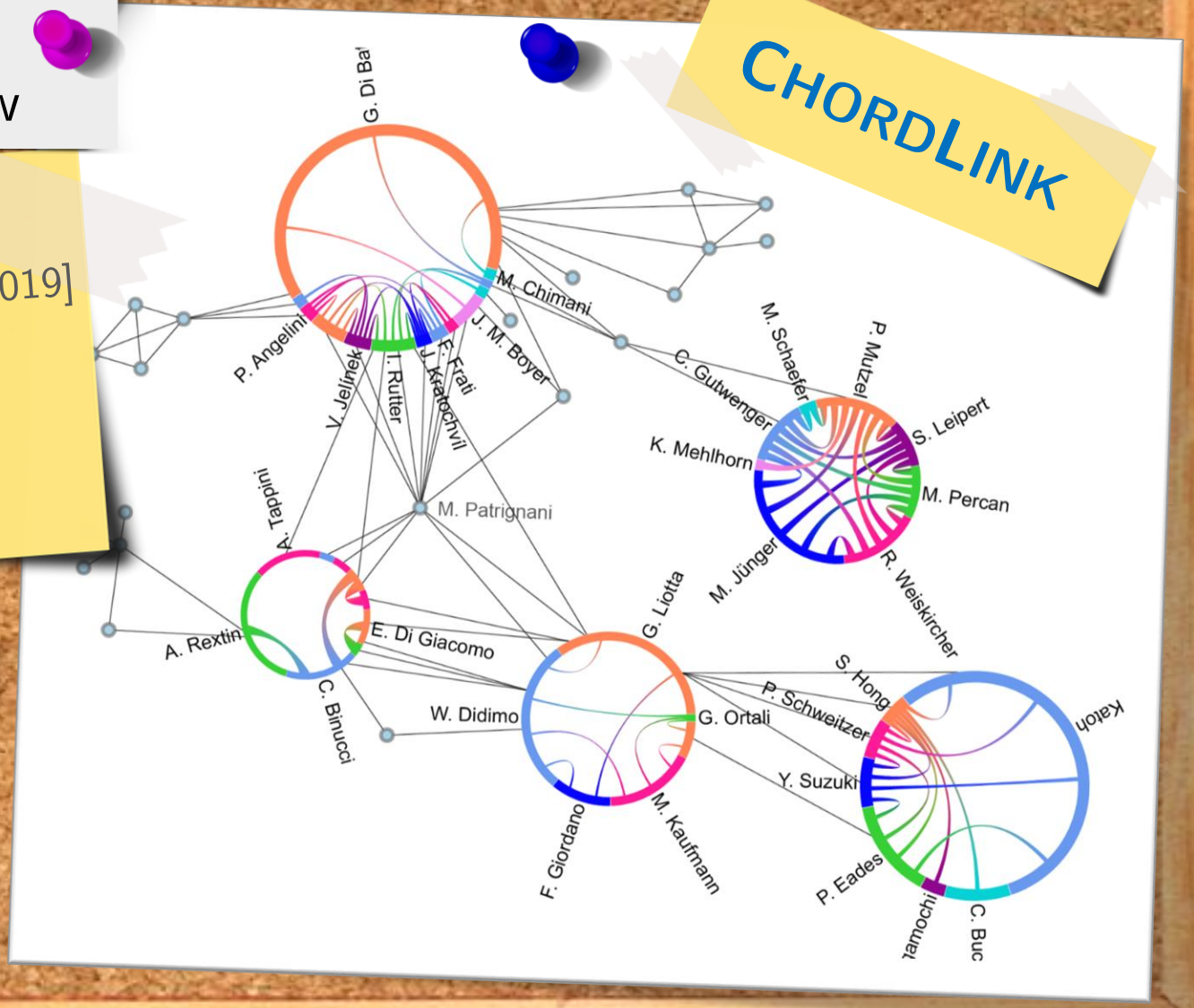
[Angori, Didimo, Montecchiani, Pagliuca, Tappini, 2019]

- Global structure ⟶ Node-link paradigm
- Clusters ⟶ Chord diagrams

Nodes may be replicated

- to preserve the geometry and the user's mental map

Edges are curves (similar to node-link)



Theoretical Contributions

- P. Angelini, G. Da Lozzo, G. Di Battista, F. Frati, M. Patrignani, I. Rutter: *Intersection-Link Representations of Graphs*. GD 2015, **JGAA 2017**
- G. Da Lozzo, G. Di Battista, F. Frati, M. Patrignani: *Computing NodeTrix Representations of Clustered Graphs*. GD 2016, **JGAA 2018**
- E. Di Giacomo, G. Liotta, M. Patrignani, A. Tappini: *NodeTrix Planarity Testing with Small Clusters*. GD 2017, **Algorithmica 2019**
- P. Angelini, P. Eades, S.-H. Hong, K. Klein, S. Kobourov, G. Liotta, A. Navarra, A. Tappini: *Turning Cliques into Paths to Achieve Planarity*. GD 2018
- E. Di Giacomo, W. Lenhart, G. Liotta, T. Randolph, A. Tappini: *(k, p)-Planarity: A Relaxation of Hybrid Planarity*. **WALCOM 2019**

Hybrid Planarity Testing

- J. Besa Vial, G. Da Lozzo, M. Goodrich: *Computing k-Modal Embeddings of Planar Digraphs*. **ESA 2019**
- G. Liotta, I. Rutter, A. Tappini: *Graph Planarity Testing with Hierarchical Embedding Constraints*. CoRR abs/1904.12596 (2019)
- P. Angelini, P. Eades, S.-H. Hong, K. Klein, S. Kobourov, G. Liotta, A. Navarra, A. Tappini: *Graph Planarity by Replacing Cliques with Paths*. **Algorithms 2020**
- G. Liotta, I. Rutter, A. Tappini: *Simultaneous FPQ-Ordering and Hybrid Planarity Testing*. **SOFSEM 2020**, **TCS 2021**

Application Contributions

- N. Henry, J.-D. Fekete, M. McGuffin: *NodeTrix: A Hybrid Visualization of Social Networks.* **IEEE TVCG 2007**
- N. Henry, A. Bezerianos, J.-D. Fekete: *Improving the readability of clustered social networks using node duplication.* **IEEE TVCG 2008**
- V. Batagelj, W. Didimo, G. Liotta, P. Palladino, M. Patrignani: *Visual analysis of large graphs using (X,Y)-clustering and hybrid visualizations.* **PacificVis 2010**, **IEEE TVCG 2011**
- S. Hadlak, H. Schulz, H. Schumann: *In situ exploration of large dynamic networks.* **IEEE TVCG 2011**
- B. Bach, E. Pietriga, I. Liccardi: *Visualizing populated ontologies with OntoTrix.* **IJSWIS 2013**

Hybrid Visualizations

- S. Rufiange, M. McGuffin: *Diffani: Visualizing dynamic graphs with a hybrid of difference maps and animation.* **IEEE TVCG 2013**
- X. Yang, L. Shi, M. Daianu, H. Tong, Q. Liu, P. Thompson: *Blockwise human brain network visual comparison using NodeTrix representation.* **IEEE TVCG 2017**
- L. Angori, W. Didimo, F. Montecchiani, D. Pagliuca, A. Tappini: *ChordLink: A New Hybrid Visualization Model.* **GD 2019**
- L. Angori, W. Didimo, F. Montecchiani, D. Pagliuca, A. Tappini: *Hybrid Graph Visualizations with ChordLink: Algorithms, Experiments, and Applications.* **IEEE TVCG 2020**

Motivation

Some open questions:

[Angori et al., 2019]: Perform a user study to compare ChordLink and other hybrid models

[Liotta et al., 2020]: What is the impact of reducing crossings at the expenses of independent row/column permutations in NodeTrix?

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Which hybrid model should be preferred?

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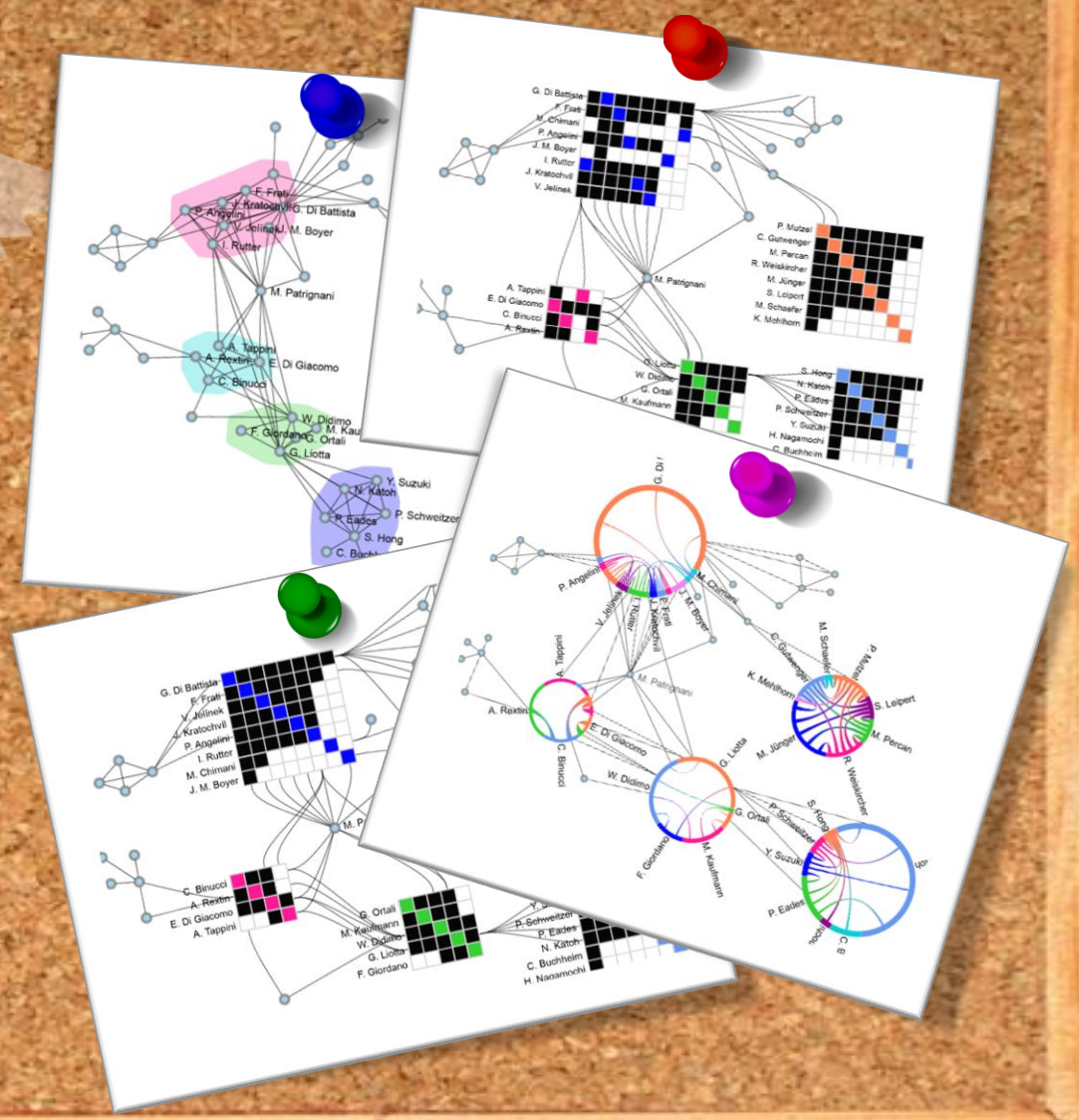
Which hybrid model should be preferred?

Let's design a user study!

Research Questions

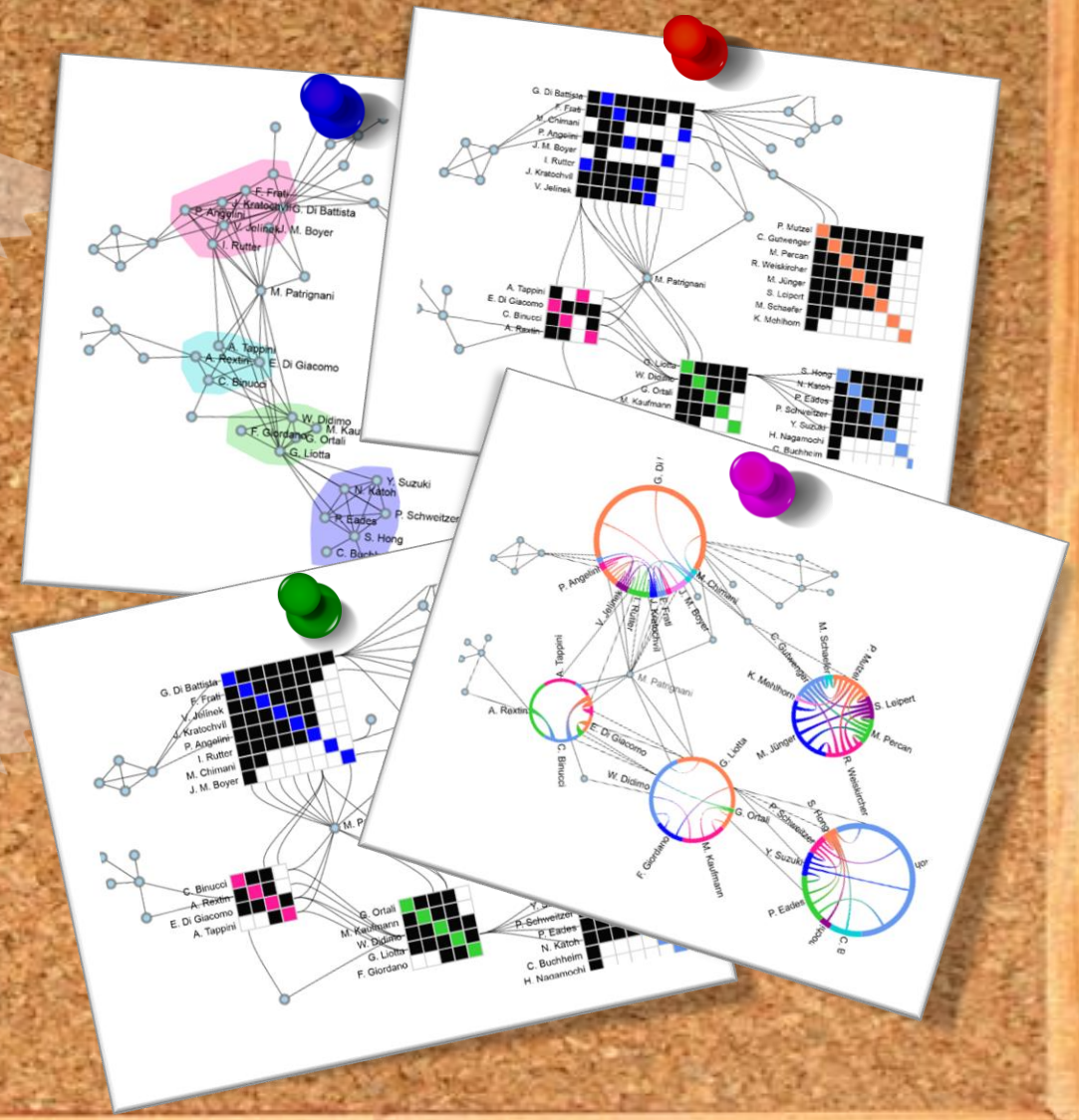
(RQ1) - Are hybrid visualizations more effective than node-link diagrams for the visual analysis of clustered networks?



Research Questions

(RQ1) - Are hybrid visualizations more effective than node-link diagrams for the visual analysis of clustered networks?

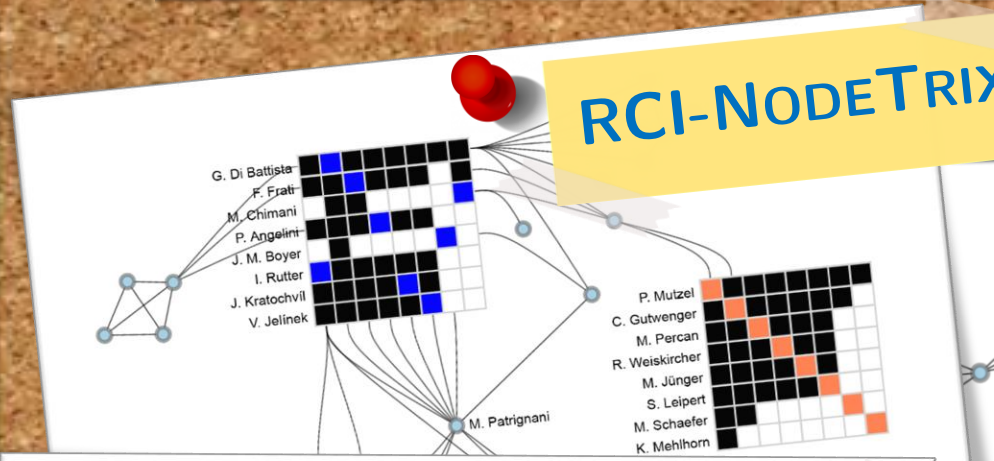
(RQ2) - When considering specfic tasks of analysis, are there differences in terms of response time or accuracy among different hybrid visualization models?



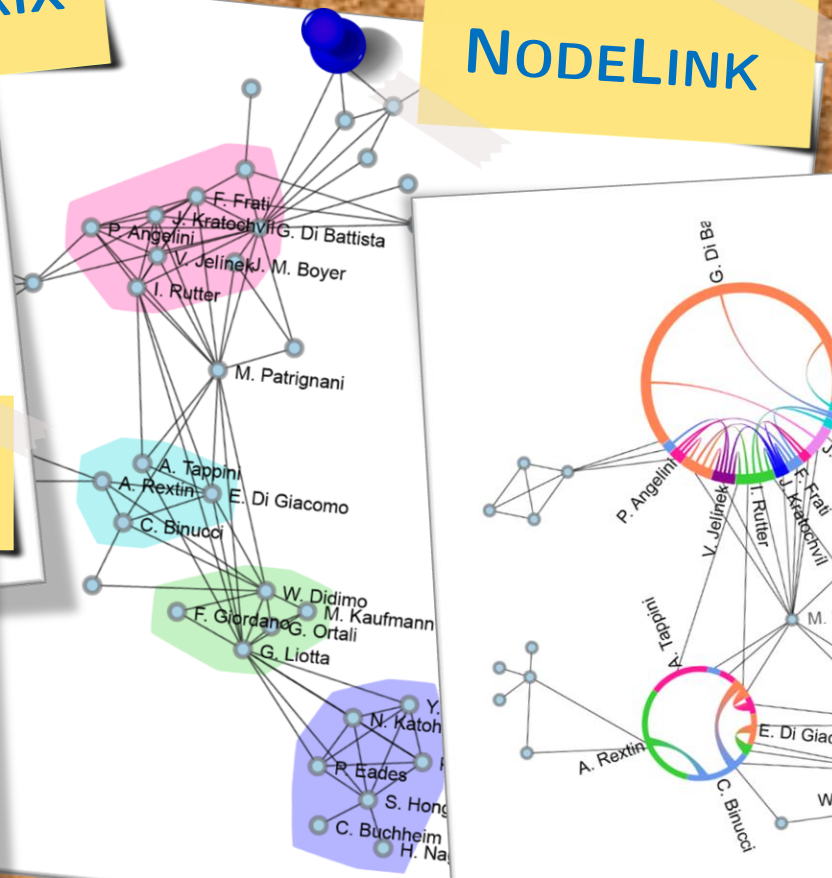
Study Design

Conditions

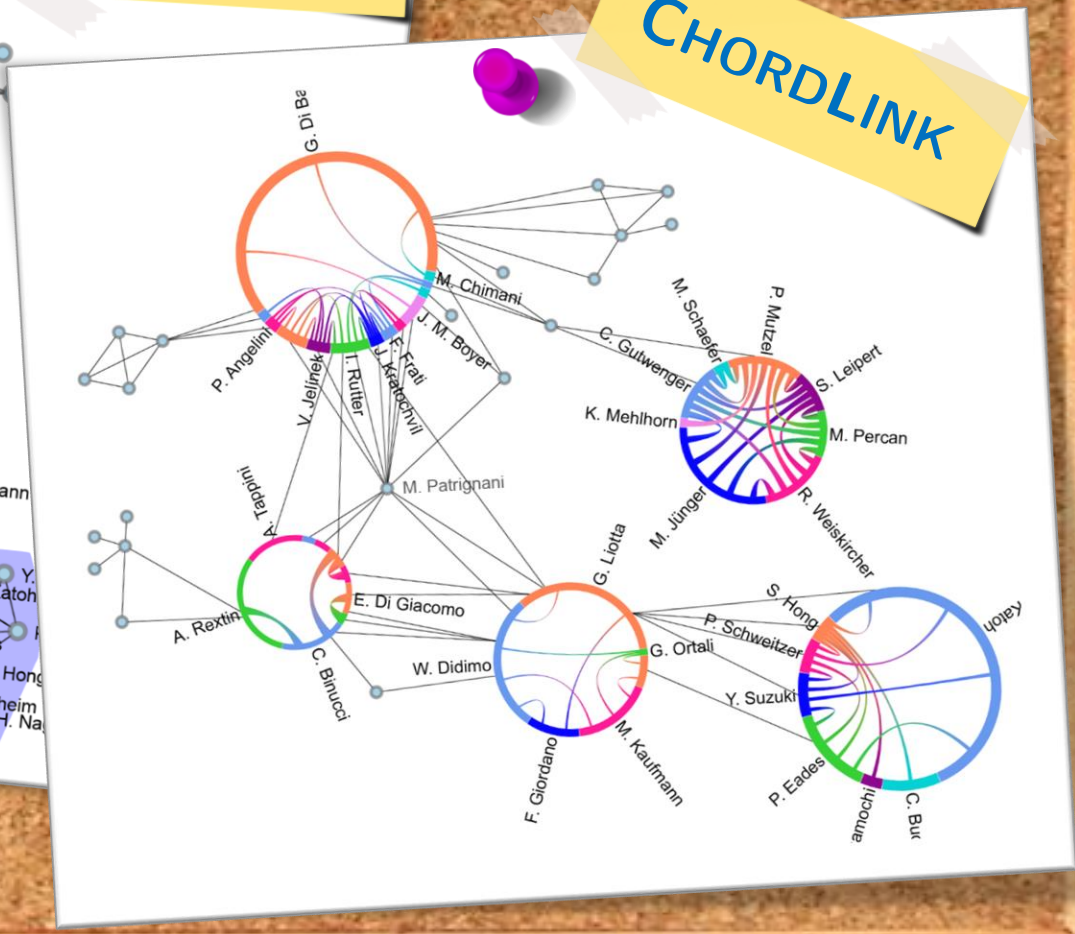
RCI-NodeTrix



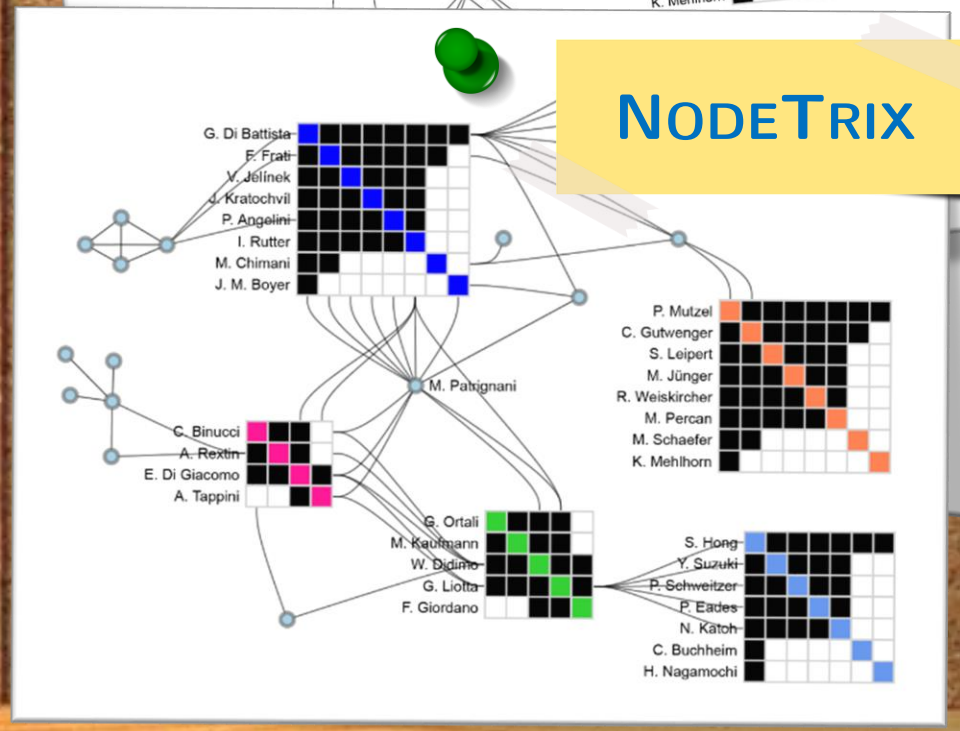
NodeLink



ChordLink



NodeTrix



Study Design

Tasks

- Require to explore the drawing globally and locally
- Easy to explain
- Easy to measure
- Can be executed quickly

Study Design

Task	LeeTax	AmarTax
T1. Is there an edge that links the two highlighted nodes?	topology-based (adjacency)	retrieve value
T2. Which of the two highlighted nodes has higher degree?	topology-based (adjacency)	retrieve value; sort
T3. Is there a path of length at most k that connects the two highlighted nodes?	topology-based (connectivity)	retrieve value; compute derived value; filter
T4. Which of the following three node labels appear in the highlighted portion of the network?	attribute-based (on the nodes)	retrieve value; filter
T5. What is the denser* cluster between the two highlighted?	overview	filter; compute derived value; sort
T6. How many edges directly connect the two highlighted parts of the drawing?	overview	filter; compute derived value

*The cluster density is the ratio between the number of edges and the number nodes in a cluster

Tasks

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[Lee et al., 2006] Task taxonomy for graph visualization
[Amar et al., 2005] Low-level components of analytic activity in information visualization

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Interpretation tasks

Evaluate

- readability
- understandability
- effectiveness

[Burch et al., 2021]

[Lee et al., 2006] Task taxonomy for graph visualization

[Amar et al., 2005] Low-level components of analytic activity in information visualization

Study Design

Topology-based tasks (T1, T2, T3)

H1	NodeLink	ChordLink	NodeTrix	RCI-NT
Time				
Accuracy				

Hypotheses

- NodeLink is intuitive and widely used
- Hybrid visualizations require to swich visualization metaphor during the visual exploration
- Hybrid visualizations reduce visual clutter
- Topology-based tasks are harder with matrices

Study Design

Topology-based tasks (T1, T2, T3)

H1	NodeLink	ChordLink	NodeTrix	RCI-NT
Time	☺	☹	☹	☹
Accuracy	☹	☺	😐	😐

Hypotheses

Attribute-based tasks (T4)

H2	NodeLink	ChordLink	NodeTrix	RCI-NT
Time	☹	☹	☺	☺
Accuracy	☹	☹	☺	☺

- Placing labels on a matrix side should be more effective
- In chord diagrams labels are rotated
- In node-link diagrams labels may be hidden by edges

Study Design

Topology-based tasks (T1, T2, T3)

H1	NodeLink	ChordLink	NodeTrix	RCI-NT
Time				
Accuracy				

Overview tasks (T5, T6)

H3	NodeLink	ChordLink	NodeTrix	RCI-NT
Time				
Accuracy				

Hypotheses

Attribute-based tasks (T4)

H2	NodeLink	ChordLink	NodeTrix	RCI-NT
Time				
Accuracy				

- Hybrid visualizations reduce visual clutter
- Density in matrices is conveyed by the proportion between black and white cells
- Estimating density in ChordLink is more difficult due to node duplication

Study Design

Experimental setting

It was difficult to perform controlled in-person experiments

Study Design

Experimental setting

On-line test
(LimeSurvey tool)

It was difficult to perform controlled in-person experiments

Study Design

On-line test
(LimeSurvey tool)

It was difficult to perform controlled in-person experiments

Experimental setting

No interaction

Study Design

It was difficult to perform controlled in-person experiments

Experimental setting

On-line test (LimeSurvey tool)

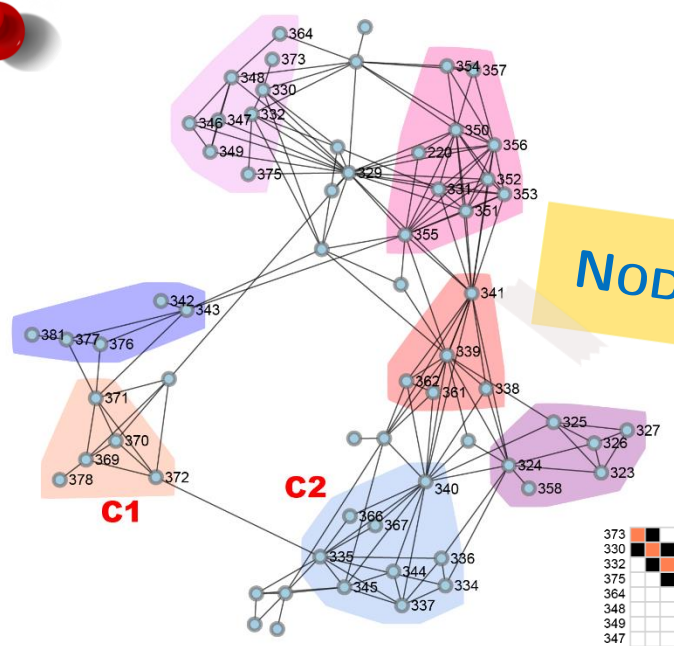
No interaction

Predefined clusters that the user cannot change

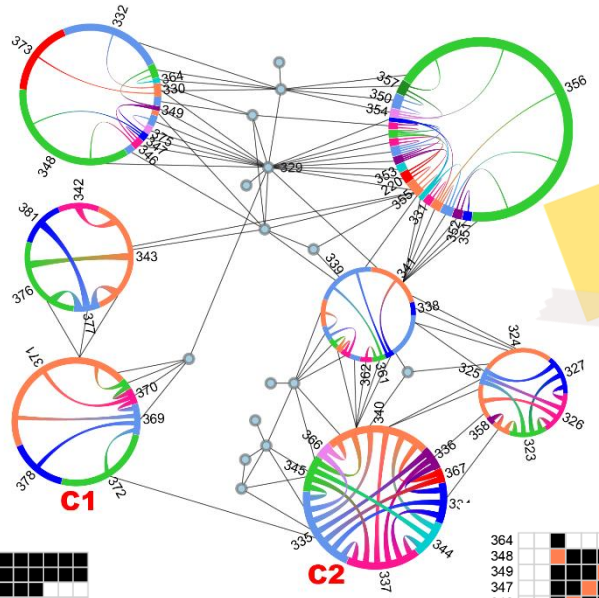
Small/medium networks that fit into the screen window

Study Design

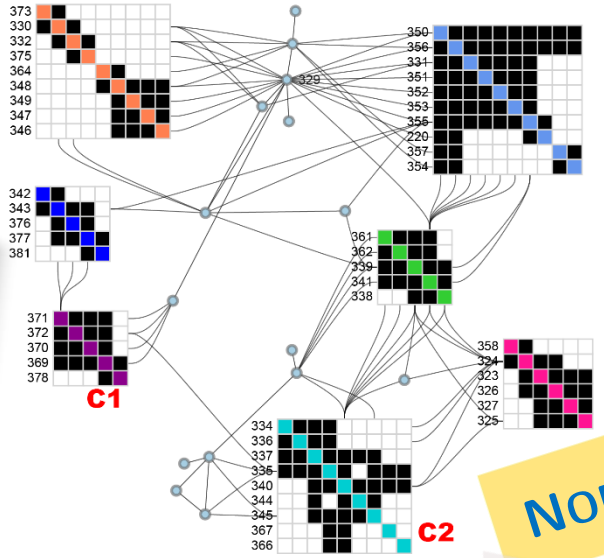
Experimental objects



NodeLink

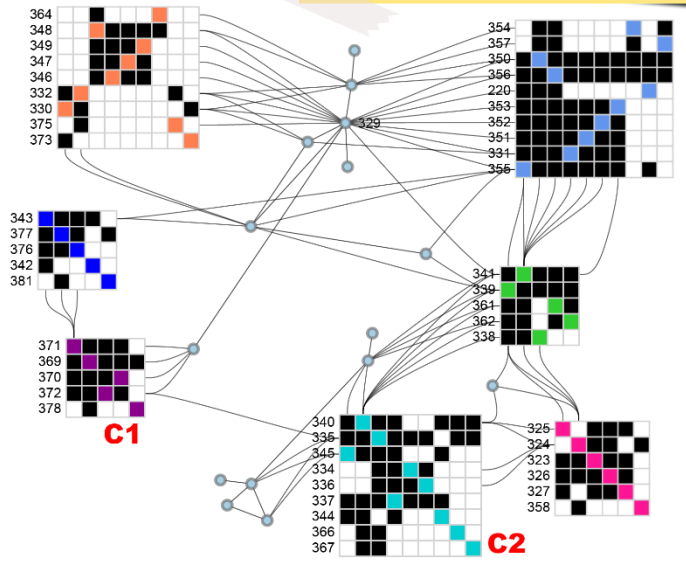


ChordLink



NodeTrix

RCI-NodeTrix

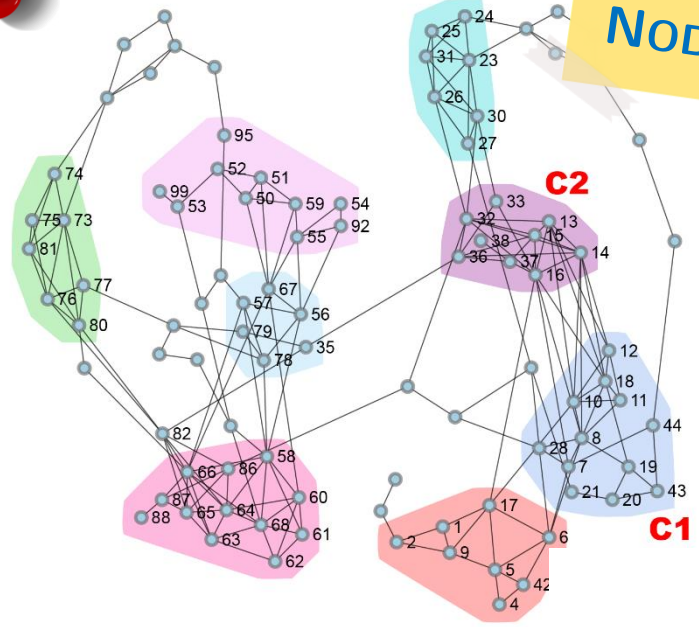


weavers

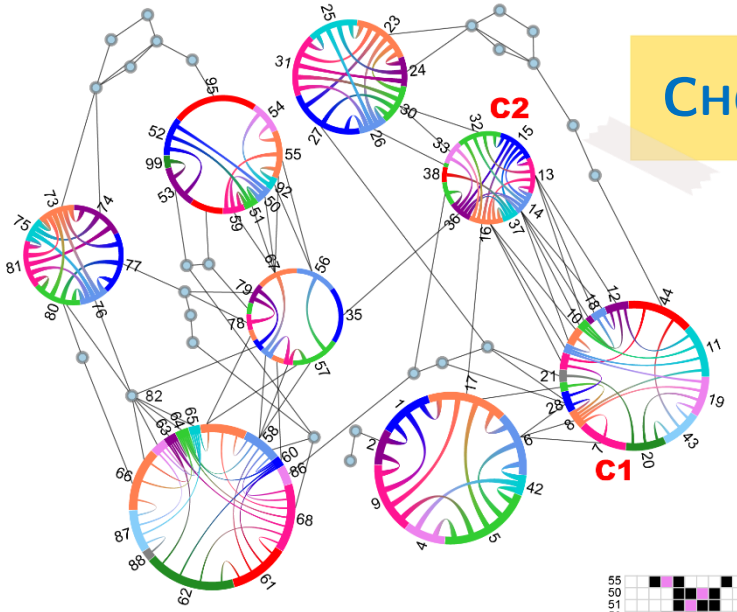
- animal social network
- 64 nodes, 177 edges

Study Design

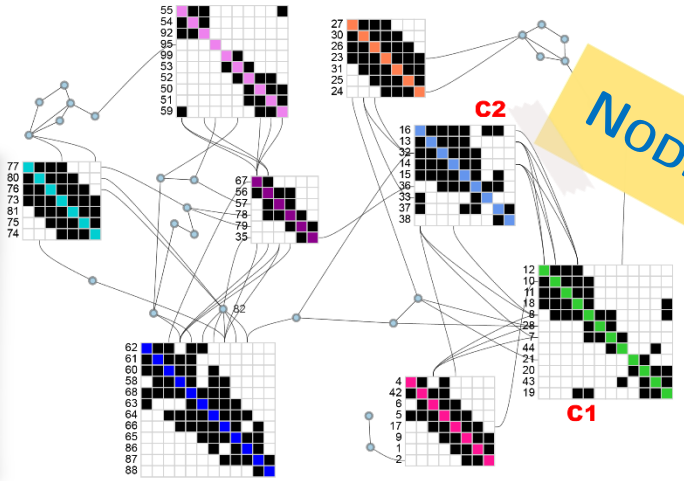
Experimental objects



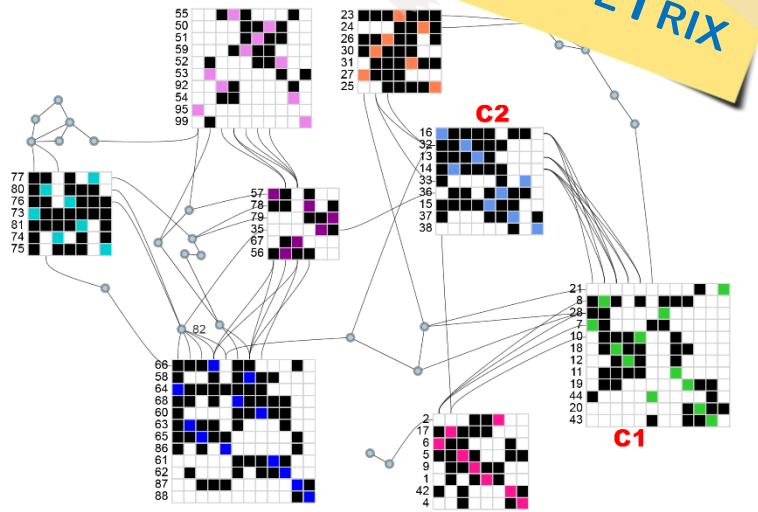
NodeLink



ChordLink



NodeTrix



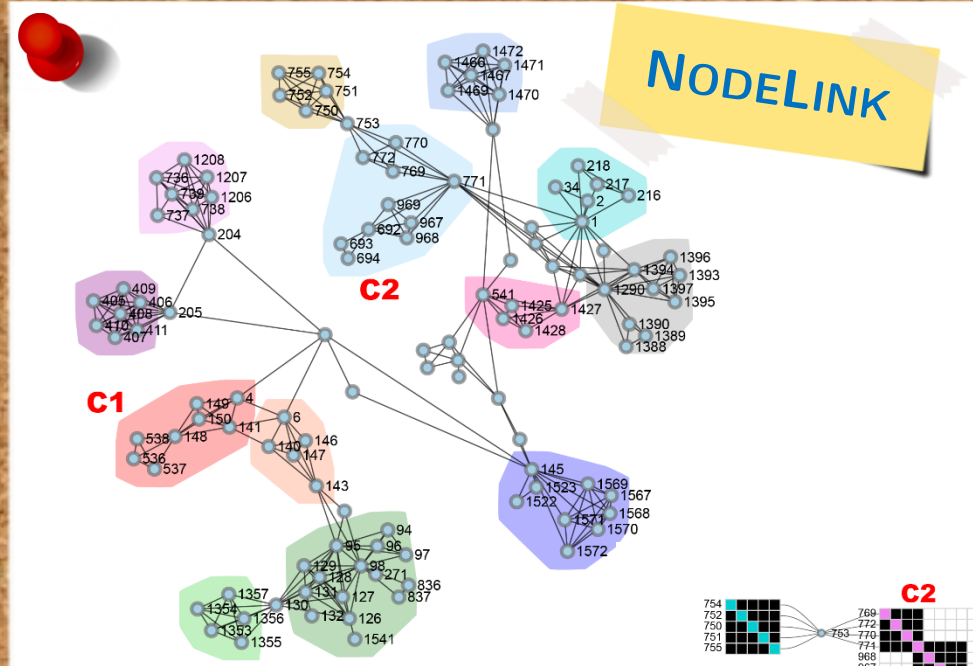
RCI-NodeTrix

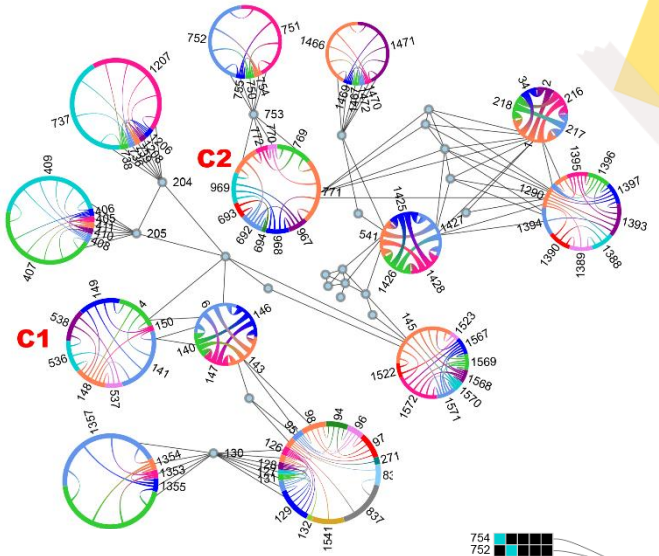
e.coli

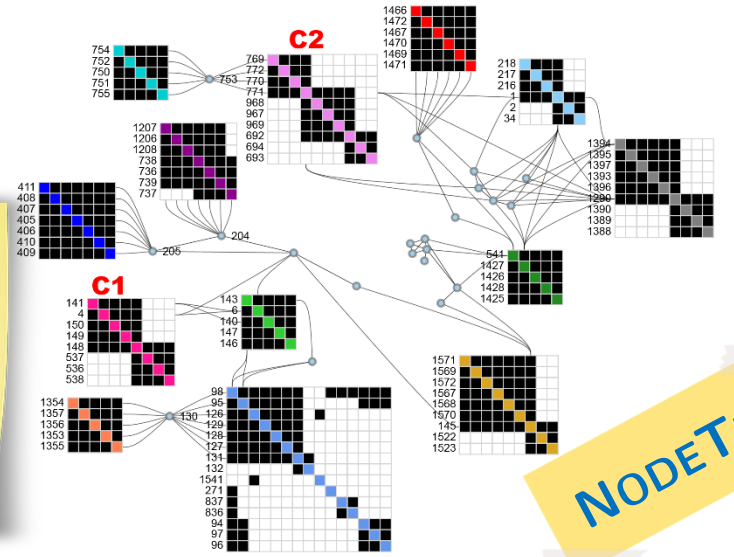
- biological network
- 97 nodes, 212 edges

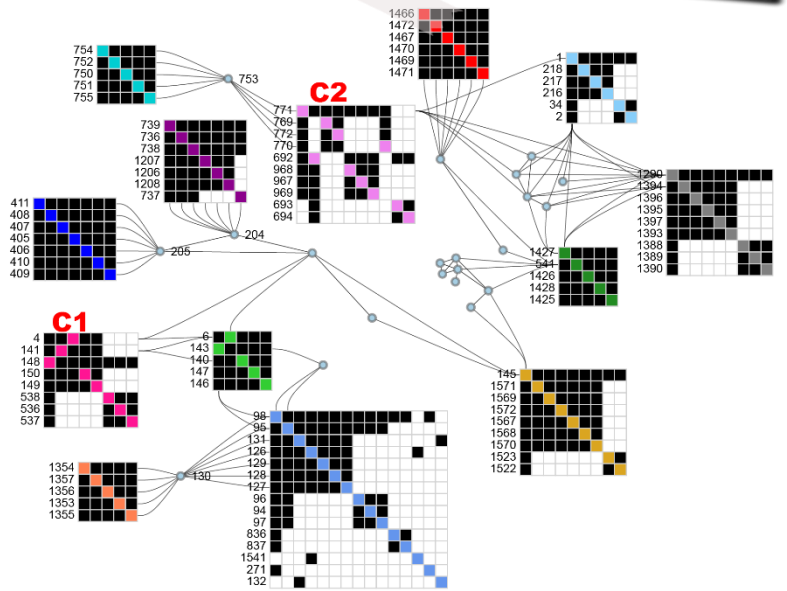
Study Design

Experimental objects









dblp

- co-authorship network
- 118 nodes, 322 edges

Study Design

- 4 models × 3 networks → 12 stimuli
- 12 stimuli × 6 tasks → 72 trials

Procedure

Study Design

- 4 models × 3 networks → 12 stimuli
- 12 stimuli × 6 tasks → 72 trials

Between-subject experiment

Each user is exposed to one condition (model) → 18 trials

Procedure

Study Design

- 4 models × 3 networks → 12 stimuli
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Between-subject experiment

Each user is exposed to one condition (model) → 18 trials

Procedure

LimeSurvey questionnaire:

- Collect some information about the user
- Assign visualization model (round robin)
- Video tutorial about the assigned model
- Training phase (one trial for each task)
- Main study: 18 trials in random order
- Qualitative feedback

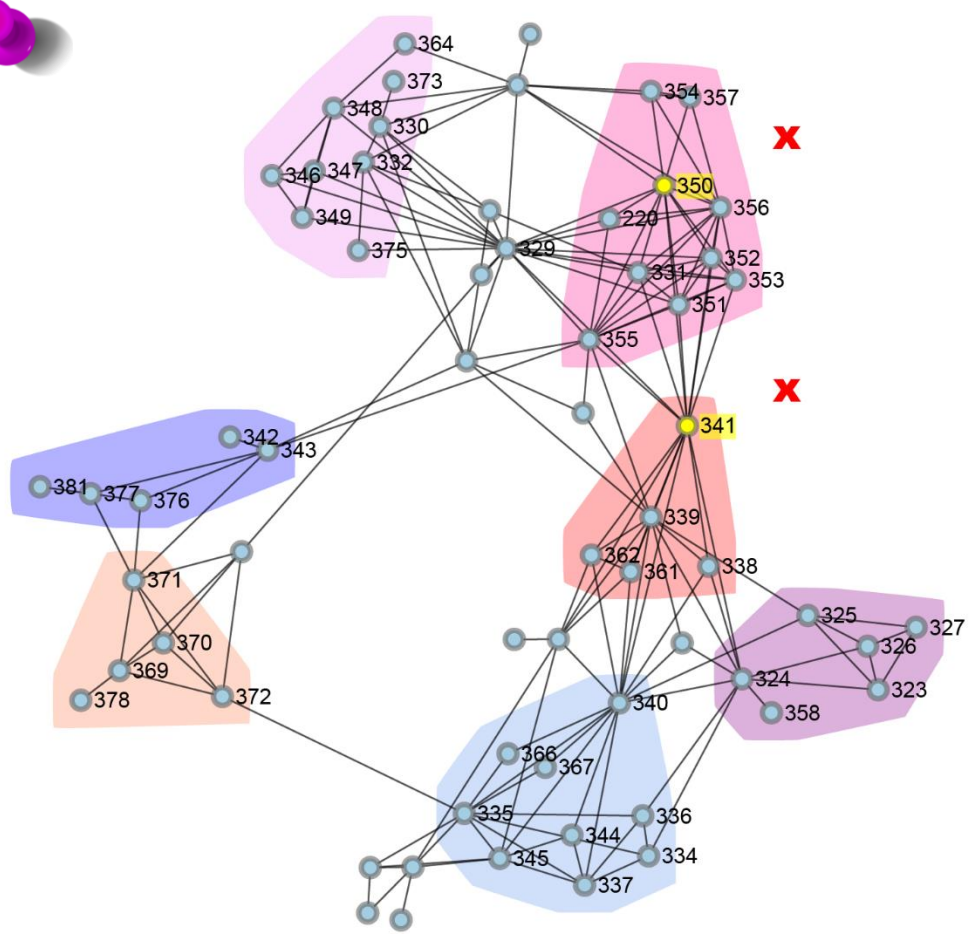
We collect:

- Answers
- Time spent for each question

Study Design

Trials

Task T1



*

Question 1/18

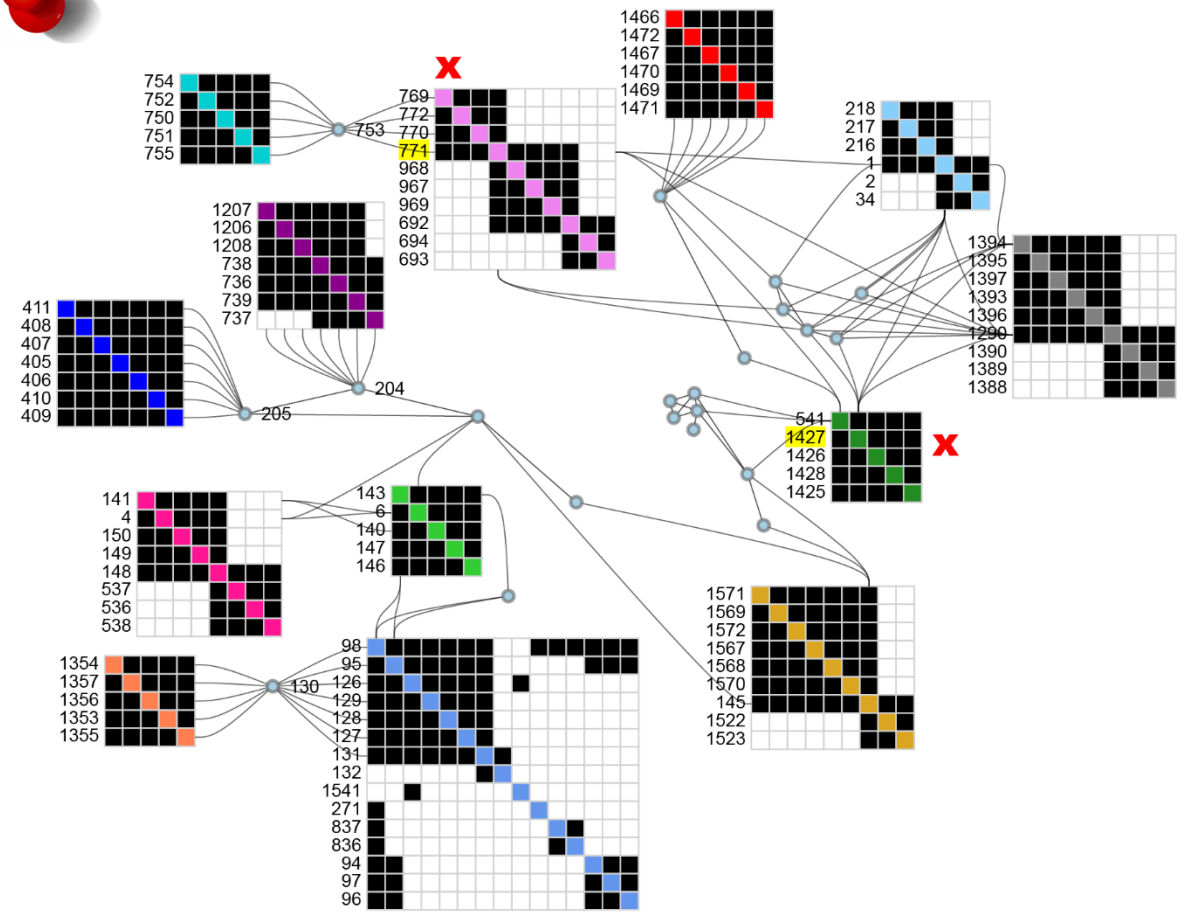
Is there an edge that links the two highlighted nodes?

- Yes
- No

Study Design

Trials

Task T2



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Question 8/18

Which of the two highlighted nodes has higher degree?

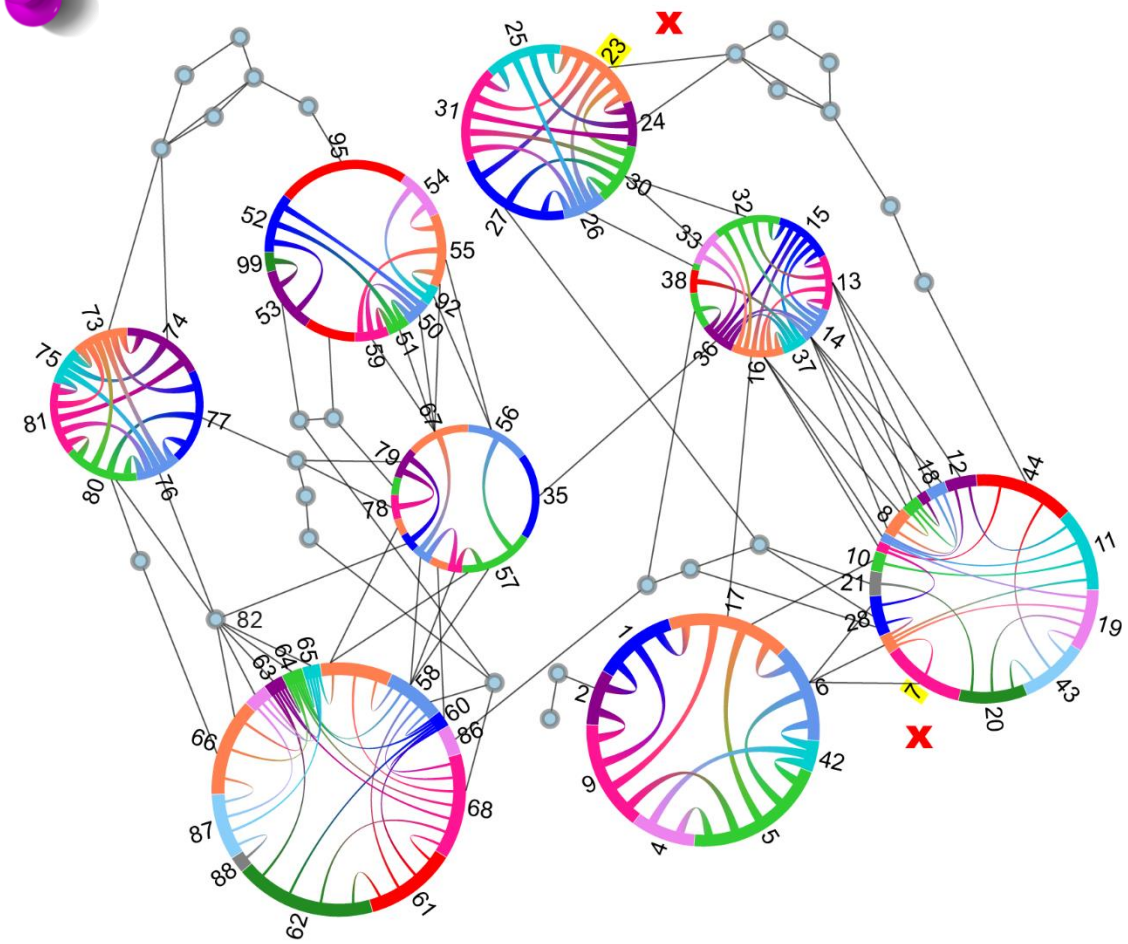
- 771
- 1427

The degree of a node is the total number of its links

Study Design

Trials

Task T3



*

Question 15/18

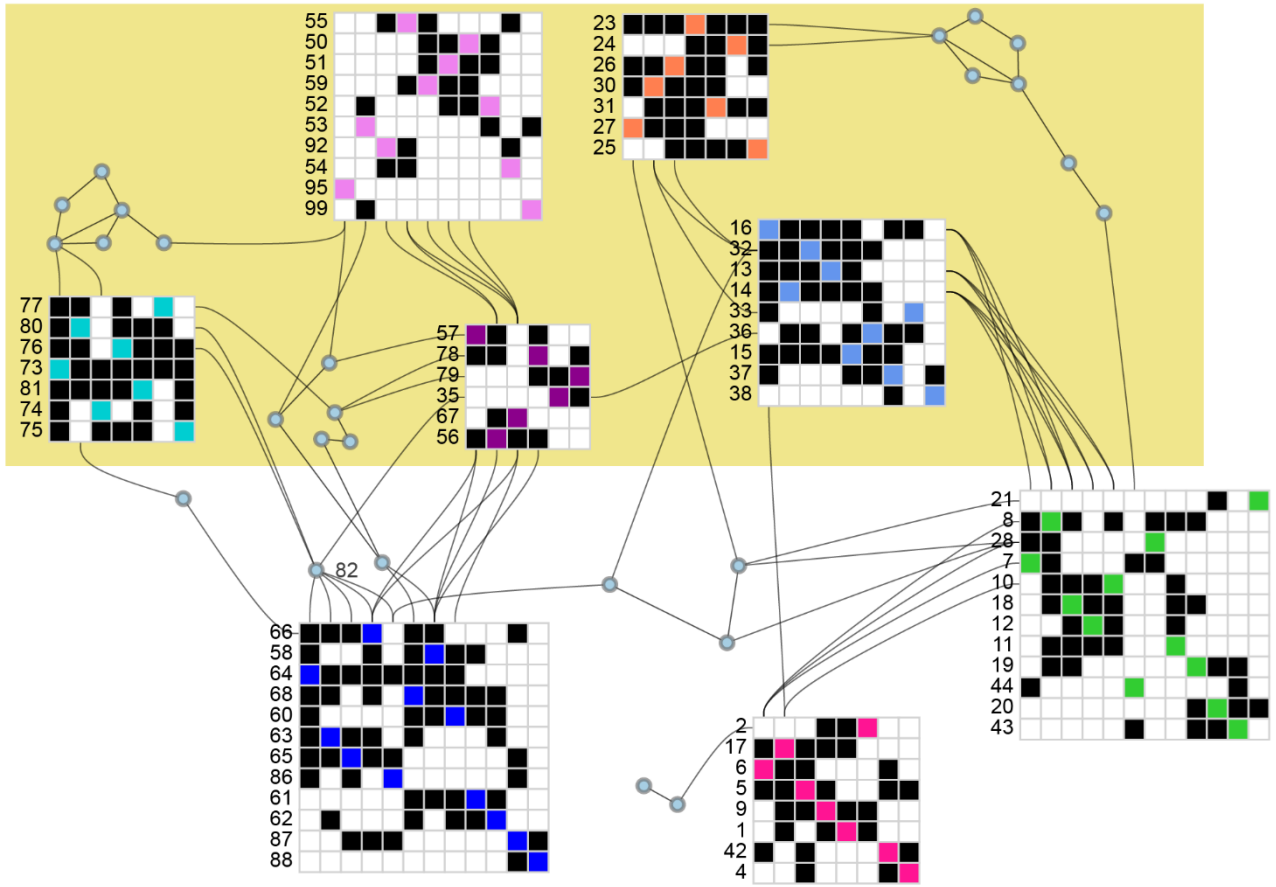
Is there a path of length at most 3 that connects the two highlighted nodes?

- Yes
- No

A path is a sequence of edges that connect the two nodes. The length of a path is the number of edges it consists of.

Study Design

Trials



Task T4

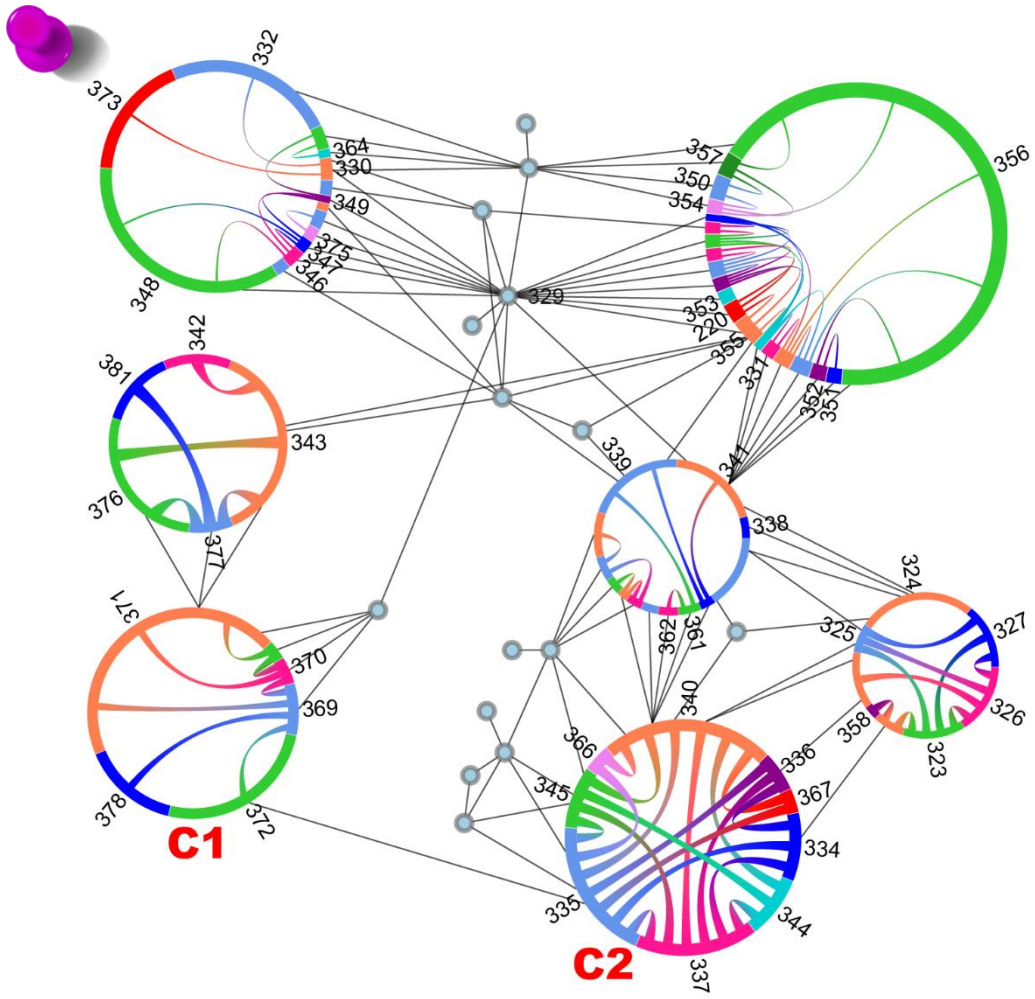
Question 16/18

Which of the following three node labels appear in the highlighted portion of the network?

- [ ] 15
- [ ] 39
- [ ] 50

Study Design

Trials



Task T5

*

Question 5/18

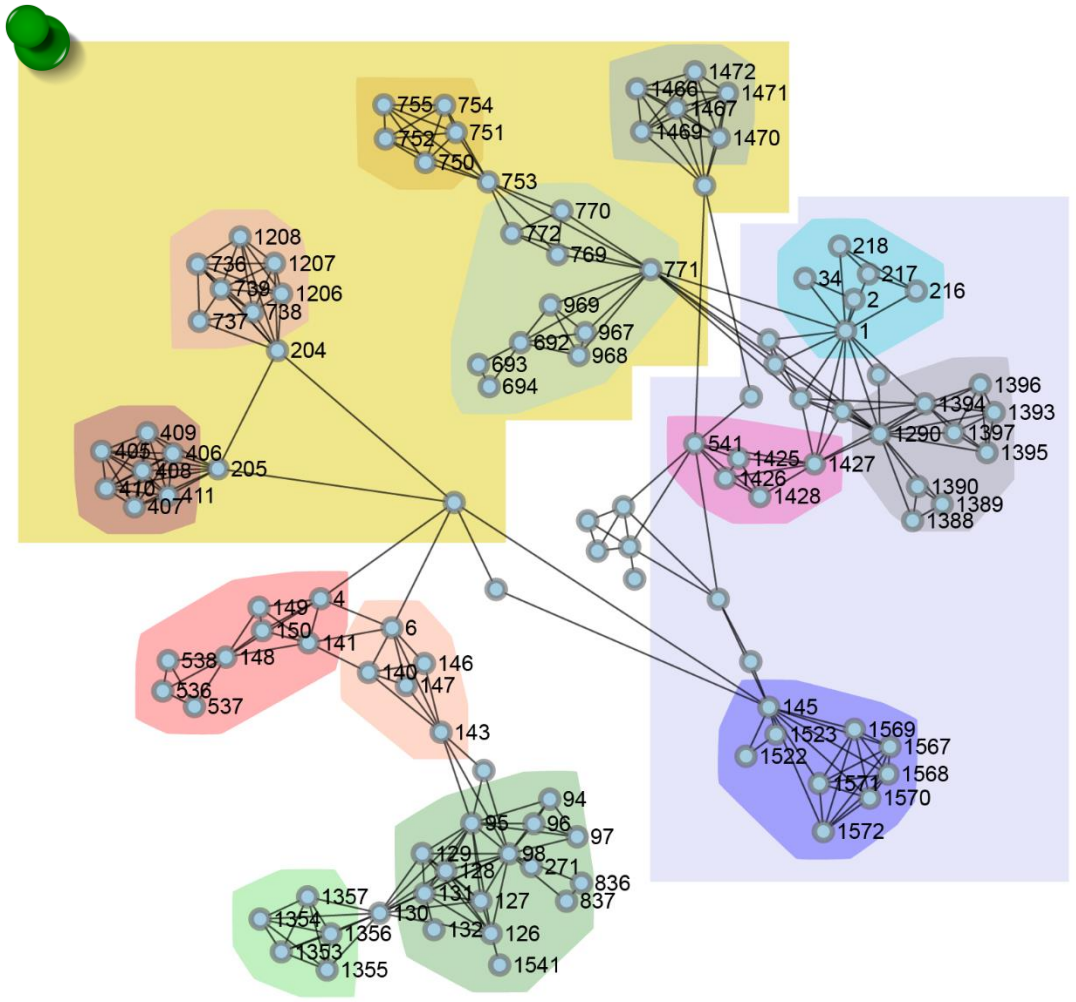
What is the "densest" cluster between C1 and C2?

- C1
- C2

The density of a cluster is the ratio between the number of edges and the number of vertices in the cluster.

Study Design

Trials



Task T6

*

Question 6/18

How many edges directly connect the two high-lighted parts?

Results

Participants

Announcements

Mailing lists:

- gdnet, ieee_vis, infovis

Computer engineering students:

- Perugia
- Roma Tre

Results

Participants

- **89 participants**
- 7 discarded tests
- We analyzed **82 tests**
- Duration: 25-30 mins on average

Announcements

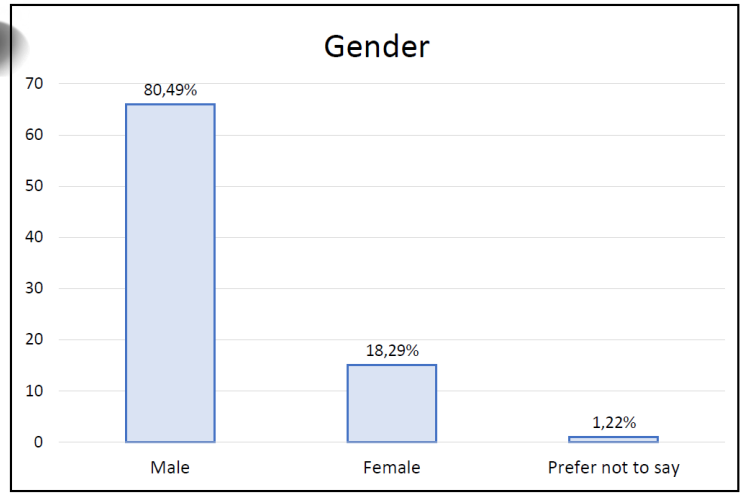
Mailing lists:

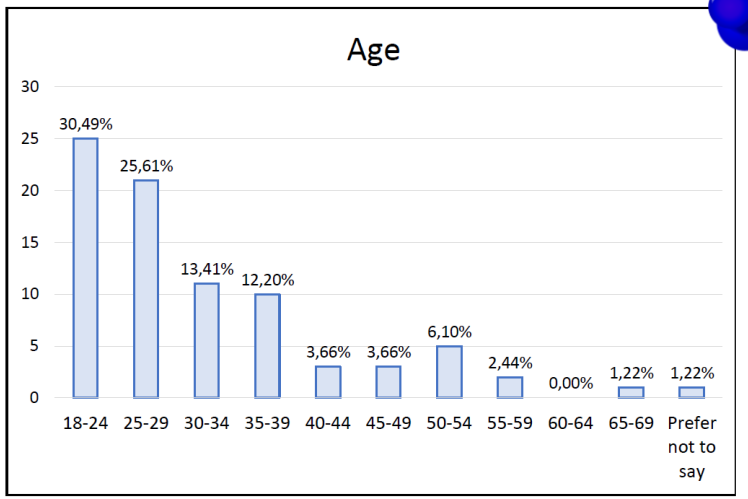
- gdnet, ieee_vis, infovis

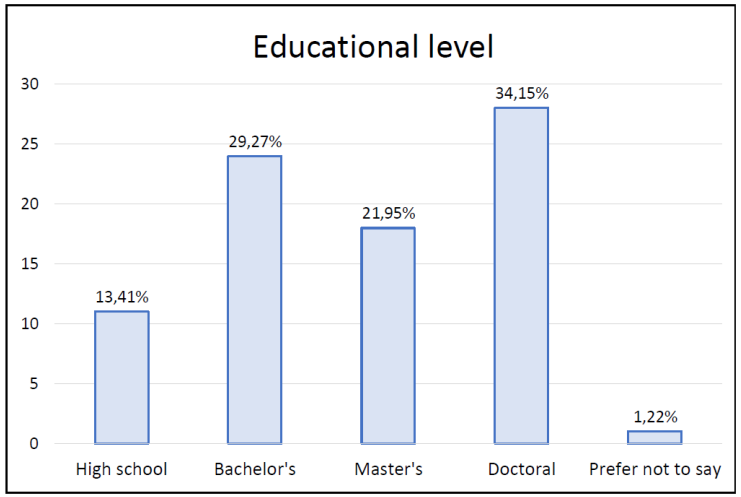
Computer engineering students:

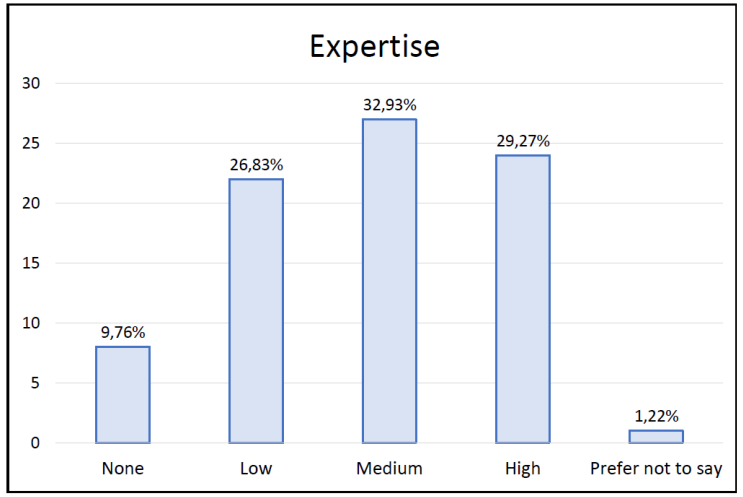
- Perugia
- Roma Tre

Results









Participants

- **89 participants**
- 7 discarded tests
- We analyzed **82 tests**
- Duration: 25-30 mins on average

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Results

Quantitative results

Compare the performance of the four models in terms of:

- Accuracy
- Response time

Shapiro-Wilk test:

- Significance level $\alpha = 0.05$
- Data were not normally distributed

Kruskall-Wallis test (non-parametric):

- Significance level $\alpha = 0.05$
- Post-hoc pairwise comparisons with Bonferroni corrections

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Statistically significant comparisons

Topology-based tasks (T1, T2, T3)

H1	NodeLink	ChordLink	NodeTrix	RCI-NT
Time				
Accuracy				

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* X > Y → X is better than Y

Statistically significant comparisons

Topology-based tasks (T1, T2, T3)

H1	NodeLink	ChordLink	NodeTrix	RCI-NT
Time				
Accuracy				

H1 is supported in terms of **response time**:

- T1: NodeLink > ChordLink, RCI-NT
- T2: NodeLink > RCI-NT
- T3: NodeLink > ChordLink, NodeTrix, RCI-NT

Results

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Statistically significant comparisons

Topology-based tasks (T1, T2, T3)

H1	NodeLink	ChordLink	NodeTrix	RCI-NT
Time	😊	☹	☹	☹
Accuracy	☹	😊	😐	😐

H1 is supported in terms of **response time**:

- T1: NodeLink > ChordLink, RCI-NT
- T2: NodeLink > RCI-NT
- T3: NodeLink > ChordLink, NodeTrix, RCI-NT

H1 is partially supported in terms of **accuracy**:

- T1: ChordLink > NodeTrix
- T3: ChordLink, RCI-NT > NodeLink

Results

Quantitative results

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Attribute-based tasks (T4)

H2	NodeLink	ChordLink	NodeTrix	RCI-NT
Time	☹	☹	☺	☺
Accuracy	☹	☹	☺	☺

Results

Quantitative results

Statistically significant comparisons

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- Accuracy
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Shapiro-Wilk test:

- Significance level $\alpha = 0.05$
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Kruskall-Wallis test (non-parametric):

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- Post-hoc pairwise comparisons with Bonferroni corrections

* X > Y → X is better than Y

Attribute-based tasks (T4)

H2	NodeLink	ChordLink	NodeTrix	RCI-NT
Time	☹	☹	☺	☺
Accuracy	☹	☹	☺	☺

H2 is partially supported in terms of **response time**:

- T4: NodeTrix > ChordLink

Results

Quantitative results

Statistically significant comparisons

Compare the performance of the four models in terms of:

- Accuracy
- Response time

Shapiro-Wilk test:

- Significance level $\alpha = 0.05$
- Data were not normally distributed

Kruskall-Wallis test (non-parametric):

- Significance level $\alpha = 0.05$
- Post-hoc pairwise comparisons with Bonferroni corrections

* X > Y → X is better than Y

Attribute-based tasks (T4)

H2	NodeLink	ChordLink	NodeTrix	RCI-NT
Time	☹	☹	☺	☺
Accuracy	☹	☹	☺	☺

H2 is partially supported in terms of **response time**:

- T4: NodeTrix > ChordLink

H2 is not supported in terms of **accuracy**:

- T4: No statistically significant difference among the models

Easy task

Results

Quantitative results

Statistically significant comparisons

Compare the performance of the four models in terms of:

- Accuracy
- Response time

Shapiro-Wilk test:

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Kruskall-Wallis test (non-parametric):

- Significance level $\alpha = 0.05$
- Post-hoc pairwise comparisons with Bonferroni corrections

* X > Y → X is better than Y

Overview tasks (T5, T6)

H3	NodeLink	ChordLink	NodeTrix	RCI-NT
Time	☹	😐	☺	☺
Accuracy	☹	😐	☺	☺

H3 is not supported:

- No statistically significant difference among the models

Discussion: Limitations

Interaction

- Predefined clusters that the user cannot change
- Small/medium networks that fit into the screen window
- Enabling interaction requires a different study design → Controlled experiment
- It is difficult to design interaction features that are fair to all models

Discussion: Limitations

Interaction

- Predefined clusters that the user cannot change
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- Enabling interaction requires a different study design → Controlled experiment
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6 tasks

- In line with other experiments
- A larger number of tasks:
  - long execution times
  - high fatigue effect

Discussion: Limitations

Interaction

- Predefined clusters that the user cannot change
- Small/medium networks that fit into the screen window
- Enabling interaction requires a different study design → Controlled experiment
- It is difficult to design interaction features that are fair to all models

6 tasks

- In line with other experiments
- A larger number of tasks:
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  - high fatigue effect

Layout algorithms

Visualization models may be sensitive to the algorithms we used

Conclusions

(RQ1) - Are hybrid visualizations more effective than node-link diagrams for the visual analysis of clustered networks?

Hybrid visualizations may help to overcome some limits of node-link diagrams in accurately executing topology-based tasks on globally sparse but locally dense networks, at the expenses of the execution time

Conclusions

(RQ1) - Are hybrid visualizations more effective than node-link diagrams for the visual analysis of clustered networks?

(RQ2) - When considering specfic tasks of analysis, are there differences in terms of response time or accuracy among different hybrid visualization models?

Hybrid visualizations may help to overcome some limits of node-link diagrams in accurately executing topology-based tasks on globally sparse but locally dense networks, at the expenses of the execution time

We cannot conclude that any of the models is superior.
For some topology-based tasks:

- better accuracy with ChordLink
- faster execution with NodeTrix

Future Research

Further experiments

Larger networks

Additional tasks

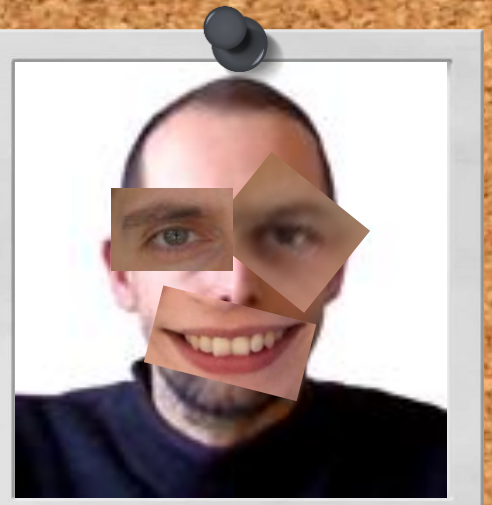
Interaction features

More participants

Thank you
for your attention

Emilio

Fabrizio



Hybrid

Walter

Alessandra